



J R C T E C H N I C A L R E P O R T S

# Bioenergy and Water

Editors: J.F. Dallemand & P.W. Gerbens-Leenes

2013

European Commission  
Joint Research Centre  
Institute for Energy & Transport

Contact information

J.F.Dallemand

Address: Joint Research Centre, Via Enrico Fermi 2749, TP 450, 21027 Ispra (VA), Italy

E-mail: [jean-francois.dallemand@ec.europa.eu](mailto:jean-francois.dallemand@ec.europa.eu)

Tel.: +39 0332 789937

<http://xxx.jrc.ec.europa.eu/>

<http://www.jrc.ec.europa.eu/>

Legal Notice

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

Europe Direct is a service to help you find answers to your questions about the European Union  
Freephone number (\*): 00 800 6 7 8 9 10 11

(\*): Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.  
It can be accessed through the Europa server <http://europa.eu/>.

JRCxxxxx

EUR xxxxx EN

ISBN xxx-xx-xx-xxxxx-x (pdf)

ISBN xxx-xx-xx-xxxxx-x (print)

ISSN xxxx-xxxx (print)

ISSN xxxx-xxxx (online)

doi:xx.xxxx/xxxxx

Luxembourg: Publications Office of the European Union, 20xx

© European Union, 20xx

Reproduction is authorised provided the source is acknowledged.

Printed in 2013

European Commission

EUR xxxxx – Joint Research Centre – Institute for Energy & Transport

Title: Bioenergy and Water

Editors: J.F.Dallemand, P.W.Gerbens-Leenes

Luxembourg: Publications Office of the European Union

2013 – 290 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN xxxx-xxxx (print), ISSN xxxx-xxxx (online)

ISBN xxx-xx-xx-xxxx-x (pdf)

ISBN xxx-xx-xx-xxxx-x (print)

doi:xx.xxxx/xxxxx

#### Abstract

Bioenergy is the production of renewable energy from organic material. It corresponds to three main feedstock categories (agriculture, forestry & waste) for three main uses (transport, heat & electricity). The development of bioenergy is often retained as a positive option due to its contribution to the mitigation of climate change, agricultural and rural development, energy security, innovation policies. Nevertheless, concerns have been raised during the last few years about risks or bad practices, sometimes evolving into large scale controversy, especially in relation to GHG emissions. The need to ensure that bioenergy development will be based on sustainable water management is essential, taking into account the need to increase food production and to accommodate simultaneously other uses of water resources, both for quantity & quality. This publication thus contains data and information related to methodologies of impact assessment, practical case studies, scenario analysis, discussion of sustainability certification schemes, all focusing on bioenergy & water.

This publication has been prepared as a follow-up of the Session on Bioenergy & Water of the Sixth World Water Forum (Marseille, 2012). This document was prepared by the Joint Research Centre of the European Commission, with the support of the Twente University (Netherlands) and of the International Energy Agency Bioenergy Task 43 (Biomass Feedstock for Energy Markets).

This Report is based on scientific contributions from Argentina, Australia, Brazil, the European Commission, France, Germany, India, the International Energy Agency, Netherlands, South Africa, Sweden and the United States. This document is aiming to be a useful reference for those interested in the sustainability of bioenergy and a contribution to the diffusion of good practices of water management at global, national or local level.



# Bioenergy and water

## Table of contents

- Foreword, <i>JF Dallemand, European Commission, Joint Research Centre, W.Gerbens Leenes, Twente University, The Netherlands</i>	
- The Biofuel and Bioenergy Roadmaps of the International Energy Agency, <i>A.Eisentraut, International Energy Agency (IEA) Paris</i> .....	page 3
- EU framework, Renewable Energy Directive and the quantitative targets from the NREAPs (National Renewable Energy Action Plans) of the 27 European Union Member States <i>N.Scarlat, JF Dallemand, European Commission, Joint Research Centre</i> .....	page 15
- Bioenergy & Water, Challenges & opportunities, <i>G.Berndes, Chalmers University of Technology, Sweden</i> .....	page 49
- Water footprint quantification of energy at global level, <i>W.Gerbens Leenes, Twente University, The Netherlands</i> .....	page 61
- Agrofuels and water in Argentina, <i>A.Anschau, A.Acevedo, Centro de Investigación en Recursos Naturales, Argentina</i>	page 77
- Bioenergy & water: Brazilian sugar cane ethanol, <i>F.Scarpare, Brazilian Bioethanol Science &amp; Technology Laboratory, CTBE, Campinas, Brazil</i> .....	page 89
- Hydrological consequences of jatropha on waste lands in developing countries, <i>S.Wani, International Crops Research Institute for the Semi-Arid Tropics, ICRISAT, India</i> .....	page 103
-Water Impact of French biofuels development at the 2030 horizon, <i>J.F.Bonnet, Université de Bordeaux D.Lorne IFP Energies Nouvelles, Rueil-Malmaison, France</i> .....	page 117
- Bioenergy & water in Australia, <i>B.George, University of New England and New South Wales, Australia</i> .....	page 143
- Impact of land use change due to bioenergy on regional hydrology, <i>C.Bernacchi, University of Illinois, Urbana Champaign/Energy Bioscience Institute, USA</i> .....	page 159

- Mapping the potential water use of biofuel feedstock production in South Africa,  
*R.Kunz, G.Jewitt, Centre for Water Resources Research, University of KwaZulu-Natal, Pietermaritzburg, South Africa* ..... page 173
- The water footprint of biofuels from microalgae,  
*W.Gerbens Leenes, Twente University, The Netherlands* ..... page 191
- EU Legislative tools to protect water resources,  
*F.Bouraoui, European Commission, Joint Research Centre* ..... page 201
- U.S. Federal and State Water Laws' Impact on Bioenergy Policy,  
*J.Endres, University of Illinois, Urbana Champaign/Energy Bioscience Institute* .. page 211
- Certification systems and other schemes for bioenergy-related water impacts,  
*H.Fehrenbach, IFEU, Institute for Energy and Environment, Heidelberg, Germany* ..... page 225
- Bioenergy & water: Doing the right thing ? A literature review,  
*M.Banja, JF Dallemand, European Commission, Joint Research Centre* ..... page 243

## Foreword

An important challenge in the twenty-first century is to supply the growing world population that requires more and more energy per person with sufficient energy. Today, this energy supply is mainly based on fossil energy carriers that have large drawbacks, like the impact on climate change and the depletion of the resources. Renewable energy, for example wind energy, solar energy or bioenergy, might be important energy sources in the future. Bioenergy is renewable energy from organic material. It corresponds to three main feedstock categories (agriculture, forestry & waste) for three main uses (transport, heat & electricity). The development of bioenergy is often considered as a positive option due to its contribution to the mitigation of climate change, agricultural and rural development, energy security and innovation policies. Nevertheless, concerns have been raised during the last few years about risks or bad practices, sometimes evolving into large scale controversy, especially in relation to greenhouse gas emissions. The need to ensure that bioenergy development will be based on sustainable water management is in our view essential, taking into account the need to increase food production and to simultaneously accommodate other uses of water resources, both for quantity & quality. This publication thus contains data and information related to methodologies of impact assessment, practical case studies, scenario analysis, discussion of sustainability certification schemes, all focusing on bioenergy & water.

This publication has been prepared as a follow-up of the Session on Bioenergy & Water of the Sixth World Water Forum (Marseille, 2012). This document was prepared by the Joint Research Centre of the European Commission, with the support of the University of Twente (the Netherlands) and of the International Energy Agency Bioenergy Task 43 (Biomass Feedstock for Energy Markets).

This Report is based on voluntary contributions and we wish to thank all the contributors from Argentina, Australia, Brazil, the European Commission, France, Germany, India, the International Energy Agency, the Netherlands, South Africa, Sweden, the United States, for their availability and their scientific input. We do hope this document will become a useful reference for those interested in the sustainability of bioenergy and will contribute to the diffusion of good practices of water management at global, national or local level.

**J.F. Dallemand (European Commission Joint Research Centre)**

**P.W. Gerbens Leenes (University of Twente)**



# The Biofuel and Bioenergy Roadmaps of the International Energy Agency

A.Eisentraut

International Energy Agency, Renewable Energy Division,  
9 Rue de la Fédération, 75739, Paris Cedex 15, France

## Abstract

Bioenergy is the largest source of renewable energy today and can provide heat, electricity, as well as transport fuels. The Technology Roadmaps Bioenergy for Heat and Power, and Biofuels for Transport highlight the importance of bioenergy in providing renewable electricity, heat in buildings and in industry, as well as low-carbon biofuels in the transport sector. The roadmaps envisage world total primary bioenergy supply increasing from 50 EJ today to 160 EJ in 2050, with 100 EJ of this for generation of heat and power.

By 2050 bioenergy could provide 3 000 TWh of electricity, i.e. 7.5% of world electricity generation. In addition heat from bioenergy could provide 22 EJ (15% of total) of final energy consumption in industry and 24 EJ (20% of total) in the buildings sector in 2050. Biofuels could provide 32 EJ of low-carbon fuels, meeting 27% of world transport fuels demand in 2050. In total this could provide 3.6 Gt CO<sub>2</sub>-equivalent (CO<sub>2</sub>-eq.) emission savings per year in 2050 compared to a business-as-usual scenario, if the feedstock can be produced sustainably and used efficiently, with very low life-cycle GHG emissions.

The roadmap identifies key actions by different stakeholders in the bioenergy sector, and sets out milestones for technology development in order to achieve a doubling of global bioenergy supply by 2050. It addresses the need for further research and development (R&D) efforts, highlights measures to ensure sustainability of biomass production, and underlines the need for international collaboration to enhance the production and use of sustainable, modern bioenergy in different world regions.

## 1. Background

Current trends in energy supply and use are unsustainable—economically, environmentally and socially, and International Energy Agency (IEA) analysis shows that without decisive action, energy-related greenhouse gas (GHG) emissions could more than double by 2050, and energy security could be seriously compromised in many regions (IEA, 2012). To address these challenges, the IEA, at the request of the G8, is developing a series of technology roadmaps for some of the most important low-carbon technologies needed to reduce global energy-related CO<sub>2</sub> emissions by 50% in 2050<sup>1</sup> compared to 2005 levels. The basis for all roadmaps is the 2°C scenario (2DS) developed for the IEA publication Energy Technology Perspectives (IEA, 2012).

Two recently published roadmaps are focussing on Biofuels for Transport and Bioenergy for Heat and Power. Each roadmap develops a growth path for the covered technologies from today to 2050, and identifies technology, financing, policy and public engagement milestones that need to be achieved to realise the technology's full potential (for more information and to download the roadmaps visit: [www.iea.org/roadmaps](http://www.iea.org/roadmaps)).

---

<sup>1</sup> Energy-related CO<sub>2</sub> emissions are cut by more than half in 2050, compared with 2009, and continue to fall after that. This emission trajectory is consistent with what the latest climate science research indicates would give a 80% chance of limiting long-term global temperature increase to 2°C, provided that non-energy related CO<sub>2</sub> emissions, as well as other greenhouse gases, are also reduced.

## 2. Current status of bioenergy and biofuels

### Definitions

**Biomass:** Any organic, *i.e.* decomposing, matter derived from plants or animals available on a renewable basis. Biomass includes wood and agricultural crops, herbaceous and woody energy crops, municipal organic wastes as well as manure.

**Bioenergy** is energy derived from the conversion of biomass where biomass may be used directly as fuel, or processed into liquids and gases.

**Traditional biomass use** refers to the use of wood, charcoal, agricultural residues and animal dung for cooking and heating in the residential sector. It tends to have very low conversion efficiency (10% to 20%) and often unsustainable biomass supply.

**Primary bioenergy supply** refers to the energy content of biomass feedstocks before conversion.

**Final bioenergy consumption** refers to the use of biomass in different end-use sectors. In some cases (*e.g.* buildings, industry) this category is equal to the biomass input.

**Useful bioenergy** refers to the net-energy generation (*i.e.* electricity, heat) excluding transformation losses.

**Biofuels** refers to liquid and gaseous fuels produced from biomass and used in the transport sector.

**Conventional biofuel** technologies (also referred to as 1st generation) include include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. Typical feedstocks used in these processes include sugarcane and sugar beet, starch-bearing grains like corn and wheat, oil crops like rape (canola), soybean and oil palm, and in some cases animal fats and used cooking oils.

**Advanced biofuel** technologies (also referred to as 2nd and 3rd generation) are conversion technologies which are still in the research and development, pilot or demonstration phase. This category includes hydrotreated vegetable oil, which is based on animal fat and plant oil, as well as biofuels based on lignocellulosic biomass, such as cellulosic-ethanol, biomass-to-liquids diesel and bio-synthetic gas (bio-SG). The category also includes novel technologies that are mainly in the R&D and pilot stage, including algae-based biofuels and the conversion of sugar into diesel-type biofuels using biological or chemical catalysts.

Bioenergy is the largest single source of renewable energy today and provided roughly 10% (50 EJ)<sup>2</sup> of world total primary energy supply (TPES) in 2009 (IEA, 2011a). Most of this was consumed in the buildings sector in developing countries, mainly for cooking and space

---

<sup>2</sup> This figure is subject to some uncertainties, since no accurate data on the actual use of different biomass feedstocks in the residential sector exist, in particular in developing countries. According to the IPCC (2011) an estimated 6-12 EJ/year of biomass for the informal sector is not included in official energy balances.

heating. This traditional use of biomass plays a crucial role in many developing countries, where it provides basic energy for cooking and space heating, but often at the price of severe health and environmental impacts. In most OECD countries bioenergy plays only a minor role in buildings. However, in some countries such as Sweden, Finland, and Austria the use of biomass for district heating is common and other countries are now following this path.

Bioenergy electricity supply has been rising steadily over the last decade and in 2010 bioenergy provided some 280 TWh of electricity globally, equivalent to 1.5% of world electricity production. Power generation from biomass is still concentrated in OECD countries, but China and Brazil are also becoming increasingly important producers thanks to support programmes for biomass electricity generation. Models established in China and Brazil could also become a viable way to promote bioenergy electricity generation in other non-OECD.

While biofuels for transport have been produced since the late 19th century, it was only until the 1970s that commercial biofuel production gained momentum with both the US (corn ethanol) and Brazil (sugarcane ethanol) introducing ambitious support programs. The strongest growth in global production took place in the last decade, during which biofuel production increased from 18 billion litres in 2001 to 105 billion litres in 2011 (IEA, 2011b), mainly as result of strong support policies.

### **3. Vision for bioenergy and biofuels**

In the 2DS of ETP 2012 that serves as the basis for this roadmap, the contribution of bioenergy to global primary energy supply increases from around 50 EJ in 2009 to about 160 EJ in 2050. Bioenergy would then provide around one fourth of TPES in 2050 compared to 10% today. Around 100 EJ of this primary bioenergy supply are needed to provide electricity as well as heat, and another 60 EJ for production of transport fuels.

#### **3.1 Technology options for heat and power**

To achieve this vision of bioenergy heat and electricity supply, in a cost and resource efficient manner will require the deployment of a set of conversion technologies at different scales. Small-scale systems (<1 MW), including efficient biomass stoves, are best suited to provide heat only. In many cases, the heat can be provided at costs similar to or even lower than fossil fuel derived heat. At larger scales heat generation from biomass becomes generally competitive in both industry and commercial buildings, and this competitive advantage could be further enhanced by introducing a CO<sub>2</sub> price for fossil fuels. Where a steady heat demand exists, for example through a district heating network, co-generation plants for heat and power can also be a viable and very efficient option, and can justify the higher capital costs compared to a heating or power-only plant.

In terms of electric efficiency, small-scale power plants of less than 10 MW suffer from poor electric efficiencies and high capital costs per output unit. Generation costs for bioenergy electricity in those plants are thus only competitive if feedstocks can be sourced at very low costs and fossil-generated electricity is relatively costly. Large-scale electricity and co-generation plants will therefore be key to achieving the roadmap targets outlined above, as they allow for higher generation efficiency, and lower generation costs. But a solid CO<sub>2</sub> price around USD 90/t CO<sub>2</sub> by 2030, or dedicated economic support measures would be needed, together with further technology improvements, to make bioenergy electricity generation generally competitive with coal and gas-generated electricity. Co-firing is a suitable measure to replace coal-fired electricity generation with biomass, and reduce related emissions. The advantage is that only little additional investments are required, and electricity generation

costs are typically low. However, electric conversion efficiencies in older coal-fired power plants are not as high as in modern biomass plants, and co-firing is thus rather a short term solution in most regions.

New technologies that are currently on the edge of commercialisation, such as biomass integrated gasification combined cycle, biomass gasification and upgrading to biomethane, and high-efficient small-scale co-generation systems will be needed in the longer term to achieve the targets of bioenergy electricity, and to a smaller extent heat supply, envisioned in the roadmap.

### **3.2 Biofuel technologies**

Conventional biofuels produced from starch- sugar- or oil bearing crops and to a smaller extent from waste cooking oil and animal fats, account for virtually all biofuel in the market today. Those fuels can in some cases be competitive with conventional gasoline and diesel, but often production costs are more expensive than that of fossil fuels. One of the key sensitivities is the price of feedstock that can account for up to 80% in conventional biofuels. Some scope to improve conversion efficiencies, reduce energy demand, and develop more profitable co-product streams still exists and production costs could thus improve somewhat. However, in the longer term feedstock price volatility, will threaten margins, and sustainability concerns such as CO<sub>2</sub> reduction potential will likely limit the role of conventional biofuels in the longer term.

To achieve the IEA Biofuel Roadmap vision advanced biofuels produced from lignocellulosic energy crops and residues will play a key role. Cellulosic ethanol, biomass-to-liquid fuels, as well as bio-synthetic natural gas that are currently in a pre-commercial stage, still have quite some potential for production cost reductions. Scaling up production units will be a key to materialise those costs reductions, in addition to further improvements in process efficiencies. Around 2030 several advanced biofuels could become competitive with fossil gasoline and diesel, or at least get in close range.

### **3.3 Vision for bioenergy electricity**

With increasing economic growth, world electricity demand in the ETP 2DS will grow rapidly from about 20 000 TWh in 2009 to 42 000 TWh in 2050. The share of renewable electricity will increase from 19% in 2009 to almost 60% in 2050. The remaining 40% would come from nuclear as well as coal, natural gas and other fossil sources, most of which equipped with carbon capture and storage (CCS) technology.

Global bioenergy electricity generation capacity in this roadmap increases from around 50 GW in 2009 to 560 GW in 2050, 50 GW of which are equipped with carbon capture and storage (CCS) technology. World bioenergy electricity generation increases more than tenfold from around 290 TWh in 2009 to 3 100 TWh in 2050, around 300 TWh of this comes from plants equipped with CCS. Total bioenergy electricity generation could provide around 7.5% of world electricity generation, compared to 1.5% today.

### **3.4 Vision for bioenergy use in buildings**

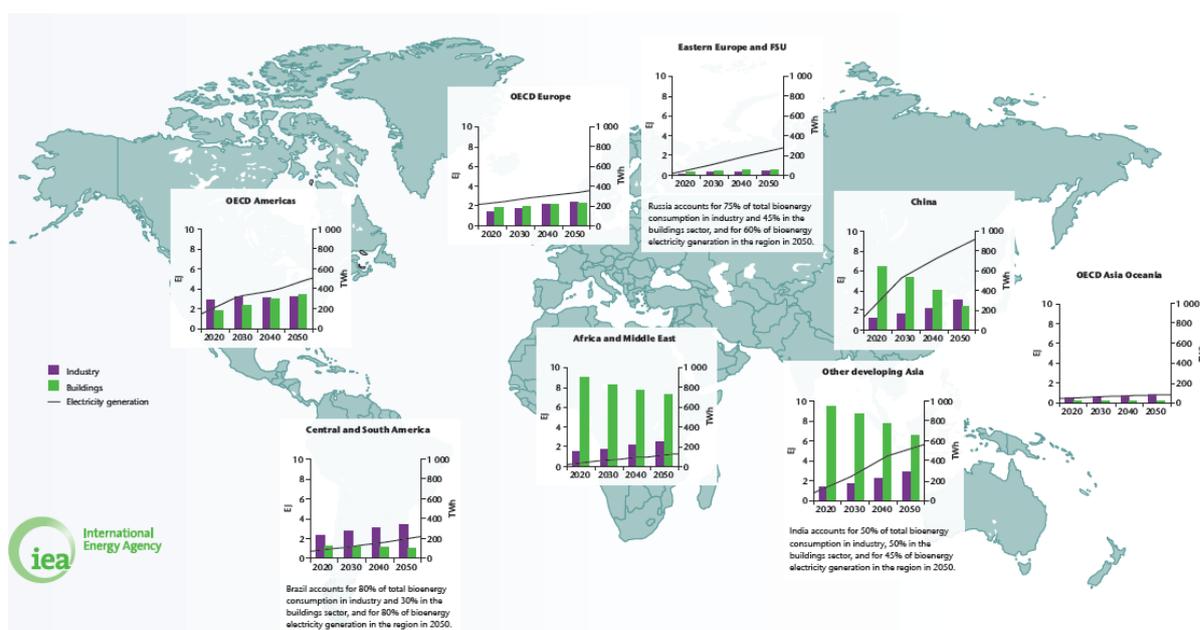
The buildings sector is the largest consumer of bioenergy today, and will keep this position throughout the projection period. This is despite a considerable decrease in total bioenergy demand for heating and cooking that is projected to decline from 35 EJ in 2009 to 25 EJ in 2050. Driven by fast growing population, biomass use for cooking and heating will remain an important source of energy, particularly in rural areas of many developing countries in Africa

and Asia. The widespread deployment of efficient biomass cook stoves and household biogas systems, as well as alternative technologies (*e.g.* solar cooker, solar-heating installations) will be crucial to ensure this growing energy demand is met with clean and efficient technologies. This switch to clean, and more efficient fuels, in combination with energy efficiency improvements of buildings, will eventually lead to the envisioned reduction in total bioenergy demand in the sector. Still, bioenergy would account for 20% of total energy consumption in buildings by 2050, with most of it being consumed in Africa and Asia. In OECD countries, bioenergy demand in the residential sector will roughly double from 3 EJ in 2009 to 6 EJ in 2050 (Figure 1), driven by space heating demand. Demand for cooling might also become a potential driver for bioenergy use in buildings in the longer term, but this relatively new issue has not yet been addressed in great detail and merits greater attention.

### 3.5 Bioenergy consumption in industry

One of the fastest growing sectors in terms of bioenergy demand is the industry sector, where this roadmap sees final bioenergy demand increasing from 8 EJ in 2009 to 22 EJ (15% of total final energy demand in industry) in 2050.

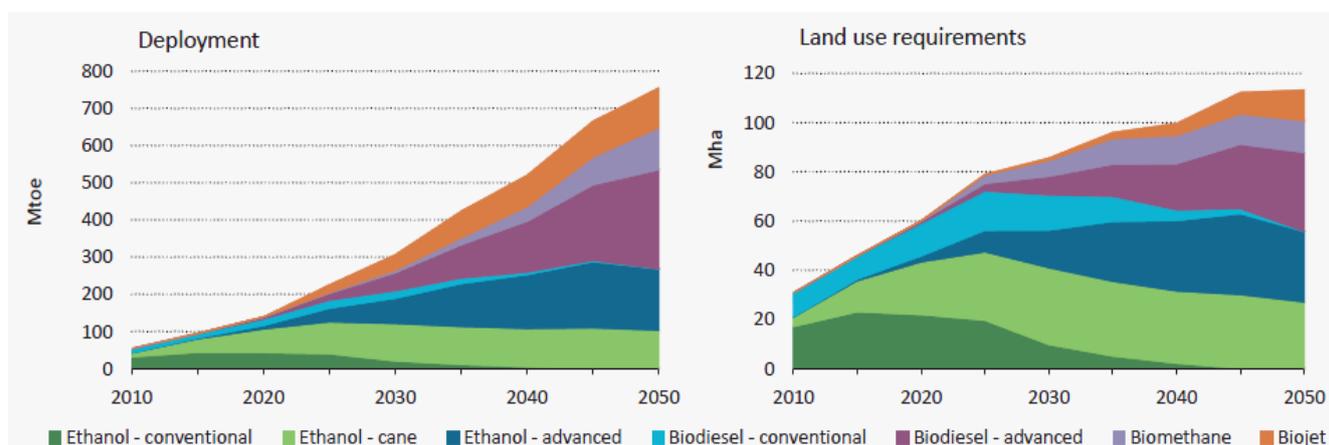
Biomass is already used today to provide process heat in the wood processing and pulp and paper industry, mainly from process residues. Considerable amounts of charcoal are also used to provide high temperature heat in the iron and cement industry in Brazil, where biomass accounts for more than a third of final energy consumption (UNIDO, 2011). To achieve this roadmap's vision, bioenergy consumption in these sectors needs to increase, and become more efficient. In addition, other energy intensive sectors such as cement, the chemical and petrochemical industry could use considerable shares of bioenergy but more concerted efforts are required since these sectors are not currently involved in biomass and bioenergy value chains. As the price for CO<sub>2</sub> emissions rises over the projection period, bioenergy demand in industry will grow considerably. In the medium term, demand growth in OECD countries slows down, but strong growth persists throughout the projection period in non-OECD countries.



**Figure 1: Regional bioenergy electricity generation and final consumption of bioenergy for heat in the buildings sector and industry**

### 3.6 Biofuels

Economic growth also translates into higher vehicle ownership rates, enhanced shipping of goods and increased air travel, amongst others. Subsequently demand for transport fuels is growing rapidly, fastest in emerging economies. Despite projected strong improvements in vehicle efficiency, and deployment of electric and plug-in hybrid vehicles, emission reduction targets in the 2DS cannot be met without a considerable contribution of low-carbon biofuels that replace fossil fuels in particular in shipping and aviation. Globally, demand for biofuels grows from 2.5 EJ (60 million tons of oil equivalent (Mtoe)) in 2011 to 32 EJ (760 Mtoe) in 2050, which means that biofuels will eventually provide 27% of global transport fuel demand by that time.



**Figure 2: Demand for biofuels by technology (left) and resulting land demand (right).**

Over the next decade biofuel demand is expected to be highest in OECD countries, but non-OECD countries will account for 60% of global biofuel demand by 2030 and roughly 70% by 2050, with strongest demand projected in China, India and Latin America. Advanced biofuels will play a key role in achieving the outlined vision, and first commercial advanced biofuel projects are have recently started production or are close to commissioning in the United States and Europe, where several pilot and demonstration plants are already operating. Conventional biofuels are expected to play a role in ramping up production in many developing countries because the technologies are less costly and less complex than for advanced biofuels. Once technologies are proven and feedstock supply concepts have been established, advanced biofuels will also be installed in other emerging and developing countries. In regions with limited land and feedstock resources, such as the Middle East and certain Asian countries, feedstock and biofuel trade will play an increasing role.

### 3.7. CO<sub>2</sub> abatement through bioenergy and biofuels

The use of bioenergy, heat, electricity and biofuels as outlined above can contribute a total of 3.6 Gt of CO<sub>2</sub> reductions to overall CO<sub>2</sub> abatement in the ETP 2012 2DS, if the biomass is sourced sustainably and provides very low lifecycle-GHG emissions. Under these conditions, the use of bioenergy for heat could provide 150 Mt CO<sub>2-eq</sub> in buildings (9% of total emission savings in this sector) and 500 Mt CO<sub>2-eq</sub> in industry (7.5% of total emission savings in this sector) in 2050 compared to the ETP 6°C Scenario (business as usual). Bioenergy electricity generation could provide an additional 1.0 Gt CO<sub>2-eq</sub> of emission savings, which together with around 300 Mt CO<sub>2-eq</sub> of emission reductions through combining bioenergy electricity

generation with carbon capture and storage (CCS) could provide 6% of total emission savings in the power sector in 2050. The use of transport fuels will be particularly vital to reduce emissions in those sectors that will rely on liquid fuels even in the longer term, such as aviation, shipping and long-haul road transport. Overall, biofuels could provide 1.6 Gt of CO<sub>2-eq</sub> emission reductions compared to the 6DS, provided that the feedstock can be sourced sustainably so as to ensure low lifecycle GHG emissions.

#### **4. Feedstock demand – implications on sustainability**

##### **4.1 Biomass demand in 2050**

To meet the demand for heat and power outlined above, a total of 100 EJ (i.e. roughly 5-7 billion dry tons) of biomass will be required, in addition to 60 EJ (3-4 billion dry tons) needed for production of transport fuels in 2050. This is a considerable increase on the estimated 50 EJ of biomass used for energy production today. Thorough analysis of global bioenergy potential estimates for 2050, as provided for instance by the Intergovernmental Panel on Climate Change (IPCC) (2011), suggest that substantial amounts of biomass could be sourced from agricultural and forestry residues and wastes. With substantial investments aimed at improving agricultural production, considerable amounts of land could be made available for cultivation of dedicated energy crops. Much of the potentially available land is located in Eastern Africa, South America, and Eastern Europe.

Residues and wastes will play an important role to supply sufficient amounts of biomass in a sustainable manner. However, complex logistics and costs related to their collection and transport will likely constrain the amount of biomass that can be mobilised in a cost-efficient manner. Dedicated energy crop plantations will thus be needed to provide the required amounts of biomass for large-scale power plants, and biofuel conversion units, that are needed to meet the demand for heat, power and transport fuel in the 2DS. In total between 270 Mha and 400 Mha of land would be needed to provide around two-third of the required 160 EJ of biomass from energy crops, assuming that the remaining share comes from residues and wastes. The amount of land needed will depend strongly on the land use efficiency, *i.e.* the yield per hectare, with which energy crops can be produced in the future.

Analysing biomass potentials over a 40 year horizon inevitably relies on assumptions on a number of uncertain factors, which will always be subject to debate. This is particularly true for bioenergy, since its development is influenced by trends not only in the energy sector, but also in the agricultural and forestry sectors. In light of these uncertainties, rather than debating whether the size of the global bioenergy potential in 2050 could reach 100 EJ or 500 EJ, a more pragmatic approach in form of an intermediate target for biomass supply is needed to plan the sector's development in the short and medium term. A key milestone in the IEA roadmaps is to find ways to validate, demonstrate, and mobilise another 50 EJ of biomass for energy purposes (*i.e.* doubling current primary bioenergy supply) in a sustainable manner by 2030. This should be done with a primary focus on “available” feedstocks such as residues and wastes, but will also need to include energy crops. Achieving this intermediate step will provide important lessons on the logistical, technical, ecological and economic feasibility of large-scale biomass supply, and a better understanding of positive and negative environmental, social and economic effects including on related sectors. This field experience should then allow more accurate expectations of the role of sustainable bioenergy in the future energy system.

## 4.2 Need to ensure sustainability

A variety of different environmental, social and economic issues need to be addressed to ensure the overall impact of bioenergy is positive compared to that of fossil fuels. The debate about potential negative environmental, social, and economic impacts of bioenergy has been principally associated with biofuels for transport, where the main feedstock categories today (starch, sugar and oil crops) are also used as feed and food. However the same sustainability issues are also relevant for heat and power generated from biomass, and the whole lifecycle impact of bioenergy production needs to be carefully considered. While GHG life-cycle emission savings are an important environmental aspect of bioenergy use, there are several other issues to be considered: biodiversity, impact on soil fertility and soil degradation, the use of water and impact on water quality, employment, and potential health impacts, among others. These aspects are covered briefly below, and have been discussed in more detail elsewhere in this publication, as well as in other studies (Eisentraut, 2010; GBEP, 2011; FAO and UNEP, 2010, Global Bio Pact, 2011).

### 4.2.1 Lifecycle greenhouse-gas savings

One important driver for the development of heat and power generated from biomass as well as for biofuels used in the transport sector is the reduction of lifecycle GHG emissions compared to the use of fossil fuels. Such emission reductions can be achieved when biomass feedstocks are sourced on a renewable basis, and GHG emissions related to cultivation, harvest, transport and conversion into final energy, are kept at a minimum level. Thorough lifecycle analyses show that under such conditions, bioenergy heat and power can provide significant emission reductions compared to fossil fuels (IPCC, 2011).

Biofuels for transport can also have a very positive impact in terms of emission reductions, but the emission saving potential strongly depends on the feedstock type: Biofuels based on agricultural crops that require intensive fertiliser and pesticide input, such as soy, canola, and cereals, typically show lower GHG reduction potential than those based on wastes (*e.g.* used cooking oil), or very efficient crops such as sugarcane. Advanced biofuels, produced from lignocellulosic crops and residues, promise to offer significant GHG reductions, but reliable data from commercial production will be needed to verify these model results (IEA, 2011).

While lifecycle GHG emissions of bioenergy heat and power and biofuels can be significantly lower than those of reference fossil fuels, concerns have been raised that the GHG benefits of bioenergy can be reduced or negated by CO<sub>2</sub> emissions caused by land-use change (LUC).<sup>3</sup> The level of such emissions depends on when and where the changes take place, and how the respective carbon stocks (in form of standing biomass as well as soil carbon) and emission cycles are modified when managed for bioenergy feedstock categories as compared to a business-as-usual scenario. Depending on the pace of plant regrowth, it might take several decades to remove the initial atmospheric CO<sub>2</sub> that is released (if any) when establishing an energy crop plantation (Bird et al., 2011; Cherubini et al., 2011). Some data on emissions from direct land-use change are available (see for instance Fritsche et al., 2010), but the exact order of magnitude of emissions related to indirect land-use change (ILUC) is still subject to intensive research efforts. Results from studies on ILUC related emissions caused by conventional biofuels for transport indicate that GHG emissions can in some cases be very

---

<sup>3</sup> The land-use change can be either *direct*, as when energy crops are grown on land that was previously used for a different purpose, or was previously not managed at all; or *indirect*, when energy crop production in one place displaces the production of other crops or increases the overall demand for biomass, which is then produced on other land (perhaps in another region or country).

high (E4Tech, 2010; Edwards et al., 2010; Tyner et al., 2010), but results vary between different studies and no consensus has yet been reached.

It is thus generally preferable to establish land use management that reduces large initial releases of GHG, and leads to additional biomass growth and thus carbon sequestration compared to the previous land use. In some cases, however, it can make sense to put large bioenergy schemes in place that cause a temporary decline in carbon stocks, if the scale of GHG savings by replacing fossil fuels still allows for longer term emission reductions in the energy sector. Such an approach should then lead to a stabilisation of atmospheric CO<sub>2</sub> levels, as envisioned in the ETP 2DS underlying the IEA Technology Roadmaps.

#### **4.2.2 Other sustainability issues**

In addition to net life-cycle CO<sub>2</sub> savings compared to fossil fuels, the production of bioenergy for heat and power and biofuels, need to have an overall positive impact with regards to environmental, social, and economic aspects. Governments should therefore adopt sustainability requirements for bioenergy, following internationally agreed sustainability criteria and evaluation methods, and making use of existing certification schemes for forest products, and those for biofuels. International harmonisation of certification schemes will be crucial, to provide credible certification schemes and avoid market disturbance or creation of trade barriers.

Specific attention must be paid to integrating smallholders in certification schemes, since these producers often cannot handle the additional costs of complying with certification. If these concerns are addressed adequately, sustainability certification will likely become a driver for the development of an international bioenergy market. However, additional measures are also needed to address the unsustainable use of land and water resources and the issues related to (indirect) land-use changes. Integrated land-use management schemes will be a key towards tackling these issues, but to be effective they will ultimately need to address the risks related to land-use change in the whole agricultural and forestry sector. This will be key in order to ensure a more efficient and sustainable production of food, feed, bioenergy and other biomaterials.

### **5. Conclusions**

Energy from biomass - be it in form of electricity, heat or transport fuels - has the potential to provide considerable greenhouse gas reductions compared to reference fossil fuels, and in addition can contribute substantially to enhance energy security and promote socio-economic development. To ensure that these benefits can be materialised, energy and resource efficient technologies, a strong policy framework, as well as commitment by all stakeholders towards sustainable production practices along the value chain will be required.

The IEA technology roadmaps highlight a number of key actions that are required in the next 10 years in order to achieve the level of bioenergy heat and power and biofuels in the 2DS:

- Create a stable, long-term policy framework for bioenergy and biofuels to increase investor confidence and allow for private sector investments in the sustainable expansion of bioenergy and biofuel production.
- Introduce efficient support mechanisms for bioenergy that effectively address the specifics of both electricity and heat markets, and provide sound support for sustainable biofuels, including dedicated measures to promote the production and use of advanced biofuels.
- Link financial support schemes to the sustainable performance of bioenergy heat and power and biofuels to ensure significant life-cycle GHG emission savings compared to fossil fuels.

- Replace traditional biomass use through more efficient stoves and clean fuels (e.g. biogas) by the creation of viable supply chains for advanced biomass cook stoves and household biogas systems.
- Support the installation of more pilot and demonstration projects, such as innovative concepts for small-scale combined heat and power plants, and advanced biofuel conversion routes, including their complete supply chains.
- Increase research efforts on development of energy crops and land suitability mapping to identify the most promising feedstock types and locations for future scaling up.
- Set medium-term targets for biofuels and bioenergy that will eventually lead to a doubling of current primary biomass supply (i.e. to 100 EJ) by 2030. This will help to establish supply chains, assess the impact on sustainability and identify viable options for effective integration of bioenergy production in biomass value chains.
- Implement internationally agreed sustainability criteria, indicators and assessment methods for bioenergy. These should provide a basis for the development of integrated land-use management schemes that aim for a more resource efficient and sustainable production of food, feed, bioenergy and other services.
- Introduce internationally aligned technical standards for biomass and biomass intermediates, in order to reduce and eventually abolish trade barriers, enhance sustainable biomass trade and tap new feedstock sources.
- Support international collaboration on capacity building and technology transfer to promote the adoption of best practices in sustainable agriculture, forestry and bioenergy production.

## References

- **Bird, N., A. Cowie, F. Cherubini and G. Jungmeier**, 2011, Using a life-cycle assessment approach to estimate the net greenhouse-gas emissions of bioenergy, IEA Bioenergy ExCo 2011:03
- **Cherubini, F., G.P. Peters, T. Berntsen, A.H. Stromman, and E. Hertwich**, 2011, CO<sub>2</sub> emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming, GCB Bioenergy, Vol. 3, No. 5, pp. 413-426.
- **E4Tech** , 2010, A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels, Study for the UK Department for Transport, E4Tech, London
- **Edwards R., Mulligan D. and L. Marelli L.**, 2010, Indirect Land-use change from increased biofuels demand. Comparison of models and results for marginal biofuels production from different feedstocks, EC Joint Research Centre, Ispra
- **Eisentraut, A.** (2010), Sustainable Production of Second-Generation Biofuels. Potential and perspectives in major economies and developing countries, OECD/IEA, Paris, [www.iea.org/papers/2010/second\\_generation\\_biofuels.pdf](http://www.iea.org/papers/2010/second_generation_biofuels.pdf)
- **FAO (Food and Agriculture Organisation of the United Nations) and UNEP (United Nations Environment Program) (2010)**, A Decision Support Tool for Sustainable Bioenergy, [www.fao.org/docrep/013/am237e/am237e00.pdf](http://www.fao.org/docrep/013/am237e/am237e00.pdf)
- **GBEP (Global Bioenergy Partnership) (2011)**, The Global Bioenergy Partnership Sustainability Indicators for Bioenergy, FAO/GBEP, Rome.
- **Global-Bio-Pact (2011)**, Report on identified biomass conversion chains, their general socioeconomic impacts and the translation of criteria into practically applicable indicators and thresholds, [www.globalbiopact.eu](http://www.globalbiopact.eu)
- **IEA**, 2012, Energy Technology Perspectives 2012, OECD/IEA, Paris
- **IEA**, 2011a, Renewables Information 2011, OECD/IEA, Paris
- **IEA**, 2011b, Medium Term Oil Market Report December 2011, OECD/IEA, Paris

- **IPCC (Intergovernmental Panel on Climate Change)**, 2011, IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, prepared by Working Group III of the Intergovernmental Panel on Climate Change (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)), Cambridge University Press, Cambridge and New York
- **Tyner W.E., Taheripour F., Zhuang Q., Birur D. and Baldos U.**, 2010, Land-use changes and Consequent CO2 Emissions due to US Corn Ethanol Production: A Comprehensive Analysis, Purdue University: West Lafayette
- **UNIDO (United Nations Industrial Development Organisation)**, 2011, Renewable Energy in Industry Applications, UNIDO, Vienna

## Abbreviations

Bio-SG	Bio-Synthetic natural Gas
CCS	Carbon Capture and Storage
GHG	Greenhouse Gas
IEA	International Energy Agency
ILUC	Indirect Land-Use Change
IPCC	Intergovernmental Panel on Climate Change
LUC	Land-Use Change
R&D	Research and Development
TPES	Total Primary Energy Supply



# **European Union (EU) renewable energy framework and bioenergy contribution from the EU Member States National Renewable Energy Action Plans (NREAPs)**

**N. Scarlat and J.F. Dallemand**  
**Joint Research Centre, Institute for Energy and Transport**  
**Renewable Energy Unit**  
**Via E. Fermi 2749 - TP 450, 21027 Ispra (Va) Italy**

## **Abstract**

The basis for the European Union (EU) policy for renewable energy was set in 1997 with the *White Paper on Renewable sources of energy* which proposed doubling the share of renewable energy in the gross energy consumption from 6% to 12% by 2010. In 2007, the European Commission proposed an integrated *Energy and Climate Change* package with a commitment to achieve at least a 20% reduction of greenhouse gases emissions by 2020, a 20% share of renewable energy in the gross final energy consumption and a 10% share of renewable energy in transport. In order to address some environmental concerns, the *Renewable Energy Directive* (2009) and *Fuel Quality Directive* (2009) proposed a set of mandatory sustainability criteria for biofuels and bioliquids, while the options to address sustainability aspects related to solid and gaseous biomass are still being investigated. In 2012, the European Commission also made a proposal for a Directive amendment aiming to take into account Indirect Land Use Change (ILUC) effects of biofuel consumption in order to limit the use of food-based biofuels and to encourage the development of advanced biofuels. At long term, the European Commission proposes to reduce further greenhouse gas emissions by 2050 (compared to 1990 levels), to develop a competitive low carbon economy by 2050 as well as an *Energy Roadmap 2050* to achieve this goal.

Significant progress has been achieved recently in renewable energy deployment. According to the National Renewable Energy Action Plans (NREAPs) from each of the 27 EU Member States, the use of renewable energy is projected to increase substantially between 2005 and 2020, from 4,143 PJ in 2005 to 10,201 PJ in 2020. Renewable energy deployment has increased to reach 6255.1 PJ in 2010, i.e. 8.7% above the 2010 NREAP projections. The contribution of different renewable energy sources is expected to change significantly until 2020.

Bioenergy will continue to play the dominant role in the RES contribution to the energy mix of the European Union until 2020, with a planned increase from 2580 PJ to 5828 PJ. Bioenergy production already reached 3601 PJ in 2010, in comparison with the 3577 PJ expected. In 2010, biofuel use in transport increased to 567 PJ i.e. below the expected 577 PJ. The total biomass primary demand is expected to increase from 3,094 PJ in 2005 to 7,407 PJ in 2020, while the biomass potential in the EU was estimated in different studies between 9,839 PJ and 15,686 PJ. Thus, the domestic biomass potential is large enough to cover the expected biomass demand (with some variation between different Member States) and in addition biomass imports are taking place and will continue.

## **1. EU Policy framework for renewable energy**

In 1997, the European Commission *White Paper for a Community Strategy and Action Plan Energy for the future: Renewable sources of energy* (COM(97) 599 final) set the basis for the EU policy on renewable energy. The White Paper proposed doubling the share of renewable energy in the EU gross internal energy consumption from 6% to 12% by 2010. The European

Commission proposed several targets for 2010 for certain renewable energy technologies: 135 Mtoe for biomass; 40 GW for wind energy; 3 GWp for photovoltaic energy; 5 GWth for geothermal heat; 1 GW for geothermal electricity and 105 GW for hydro.

Significant progress has been achieved in some technologies and the targets for 2010 were already achieved or even exceeded by some renewable energy technologies, whereas some others are lagging behind. The wind energy has reached in the EU an installed capacity of 80 GW at the end of 2010, ahead of the 40 GW target. The estimated installed capacity for PV is 29 GW, well above the 3 GW target. EU Member States have made progress towards achieving their national indicative targets, and the share of renewable energy consumption in gross inland energy consumption has increased from 4.4% in 1990, to 5.6% in 2000, 6.4% in 2005 and reached 9.8% in 2010 in the EU, as compared with the global indicative target of 12% (Eurostat, 2013). Thus, the EU indicative target of 12% renewable energy share of gross domestic energy consumption in 2010 was not reached.

The White Paper was followed in 2001 by the *Renewable Electricity Directive* 2001/77/EC. This Directive on the promotion of electricity produced from renewable energy sources set the target of 22.1% of total electricity to be produced from renewable sources by 2010 (EC, 2001). This target was realigned to 21% in 2004 when the New Member States joined the European Union. In 1997, when the European Commission has set the basis for a European renewable energy policy, the share of renewable electricity in the EU27 was 12.9%. For each Member State, a national indicative target for electricity from renewable energy sources was defined, in order to contribute to the overall target. EU Member States could choose their preferred support mechanism in order to achieve their target.

Following the *Renewable Electricity Directive*, the renewable electricity generation has increased in the EU to 668 TWh in 2010, out of which 366 TWh hydro, 149 TWh wind, 123 TWh biomass, 23 TWh solar and 6 TWh geothermal. The share of green electricity in the EU has grown continuously reaching 13.6% in 2005 and 19.9% in 2010 (Eurostat, 2013). Thus, in spite of this growth, EU failed to reach its 2010 target. In 2010 in the EU hydropower contributed the largest share with 10.9%, followed by wind with 4.5%, biomass with 3.7%, and solar power with 0.7% of the green electricity production. The biggest absolute increase between 2000 and 2010 in electricity production has been in wind (127 TWh increase) followed by biomass (89 TWh), solar (23 TWh), hydro (14 TWh). However, in relative terms, renewable electricity production from solar has expanded by far most rapidly between 2000 and 2010, followed by wind power.

In 2003, the *Biofuels Directive* 2003/30/EC on the promotion of the use of biofuels or other renewable fuels set a target for the biofuels and other renewable fuels replacing petrol and diesel in transport of 5.75% of all petrol and diesel used in the transport sector by 2010 (EC, 2003). However, these targets were only indicative. The data showed that the 2010 targets set by the Directive 2001/77/EC and the Directive 2003/30/EC were not met, even though, both sectors have experienced continued growth (COM(2011)31). The biofuel consumption in transport has increased from 125 PJ in 2005, representing 1.0% share of biofuel in the consumption of diesel and gasoline to 586 PJ biofuels in 2010, representing 4.8% of fuel consumption in the transport sector. Thus the target of 5.75% in 2010 proposed by the Directive 2003/30/EC was not met at EU level (Eurostat, 2013, Eurobserv'ER, 2011).

In 2007, the European Commission proposed an integrated *Energy and Climate Change* package on the EU's commitment to change (*Energy policy for Europe* (COM(2007) 1 final) (EC, 2007a) and *Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond* (COM(2007) 2 final) (EC, 2007b). This included an EU commitment to

achieve at least a 20% reduction of greenhouse gases by 2020 compared to 1990 levels and a mandatory EU target of 20% renewable energy, including a 10% target for renewable energy for 2020.

The *Renewable Energy Directive* 2009/28/EC (RED) on the promotion of renewable energy sources, requires the EU Member States to increase the share of renewable energy to 20% of gross final energy consumption and 10% renewable energy in the transport sector by 2020 (EC, 2009a). This comes along with the strategic energy policy objective to reduce the greenhouse gas emissions in the European Union by 20% compared to 1990 emission levels. The RED specifies objectives legally binding rather than indicative national targets for the share of renewable energy by 2020. Each Member State has a mandatory target calculated according to the share of energy from renewable sources in its gross final consumption for 2020. Moreover, the share of energy from renewable sources in the transport sector must amount to at least 10% of final energy consumption in the sector by 2020 in each Member State. In addition, the Fuel Quality Directive 2009/30/EC set a target of a 6% greenhouse gas reduction for fuels used in the transport sector in 2020 (EC, 2009b). The RED and FQD include criteria for sustainable biofuel production and procedures for verifying that these criteria are met.

The overall renewable energy share in the gross final energy consumption in the EU increased from 8.5% in 2005 to 12.5% in 2010 according to the aggregated data of the first progress reports of the Member States. The share of renewable energy used in transport increased from 1.3% in 2005 and about 5.0% of the gross final energy demand in the transport sector in 2010 (EurObserv'Er, 2011). The Renewable Energy Directive also provides for a set of provisions to facilitate the development of renewable energy, such as a legal requirement for the Member States to prepare National Renewable Energy Action Plans (NREAPs) including detailed roadmaps to reach the RES targets, measures taken to reach these targets and develop energy infrastructure. The European Commission has prepared harmonised templates for the NREAPs and for the progress reports to ensure comprehensive planning and comparability of the Member State reports.

### **1.1. Consistency with other European policies**

The EU energy and climate goals have been incorporated into the *Europe 2020 Strategy for smart, sustainable and inclusive growth* (COM(2010) 2020), (EC, 2010a) and into its flagship initiative *Resource efficient Europe* (EC, 2011). The objective of Europe 2020 is to develop:

- smart growth (education, knowledge and innovation);
- sustainable growth (a resource-efficient, greener and more competitive economy);
- inclusive growth (high employment and economic, social and territorial cohesion).

The *Europe 2020 Strategy for smart, sustainable and inclusive growth* also includes climate and energy targets: reducing greenhouse gas emissions (GHG) by 20%, increasing the share of renewables in the EU's energy mix to 20%, and achieving the 20% energy efficiency target by 2020.

*Resource Efficient Europe*, one of the seven flagships of the *Europe 2020 strategy* (COM(2011) 21), was developed in order to support the shift towards a resource-efficient, low-carbon economy and to achieve sustainable growth. The objectives of this strategy are in line with the objectives of the Commission's Communications *Europe 2020* and *Energy 2020*, for example the EU objective to reduce GHG emissions by 80 to 95% in 2050 compared to 1990 (EC, 2011a).

The *Energy 2020 - A strategy for competitive, sustainable and secure energy* (COM(2010) 639) set out the European Commission's energy strategy in the period to 2020 (EC 2010b).

The new energy strategy focuses on five priorities:

- achieving an energy efficient Europe;
- building a pan-European integrated energy market;
- empowering consumers and achieving the highest level of safety and security;
- extending Europe's leadership in energy technology and innovation;
- strengthening the external dimension of the EU energy market.

The *Strategic Energy Technology Plan (SET-Plan)* (COM(2007)723 final) was established for accelerating the development of low-carbon energy technologies, for transforming energy technologies to achieve the 2020 energy and climate change goals and for contributing to the transition to a low carbon economy (EC, 2007c, EC 2007d). Within the SET-Plan, several European Industrial Initiatives (EIIs) were created to foster the rapid development of key energy technologies at the European level in risk-sharing partnership between industry, research, the Member States and the European Commission. EIIs are established for wind, solar (photovoltaics and concentrated solar power), electricity grids, bioenergy, carbon capture and storage and nuclear fission.

The European Energy Research Alliance (EERA) and its Joint programs (JP) have been set to provide a better coordination of funding covering several technologies (photovoltaic, wind, geothermal, smart grids, bioenergy, carbon capture and storage, materials for nuclear, concentrated solar power, energy storage, fuel cells and hydrogen, ocean energy and smart cities) (SEA, 2009). A proposal for a new Implementation Plan for 2013-2015 is expected to be released by EIBI team, with a review of the goal of 4% advanced biofuels by 2020 and work on cost estimates for achieving this target (EIBI, 2013).

## **1.2. Sustainability requirements for bioenergy**

### **1.2.1. EU sustainability criteria for biofuels and bioliquids**

The *Renewable Energy Directive* 2009/28/EC of the EU includes a set of mandatory sustainability criteria (EC, 2009 a) as part of an EU sustainability scheme including also monitoring and reporting requirements for biofuels and bioliquids. Similar sustainability requirements were set in the Fuel Quality Directive (FQD) 2009/30/EC (EC, 2009b) on the specification of petrol, diesel and gas-oil, together with a mechanism to monitor and reduce GHG emissions. Biofuels and bioliquids are required to fulfil all sustainability criteria to count towards EU targets and to be eligible for financial support. The Renewable Energy Directive excludes several land categories to be used for producing biofuels and bioliquids (categories with this status in January 2008):

- high biodiversity value land: a) primary forests and other wooded land; b) areas designated for nature protection or for the protection of rare, threatened or endangered ecosystems or species recognized by international agreements or IUCN; c) highly biodiverse grassland;
- high carbon stock land, such as: a) wetlands; b) continuously forested areas; c) land covered by trees higher than 5 m and a canopy cover between 10% and 30%;
- peatlands.

For biomass feedstock produced in the EU, the cross-compliance rules of the Common Agricultural Policy (CAP) and the requirements for Good Agricultural and Environmental Conditions (GAECs) apply. The EU cross compliance regulations refer to preservation of soil and water quality, biological diversity, careful use of fertilisers/pesticides and air pollution.

The EU sustainability scheme from the Renewable Energy Directive includes monitoring and reporting requirements. The EU Member States must report on the impact of biofuels and bioliquids on biodiversity, water resources, water quality and soil quality, net GHG emission reduction, changes in commodity prices and land use associated with the increased use of biomass. The fuel suppliers are required to report on the compliance with the sustainability criteria and on the measures taken for soil, water and air protection, the restoration of degraded land and the avoidance of excessive water consumption in areas with water deficit. Although there are no criteria for social sustainability specified, the European Commission must report on the impact of biofuels on social aspects and the impact on the availability of food at affordable prices. The European Commission will monitor the origin of biofuels consumed in the EU and impacts of their production in the EU and third countries, land use and land use change, commodity prices and food security. A large number of national and international initiatives emerged for the sustainability certification for biofuels and/or bioenergy (Scarlat and Dallemand 2010). At mid 2013, a total of thirteen voluntary certification schemes have been recognised by the Commission.

### **1.2.2 GHG emission reduction requirements for biofuels and bioliquids**

In the European Union, biofuels and bioliquids should meet a minimum requirement for GHG savings of 35% relative to fossil fuels. This will increase to 50% in 2017 for existing plants and 60% in 2018 for new installations. Advanced, second-generation biofuels produced from residues, non-food cellulosic material and lignocellulosic material would be double credited towards the 10% target.

In addition to the sustainability criteria, the RED includes rules and a methodology for the calculation of GHG emissions and provides actual and default values. The GHG emissions include all emissions from the extraction or cultivation of raw materials, from processing, transport and distribution and also annualised emissions from carbon stock changes caused by land-use change (calculated over a period of over 20 years). A bonus of 29 g CO<sub>2</sub>eq/MJ shall be attributed if the land was not in use or if it was severely degraded or heavily contaminated. The GHG emissions from co-products shall be calculated in proportion to their energy content.

The European Commission also provided guidelines establishing the rules for the calculation of land carbon stocks, including soil organic carbon and carbon stock in the above and below ground vegetation both for the reference and the actual land use and values for different soil types and land use categories. The European Commission had to report on the impact of Indirect Land Use Change (ILUC) on GHG emissions and addressing ways to minimise the impact of ILUC. The report had to include a methodology for emissions from carbon stock changes caused by indirect land-use changes.

The sustainability of biofuels and bioliquids has to be checked by Member States or through voluntary schemes approved by the European Commission. The European Commission assesses the schemes that have been submitted for recognition and which meet the strict requirements of sustainability and control.

### **1.2.3 Sustainability requirements for the use of solid and gaseous biomass**

In 2010, the European Commission released a report on the sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling (COM(2010)11). The Commission acknowledged the sustainability concerns on biomass production in terms of protecting the biodiversity of ecosystems and carbon stocks (EC, 2010c).

This report provided recommendations to the EU Member States for developing national schemes for solid and gaseous biomass used in electricity, heating and cooling, with the same requirements as those laid down in the Renewable Energy Directive for biofuels and bioliquids. Biomass should therefore not be sourced from land converted from forest or other areas of high biodiversity or high carbon stock. This minimises the risk of adopting diverse and even incompatible criteria at national level, the risk of discrimination in the use of raw materials based on their final use.

The European Commission recommended small-scale producers and users (below 1 MW capacity) to be excluded from the application of sustainability criteria. Member States should keep records of the origin of biomass used in installations of 1 MW or above and monitor small-scale (mainly households) biomass use, as well as the effects of biomass use on the areas of origin. The European Commission recommended the differentiation of national support schemes for electricity, heating and cooling installations to provide incentives to achieve high-energy conversion efficiencies.

EU Member States should not impose sustainability criteria to waste, which is covered by environmental rules laid down in separate waste legislation at national and European levels. Wastes and certain residues should only comply with the greenhouse gas performance criteria. Forestry-related sustainability framework and cross compliance rules for agriculture are considered to ensure the biomass sustainability in Europe. The report on the sustainability requirements for the use of solid or gaseous biomass set out a common methodology for calculating the GHG performance of biomass, to include the conversion of biomass to electricity, heating or cooling. The minimum greenhouse gas savings from biomass should be at least 35% compared to the EU's fossil energy mix, and increasing to 50% from 2017 for existing plants and 60% for new plants from 2018. Various initiatives have been launched to prepare sustainability criteria for solid and gaseous biomass (Fritsche et al, 2012).

#### **1.2.4 Land use impact of biofuels/bioenergy development**

The contribution from biofuels to the RES targets is expected to be significant. Additional demand for biofuels might be met through an increase through land conversion of the amount of land used for agriculture, leading to an indirect increase in greenhouse gas emissions.

Land use impacts of bioenergy production depend on number of factors, assumptions and uncertainties. One main source of uncertainty is the availability of waste and residues for energy purposes and the amount of agricultural land available for the cultivation of energy crops. Various assumptions regarding future agricultural productivity and future consumption of animal products have a great impact on the results (Berndes et al, 2010, Witcover et al 2012, Tilman et al 2009). Depending on the expected developments and several assumptions relating to bioenergy production, the impact on land use might be significant (Scarlat et al, 2013).

The uncertainty in the amounts of available waste and residues from agriculture strongly depends on the future demand from different uses such as animal feed, renewable raw material, etc. The same applies for forestry biomass that has multiple uses, i.e. material, fibre and energy production. Another source of uncertainty is represented by future increase in crop yields for food, feed, fibre, energy and renewable raw materials, as the amount of available agricultural land depends on the yields which can be achieved. An important constraining factor is the application of sustainability criteria, that will exclude the use biomass that is produced under “unsustainable” conditions. The limited availability of sustainable biomass resource may require a prioritisation of its application. Biomass should be used primarily in

those sectors where there are no other renewable energy alternatives (such as aviation, etc.) or where they ensure high conversion efficiency or provide high economic value.

Indirect Land Use Changes (ILUC) might occur through the displacement of the previous crop to another location. Cascade effects may occur, and agricultural land might expand on other land type (e.g. grassland or forest land) to accommodate the need for crop production. The ILUC effects vary according to the feedstock, with a high degree of uncertainty. The results vary widely due to different modelling assumptions, including feedstock type, land use expansion vs. yield increase, land use dynamics (Edwards, 2010, Marelli, 2010). Indirect land-use change emissions would significantly reduce the expected savings from the policy if no action is taken to mitigate indirect land-use changes.

The Commission published in 2010 a report (COM(2010) 811 final) to review the impact of Indirect Land Use Change (ILUC) on greenhouse gas emissions and propose action for minimising that impact (EC, 2010d). This report:

- identified a number of uncertainties and limitations associated with the modelling to estimate indirect land use change;
- acknowledged that the impact of indirect land use change on greenhouse gas emissions savings associated with biofuels could reduce their contribution to the policy goals;
- considered that, if action is required, indirect land use change should be addressed under a precautionary approach.

This report recommended the preparation of an Impact Assessment and if appropriate, a legislative proposal for amending the Renewable Energy and Fuel Quality Directives. In the Impact Assessment (SWD(2012) 343 final) five policy options were evaluated (EC, 2012c):

- no action for the time being while continuing to monitor ILUC (option A)
- increase of the minimum greenhouse gas saving threshold for biofuels (option B)
- additional sustainability requirements on certain categories of biofuels (option C)
- attribution of greenhouse gas emissions to biofuels reflecting the estimated indirect land use change impact (option D)
- limitation of the contribution from conventional biofuels to the Renewable Energy Directive targets (option E).

These various options were analysed considering the effects on indirect land use changes, the greenhouse gas emissions savings, the availability of adequate sustainability criteria and the impact on biofuels industry. The Impact Assessment concluded that a balanced approach based on option E, complemented with options B and D and additional incentives for advanced biofuels, would be the best way to minimise indirect land-use change emissions. It is considered that this will avoid additional ILUC impacts from conventional biofuels and the additional incentives will promote advanced biofuels instead of biofuels with high indirect land-use change emissions (EC, 2012c).

### **1.3. A new proposal for the amendment of the Renewable Energy Directive**

In 2012, the Commission released a proposal (COM(2012) 595 final) to amend the Fuel Quality and Renewable Energy Directives in order to take account of indirect land use change effects of EU biofuel consumption and to encourage the development of advanced biofuels from non-food feedstock. In order to reach the 10% renewable energy target of the Renewable Energy Directive, the use of food-based biofuels (produced from cereal and other starch rich crops, sugar and oil crops) will be limited to 5% or to the share of such biofuels and bioliquids consumed in 2011 (EC, 2012a). This proposal is now with the European Parliament and the Council of Ministers for debate.

The emissions from carbon stock changes caused by the estimated indirect land-use change should be included in the reporting of greenhouse gas emissions from biofuels. This is to stimulate the development of alternative, second generation biofuels from non-food feedstock, prepare for the transition towards advanced biofuels and minimise the overall indirect land use change impacts. The proposed values for indirect land-use change emissions from biofuels are: 12 gCO<sub>2eq</sub>/MJ for cereals and other starch rich crops; 13 gCO<sub>2eq</sub>/MJ for sugar crops; 55 gCO<sub>2eq</sub>/MJ for oil crops.

The greenhouse gas emission saving shall be at least 60% for biofuels and bioliquids produced in installations starting operation after 1<sup>st</sup> July 2014. In the case of installations that were in operation on or before 1st of July 2014, biofuels and bioliquids shall achieve a greenhouse gas emission saving of at least 35% until 31<sup>st</sup> December 2017 and at least 50% from 1<sup>st</sup> January 2018. The provisions for encouraging the cultivation of biofuels in severely degraded and heavily contaminated land do not longer apply.

This proposal provides an enhanced incentive scheme to further promote sustainable and advanced biofuels from feedstocks that do not create an additional demand for land. The contribution made certain feedstock shall be considered to be four times their energy content:

- biofuels produced from: a) algae; b) biomass fraction of municipal waste; c) biomass fraction of industrial waste; d) straw; e) animal manure and sewage sludge; f) palm oil mill effluent and empty palm fruit bunches; g) tall oil pitch; h) crude glycerine; i) bagasse; j) grape marcs and wine lees; k) nut shells; l) husks; m) cobs; n) bark, branches, leaves, saw dust and cutter shavings;

- renewable liquid and gaseous fuels of non-biological origin.

Biofuels produced from the following feedstocks shall be considered to be twice their energy content: a) used cooking oil; b) animal fats; c) non-food cellulosic material; d) ligno-cellulosic material except saw logs and veneer logs. Although the multiple counting might be effective in promoting the development of advanced biofuels, it would not contribute to achieve the climate change goals.

Biofuels produced from the following feedstock categories will be considered to have estimated indirect land-use change emissions of zero: (a) feedstocks not produced from cereal and other starch rich crops, sugars and oil crops; b) feedstocks whose production has led to direct land use change, i.e. from one of the following land cover categories; forest land, grassland, wetlands, settlements, or other land, to cropland or perennial cropland. In this case, the direct land use change emission value should have been calculated in the greenhouse gas emissions.

#### **1.4. Future RES policies in the EU and follow-up after 2020**

In order to keep climate change below 2°C, both the European Council and Parliament have set the objective of reducing greenhouse gas emissions by 80-95% by 2050, compared to 1990 levels. In 2011, the European Commission adopted the *Roadmap for moving to a competitive low carbon economy in 2050* (COM(2011)112) and *Energy Roadmap 2050* (COM(2011)885 final).

The *Roadmap for moving to a competitive low carbon economy in 2050* (COM(2011)112) set out key elements for the EU's climate action helping the EU become a competitive low carbon economy by 2050. It sets intermediate milestones for a cost-efficient pathway and GHG emission reductions, policy challenges, investment needs and opportunities in different sectors. The analysis of different scenarios showed that, in order to be in line with the 80% to 95% overall GHG reduction objective by 2050, domestic reduction of greenhouse gas emissions of 40% for 2030 compared to 1990 levels, 60% for 2040 and 80% for 2050 would

be the cost-effective pathway. The share of low carbon technologies in the electricity mix was estimated to increase from around 45% today, to 60% in 2020, 75 to 80% in 2030, and almost 100% in 2050 (EC, 2011b).

The *Energy Roadmap 2050* (COM(2011) 885/2), investigated possible pathways for a transition towards a decarbonisation of the energy system and the impacts, challenges and opportunities of possible ways of modernizing the energy system. A number of scenarios to achieve an 80% reduction in greenhouse gas emissions and about 85% reduction of energy-related CO<sub>2</sub> emissions have been examined. The *Energy Roadmap 2050* showed that different options can contribute to the 2050 decarbonisation goal. Improving energy efficiency and reducing consumption are a priority in all decarbonisation scenarios. This can lead to a decrease of primary energy demand between 16% to 20% by 2030 and 32% to 41% by 2050 as compared to maximum levels reached in 2005-2006. Carbon capture and storage could contribute significantly in most scenarios with a strong role of up to 32% in power generation in the case of constrained nuclear production scenario and shares between 19 to 24% in other scenarios. Storage technologies are critical to accommodate RES supply (EC 2011c).

A higher deployment of renewable energy is a major pre-requisite for a sustainable and secure energy system. The RES share is projected to rise substantially in all scenarios, reaching between 55% and 75% of gross final energy consumption in 2050, up from the current level of around 12%. RES share in electricity consumption reaches very high levels, with 64% in a high-efficiency scenario and 97% in a high-renewables scenario, which includes significant electricity storage, compared to around 20% today (EC 2011c).

The Commission is currently preparing a *Renewable Energy Strategy*. The European Commission launched a Communication (COM(2012)271 final) on renewable energy aiming to examine the conditions for a further development of renewable energy for a medium term perspective (2030). This will cover the three pillars of energy policy (sustainability, security of supply and competitiveness) and be consistent with the long-term decarbonisation scenarios. The Commission launched a public consultation in December 2011-January 2012 on areas covering general policy approach, financial support, sustainability issues, technology development and R&D policy, etc. (EC, 2012b)

## **2. Renewable energy and bioenergy projections for 2020**

### **2.1. National Renewable Energy Action Plans**

The EU Member States prepared and submitted in 2010 National Renewable Energy Action Plans (NREAPs), as required by the Renewable Energy Directive, setting out their national targets for the share of renewable energy consumed in electricity, heating and cooling and in transport, and measures for achieving the national overall renewable energy targets (EC, 2009c).

In the NREAPs, the EU Member States had to propose two scenarios for energy consumption until 2020:

- the Reference Scenario, only taking into account the energy efficiency and saving measures adopted before 2009;
- the Additional Energy Efficiency Scenario, including all energy efficiency and saving measures adopted and expected to be adopted after 2009. The contribution of different RES technologies and their targets in electricity, heating & cooling and transport in the NREAPs are based on this Additional Energy Efficiency scenario.

These plans provide detailed roadmaps of how each EU Member State expects to reach its legally binding 2020 targets for the share of renewable energy in the final energy consumption. The NREAPs include additional information to substantiate the targets and measures envisaged to reach them, including the estimated costs and benefits of the measures planned, actions for the extension or reinforcement of the existing grid infrastructure, national support schemes for renewables and the use of renewable energy in buildings.

Member States also have to prepare progress reports on the developments in the RES against the interim targets established in their NREAPs. The reports describe the overall renewable energy policy developments in each Member State, the progress made in the use of renewable energy and their shares, their compliance with the measures set out in the Directive, in comparison with the National Renewable Energy Action Plans (EC 2009a).

## 2.2. Expected development of RES and bioenergy contribution

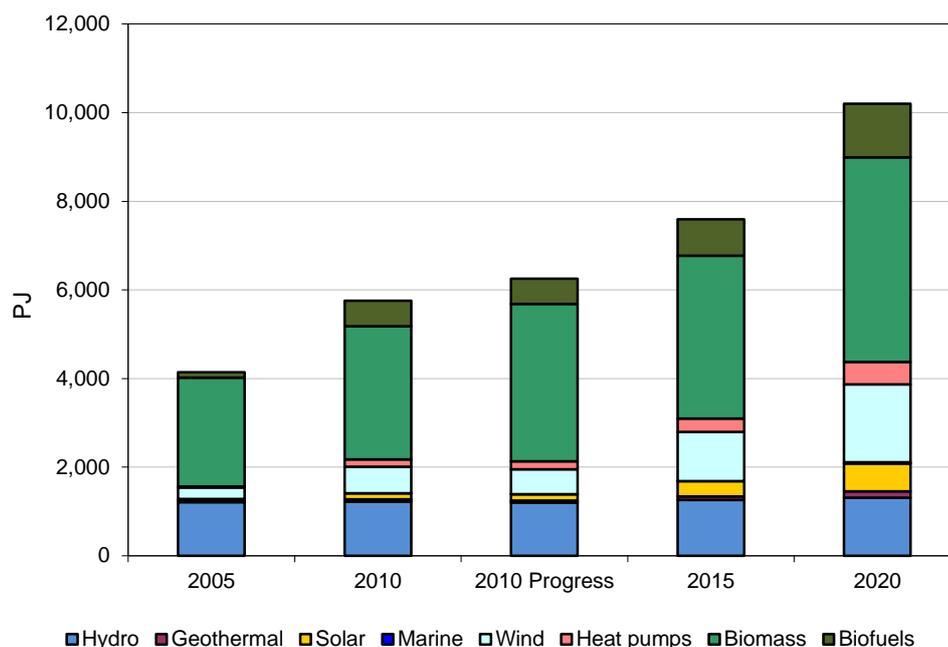
The analysis of the National Renewable Energy Action Plans shows that the use of renewable energy is projected to increase more than two fold between 2005 and 2020, increasing from 99 Mtoe (4,143 PJ) in 2005 to about 243.7 Mtoe (10,201 PJ) in 2020 (Szabo et al 2011, Banja et al. 2013).

An important increase (see Table 1) is expected from biomass (including biofuels), wind, solar, heat pumps, geothermal, hydro. According to the aggregated data from the first progress report of the Member States, significant progress has been achieved until 2010. The renewable energy deployment increased from 4143 PJ in 2005 to 6255 PJ in 2010, an increase of 1946 PJ (47.3%). The renewable use in the EU was 8.7% above the NREAP projections of 5754.4 PJ for 2010 (EC, 2011d).

**Table 1: Final renewable energy consumption in the EU 27 [PJ]**

	<b>2005</b>	<b>2010</b>	<b>2010*</b>	<b>2015</b>	<b>2020</b>
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Hydro</b>	1,209	1,223	1,201	1,255	1,305
<b>Geothermal</b>	38	50	42	83	149
<b>Solar</b>	34	136	146	344	627
<b>Marine</b>	2	2	2	3	23
<b>Wind</b>	253	597	559	1,107	1,759
<b>Heat pumps</b>	26	168	183	303	509
<b>Biomass</b>	2,455	3,001	3,553	3,677	4,618
<b>Biofuels</b>	125	577	567	820	1,210
<b>Total RES</b>	4,143	5,754	6,255	7,592	10,201

\* achieved, according to aggregated data of the Member States Progress reports



**Figure 1: Projected trend of renewable final energy consumption in the EU**

Renewable heating & cooling made the most significant progress between 2005 and 2010, with an increase of 1097 PJ, followed by renewable electricity with 572 PJ and renewable energy in transport with 445 PJ. The use of renewable energy in heating increased from 2280 PJ in 2005 to 3376 PJ in 2010, 18.5% above the projected level of 2849 PJ. The renewable electricity increased from 1737.6 PJ in 2005 to 2309 PJ in 2010, but this is 0.8% below the target of 2329 PJ. The use of RES in transport grew from 171 PJ in 2005 to 616 PJ in 2010, which is however 2.4% below the target of 631 PJ (EC, 2011d).

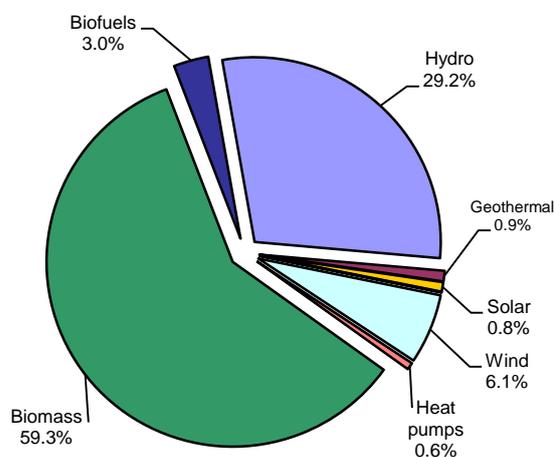
The European Union had a share of renewable energy source of 8.5% in the gross final energy consumption in 2005. According to the NREAPs aggregated data this is expected to reach 20.6% in 2020, in the Additional Energy Efficiency Scenario, just above the 20% target set by the Directive 2009/28/EC. The combined EU renewable energy share in electricity is expected to grow from 14.8% in 2005, 19.6% in 2010 to 34.1% in 2020, in heating and cooling from 9.3% in 2005, 12.5% in 2010, to 21.3% and in transport from 1.3% in 2005 to 5.0% in 2010 and to 11.4% (Table 2).

**Table 2: Total and sectorial RES share in the EU 27.**

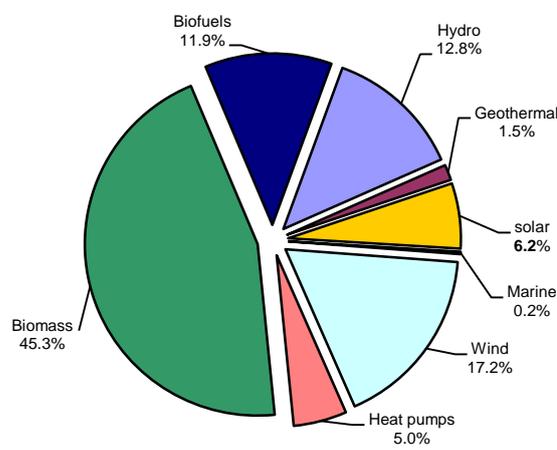
	2005	2010	2010*	2015	2020
	[%]	[%]	[%]	[%]	[%]
<b>RES heating</b>	9.3	12.5	14.3	15.9	21.3
<b>RES electricity</b>	14.8	19.6	19.5	26.3	34.1
<b>RES transport</b>	1.3	5.0	5.0	7.2	11.4
<b>RES</b>	8.5	11.6	12.5	15.3	20.6

\* achieved, according to aggregated data of the Member States Progress reports

The contribution of different renewable energy sources is expected to change significantly until 2020. The share of biomass energy is expected to decrease from 62.3% in 2005 to 57.2% in 2020, hydro energy should decrease from 29.2% in 2005 to 12.8%, while the contribution of other renewables would increase: wind from 6.1% to 17.2%, solar from 0.8% to 6.2%, heat pumps from 0.6% to 5.0%, geothermal from 0.9% to 1.5%, marine energy from 0% to 0.2% (Figures 2 and 3).



**Figure 2: Final renewable energy consumption in 2005 in the EU**



**Figure 3: Final renewable energy consumption in 2020 in the EU**

The aggregated data from NREAPs shows that bioenergy will play the dominant role in the contribution of RES in the energy mix in the EU until 2020, with a share of about 57.2% of total renewable energy use in 2020, while decreasing from 62.3% in 2005. Overall, the share of bioenergy in the gross final energy consumption will increase from 5.3% in 2005 to about 11.7% in 2020, according to the NREAPs forecast (Szabo et al 2011, Manja et al 2013). The total use of biomass electricity, heating and cooling and biofuels in transport is estimated to increase from 2,581 PJ Mtoe in 2005 to about 3,578 PJ in 2010 and 5,829 PJ in 2020, including biofuels with 1,210 PJ (see Table 3).

**Table 3: Total final biomass in electricity, heating and cooling and transport in EU27.**

	2005	2010	2010*	2015	2020
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Solid biomass</b>	2,330	2,650	3,269	3,186	3,945
<b>Biogas</b>	71	165	171	271	418
<b>Bioliquids</b>	54	185	113	219	255
<b>Biofuels</b>	125	577	567	820	1,210
<b>Total biomass</b>	2,581	3,577	3,601	4,496	5,829
<b>Share in energy consumption</b>	5.3%	7.2%	7.2	9.1%	11.7%
<b>Share in RES consumption</b>	62.3%	62.2%	57.6	59.2%	57.1%

\* achieved, according to aggregated data of the Member States Progress reports

### 2.3. Renewable electricity

The renewable electricity capacity increased in the European Union from 164,889 MW in 2005 to 241,097 MW in 2010, below the expected 243,288 MW for 2010. Significant progress was made in the installed capacity in most sectors, especially in solar power (from 2221 MW

in 2005 to 25912 MW in 2010), wind power (from 40,441 MW in 2005 to 84347 MW in 2010) and biomass (from 15,703 MW in 2005 to 25083 MW in 2010).

**Table 4:. Installed RES capacity in EU27.**

	<b>2005</b>	<b>2010</b>	<b>2010*</b>	<b>2015</b>	<b>2020</b>
	[MW]	[MW]	[MW]	[MW]	[MW]
<b>Hydropower</b>	105,543	108,134	100,951	114,436	121,895
<b>Geothermal</b>	741	816	823	1,042	1,613
<b>Solar</b>	2,221	25,912	29,650	57,432	90,014
<b>Marine energy</b>	240	245	243	362	2,243
<b>Wind power</b>	40,441	85,502	84,347	143,284	210,763
<b>Biomass</b>	15,703	22,678	25,083	32,683	43,637
<b>Total</b>	164,889	243,288	241,097	349,239	470,164

\* achieved, according to aggregated data of the Member States Progress reports

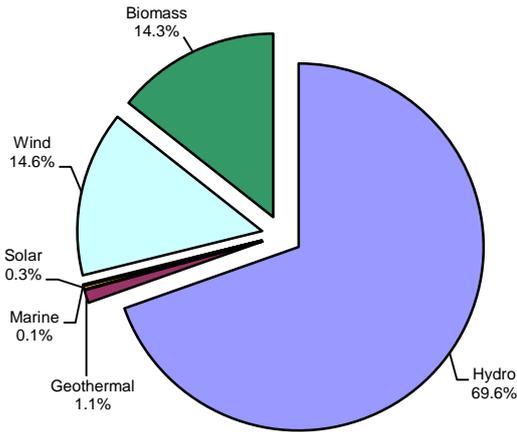
In the EU, electricity production from RES increased from 482,660 GWh in 2000 to 641,500 GWh in 2010. The renewable energy contribution to electricity generation in the EU is expected to reach 1,203,065 GWh in 2020 and the share of RES electricity is forecast to increase from 14.8% in 2005 to 34.1% of gross final electricity consumption by 2020 (Szabo et al. 2011; Banja et al. 2013).

**Table 5: Renewable electricity production [GWh]**

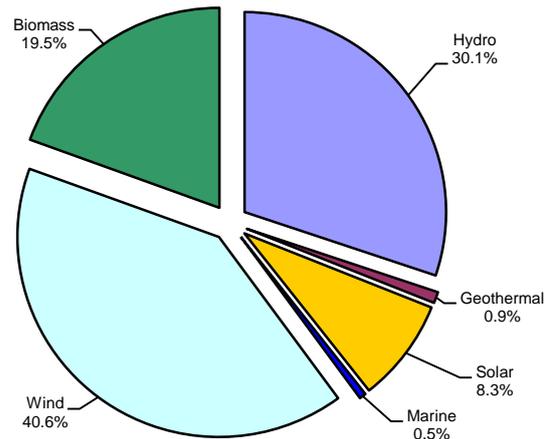
	<b>2005</b>	<b>2010</b>	<b>2010*</b>	<b>2015</b>	<b>2020</b>
	[GWh]	[GWh]	[GWh]	[GWh]	[GWh]
<b>Hydropower</b>	335,777	339,747	333,665	348,641	362,570
<b>Geothermal</b>	5,477	5,977	5,619	7,342	10,893
<b>Solar</b>	1,470	20,703	23,164	60,403	100,385
<b>Marine energy</b>	535	501	478	864	6,506
<b>Wind power</b>	70,362	165,918	155,195	307,595	488,564
<b>Biomass</b>	69,039	114,075	123,380	170,197	234,148
<b>Total</b>	482,660	646,921	641,500	895,041	1,203,065

\* achieved, according to aggregated data of the Member States Progress reports

By 2020 wind would become the most important renewable energy source providing 40.6% of all renewable electricity compared to 14.6% in 2005, the contribution of solar electricity would also grow from 0.3% to 8.3%. The role of hydro would decrease from 69.6% in 2005, to 30.1% in 2020. The contribution of geothermal and marine energy are still expected to remain marginal until 2020 with 0.9% and 0.5%, respectively.



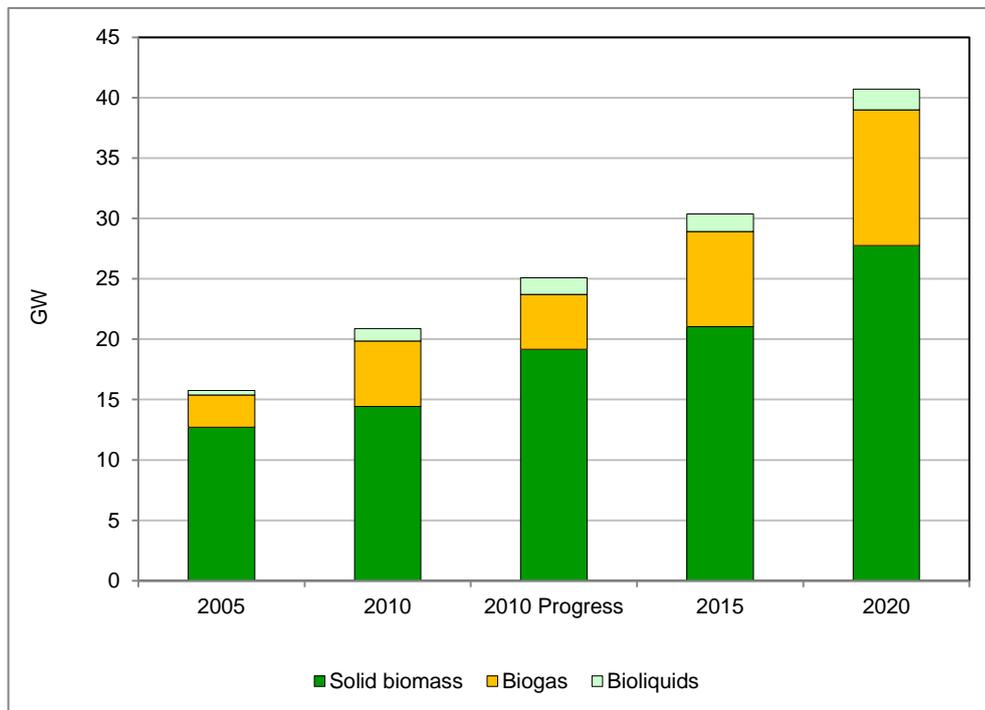
**Figure 4: Share of renewable electricity generation in 2005 in the EU**



**Figure 5: Share of renewable electricity generation in 2020 in the EU**

### 2.3.1. Biomass electricity capacity

The installed biomass power capacity in the EU according to the NREAPs is expected to increase from 15.7 GW in 2005 to 43.6 GW in 2020, with solid biomass having an installed capacity of 27.7 GW, biogas 11.2 GW and liquid biofuels 1.7 GW (Szabo et al 2011, Manja et al 2013). The progress reports show that biomass power installed capacity increased in the EU to 25.1 GW in 2010, 10.6% above the expected installed plant capacity of 22.7 GW (EC, 2011d).



**Figure 6: Installed biomass electricity capacity in the EU**

Solid biomass is the main contributor in biomass electricity installed capacity since 2005 with 80.9% of biomass plant installed capacity and will remain still in the same position, even in 2020 with a share of 63.6%. The share of installed biogas plants is expected to increase

significantly from 17.0% in 2005 to 25.8% of total biomass installed capacity in 2020. The share of installed plants using bioliquids is also expected to increase from 2.3% in 2005 to 3.9% of total biomass installed capacity in 2020.

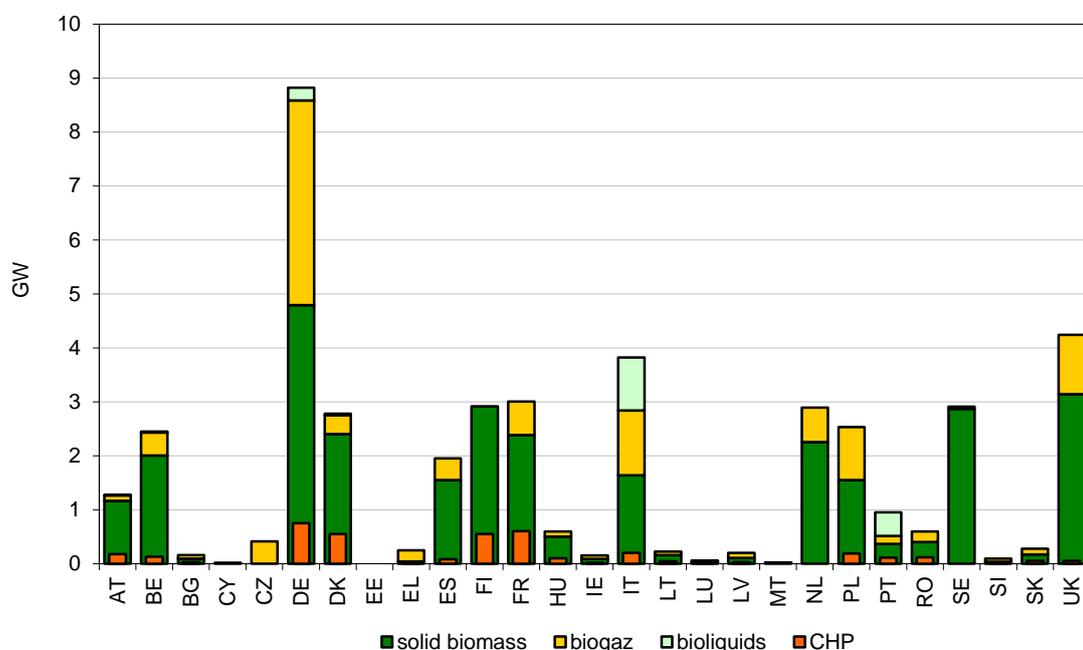
The share of installed biomass power plant capacity in the total renewable power capacity (Table 6) increased from 9.4% in 2005 to 10.4% in 2010, while the projected share for 2010 was 9.3% (EC, 2011d). With a significant increase in the biomass power capacity expected until 2020, the share of installed biomass power capacity is expected to decrease to 9.3% until 2020.

**Table 6: Installed biomass electricity capacity in the EU [MW]**

	2005	2010	2010*	2015	2020
	[MW]	[MW]	[MW]	[MW]	[MW]
<b>Solid biomass</b>	12,701	14,421	19,158	21,042	27,769
<b>Biogas</b>	2,670	5,428	4,553	7,884	11,237
<b>Bioliquids</b>	368	1,039	29,959	1,438	1,711
<b>Biomass</b>	15,703	22,678	25,083	32,683	43,637
<b>Total RES</b>	164,889	243,288	241,097	349,239	470,164
<b>Share in RES capacity</b>					
[%]	9.5	9.3	10.4	9.4	9.3

\* achieved, according to aggregated data of the Member States Progress reports

The leading countries in biomass installed capacity in 2010 were Germany 6650 MW, followed by Sweden with 3854 MW, UK with 2097 MW, Italy with 2053 MW and Finland with 1910 MW. In 2020 (Figure 7), the leading countries are expected to be Germany with 8825 MW, followed by UK with 4240 MW, Italy with 3820 MW, France with 3007 MW and Finland with 2920 MW installed capacity.

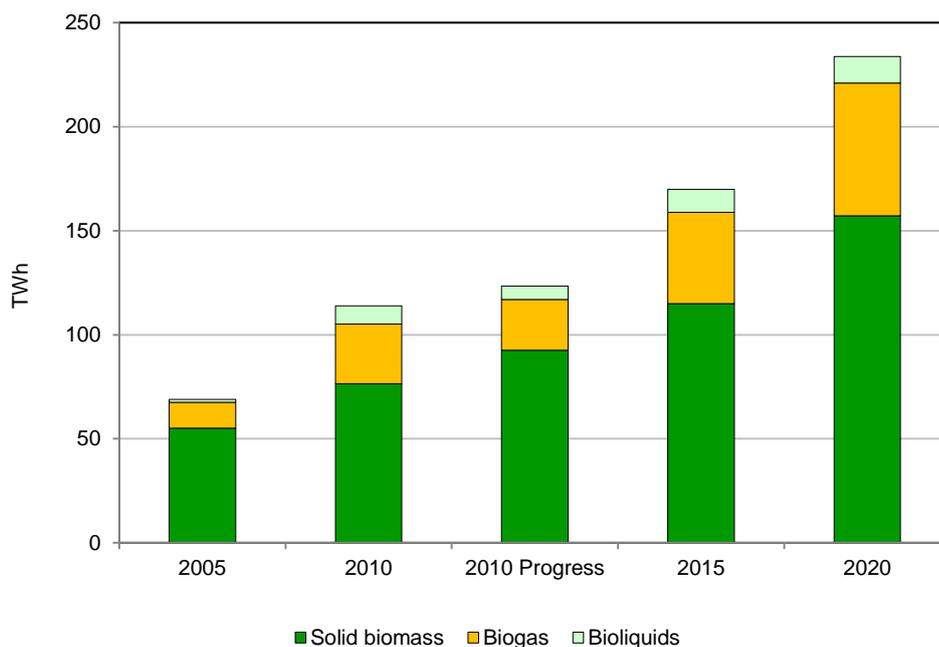


**Figure 7: Expected biomass electricity capacity in 2020**

### 2.3.2. Biomass electricity production

The biomass use for electricity generation (Figure 8) is expected to have a significant increase from 69039 GWh (248.5 PJ) in 2005 to 234,148 GWh in 2020 (about 3.4 fold increase compared to 2005) (Szabo et al 2011, Manja et al 2013). The data from progress reports shows that biomass electricity generation has increased to 123,380 GWh (444.2 PJ) in 2010, which is 9.3% above the expected level of 114075 GWh (406.4 PJ) in 2010 (EC, 2011d).

For 2020 the electricity generation from biomass is projected to reach 234148 GWh (843 PJ) in 2020. The additional biomass electricity generation in 2010-2020 is expected to be 110769 GWh (398.8 PJ), which is almost the 2010 biomass electricity production. In comparison, biomass power production has increased by 54341 GWh (195.6 PJ) in 2005-2010.



**Figure 8: Expected trend in electricity generation from biomass in the EU in 2005-2020**

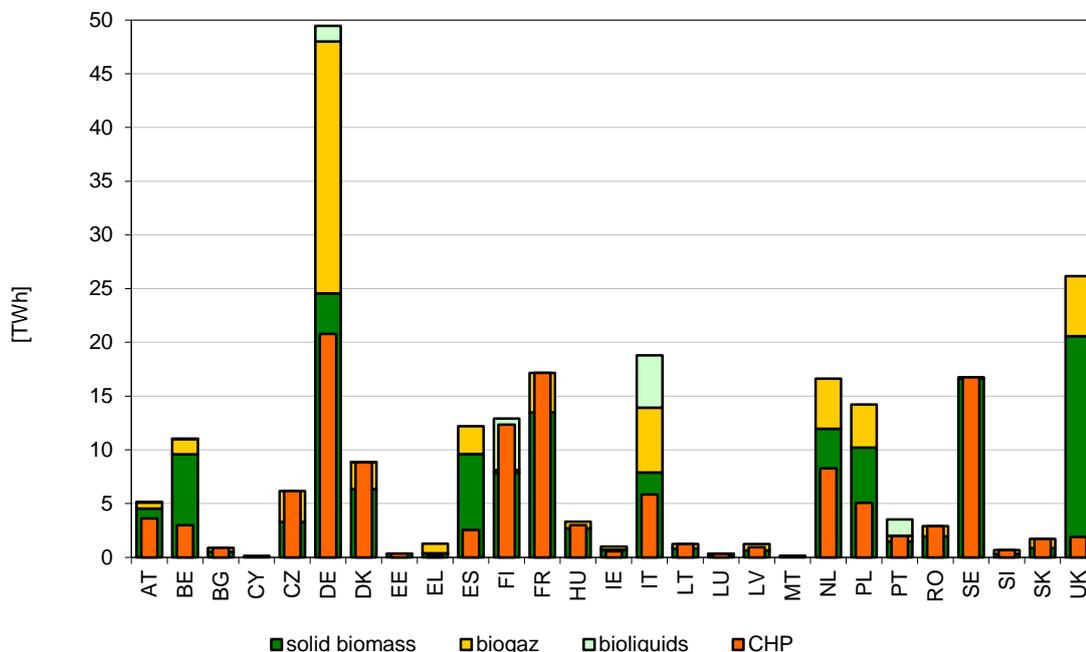
The share of biomass electricity in total renewable electricity generation increased from 14.3% in 2005 to 19.2% in 2010, above the expected share of 17.7% for 2010. The contribution to electricity made by bioenergy will then increase to around 19.1% of total renewable electricity generation in 2020. In 2020 biomass electricity will contribute to overall energy generation with 6.6%.

**Table 7: Gross electricity generation expected from biomass in the EU [GWh]**

	2005	2010	2010*	2015	2020
<b>Solid biomass</b>	55,054	76,518	92,587	114,979	157,100
<b>Biogas</b>	12,482	28,683	24,442	43,928	63,955
<b>Bioliquids</b>	1,470	8,633	6,351	10,944	12,747
<b>Total biomass</b>	69,039	114,075	123,380	170,197	234,148
<b>Total RES</b>	482,660	646,921	641,500	895,041	1,203,065
<b>Share of biomass in RES</b>	14.3	17.6	19.2	19.0	19.4
<b>Total electricity</b>	3,266,786	3,296,214	3,296,495	3,404,724	3,526,427
<b>Share of biomass in electricity</b>					
<b>[%]</b>	2.1	3.5	3.7	5.0	6.6

\* achieved, according to aggregated data of the Member States Progress reports

High progress is expected from biogas, with an increase from 12,482 GWh in 2005 to 63,978 GWh in 2020, solid biomass with an increase from 55,087 GWh in 2005 to 155,246 GWh in 2020, while the electricity produced from bioliquids should grow from 1,470 GWh in 2005 to 12,747 GWh in 2020. The main contribution to biomass electricity will come from solid biomass (68.9%), biogas will produce 25.6 % and bioliquids will produce 5.5 % of biomass electricity in 2020.



**Figure 9: Expected biomass electricity generation in 2020**

Solid biomass is the main contributor to biomass electricity generation since 2005 with 79.7% of biomass electricity and will remain still in the same position, even in 2020 with a share of 67.1%. The share of biogas electricity is expected to increase significantly from 18.1% in 2005 to 27.3% of total biomass electricity generation in 2020. The share of electricity from bioliquids is also expected to increase from 2.1% in 2005 to 5.4% in 2020.

#### 2.4. Renewable Heating and Cooling

In EU 27, the renewable energy in heating and cooling was 2280 PJ (54.5 Mtoe) in 2005 and it is projected to reach 4660 PJ (111.3 Mtoe) in 2020. The heat generation from biomass has increased since 2005 from 2206.7 PJ (52706 ktoe) to 3109 PJ (74259 ktoe) in 2010, which is 18.5% above the expected level of 2590 PJ (61864 ktoe) in 2010 (EC, 2011d). For 2020 the heat generation from biomass is projected to reach 3775 PJ (90170 ktoe) in 2020.

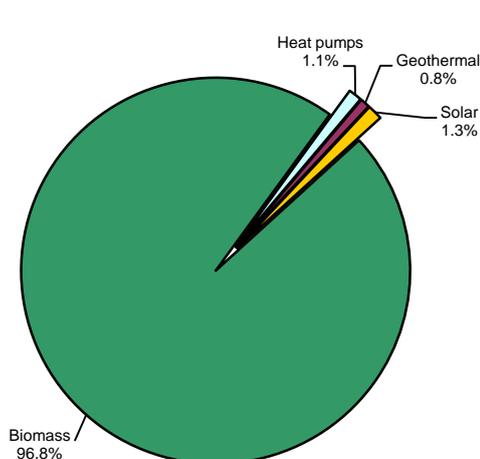
The share of renewable energy in the heating and cooling consumption is expected to increase from 9.3% in year 2005 to 21.4% by 2020. According to the NREAPs, major RES heating and cooling markets (Austria, Sweden, Germany, and France) will see further developments and new markets will emerge, such as the United-Kingdom (Szabo et al 2011, Manja et al 2013).

Although the biomass heating and cooling generation is expected to grow 1.5 times between 2005 and 2020, its share in RES heating will decrease from 96.8% in 2005 to 81.0% in 2020. Other renewables, such as solar heating would increase to 5.7% of renewable heating and cooling compared to 1.3% in 2005, heat pumps should grow from 1.0% in 2005 to 10.6%, and geothermal is expected to contribute 2.4% in 2020 compared to 0.8% (Figures 10 and 11).

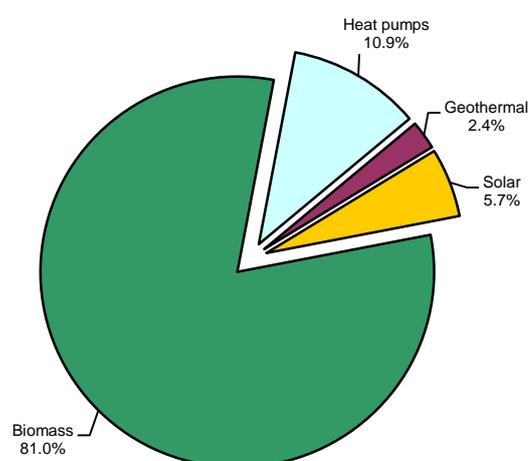
**Table 8: Renewable heating and cooling in EU 27**

	2005	2010	2010*	2015	2020
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Geothermal</b>	18	29	22	56	110
<b>Solar</b>	29	62	63	126	266
<b>Biomass</b>	2,207	2,590	3,109	3,064	3,775
<b>Heat pumps</b>	26	168	183	303	509
<b>Total</b>	2,280	2,849	3,376	3,550	4,660
<b>of which DH</b>	245	343	479	486	745
<b>of which biomass in households</b>	1,175	1,263	1,601	1,343	1,479

\* achieved, according to aggregated data of the Member States Progress reports



**Figure 10: Renewable Heating & Cooling in 2005 in the EU**



**Figure 11: Expected Renewable Heating & Cooling in 2020 in the EU**

#### 2.4.1 Biomass Heating and Cooling

The main contribution of biomass in renewable energy generation is found in the heating and cooling sector. According to the aggregated NREAPs data, the 2020 targets will entail an increase in the use of heating and cooling from biomass from 2,207 PJ (52.7 Mtoe) in 2005 to 3,775 PJ (90.2 Mtoe) in 2020.

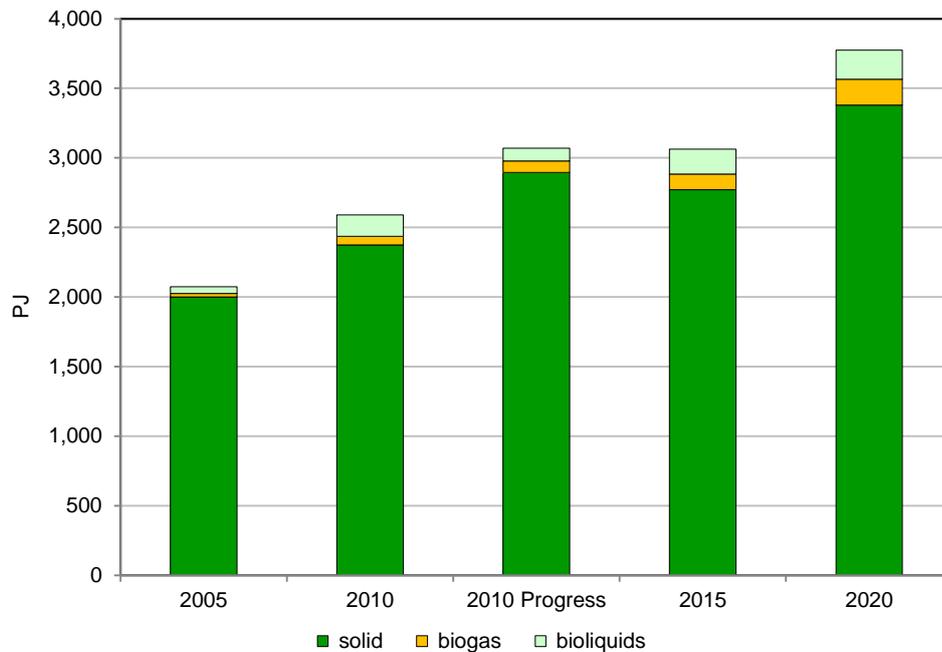
**Table 9: Total contribution expected from biomass in heating and cooling in the EU**

	2005	2010	2010*	2015	2020
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Solid biomass</b>	2132	2374	2936	2771	3379
<b>Biogas</b>	26	62	83	113	187
<b>Bioliquids</b>	49	154	90	180	209
<b>Total biomass</b>	2207	2590	3109	3064	3775
<b>of which DH</b>	245	343	479	486	745
<b>of which biomass in households</b>	1175	1263	1601	1343	1479
<b>Share of biomass in RES heating [%]</b>					
<b>[%]</b>	96.8	90.9	91.4	86.3	81.0
<b>Share of biomass in heating [%]</b>					
<b>[%]</b>	9.0	11.3	13.1	13.7	17.3

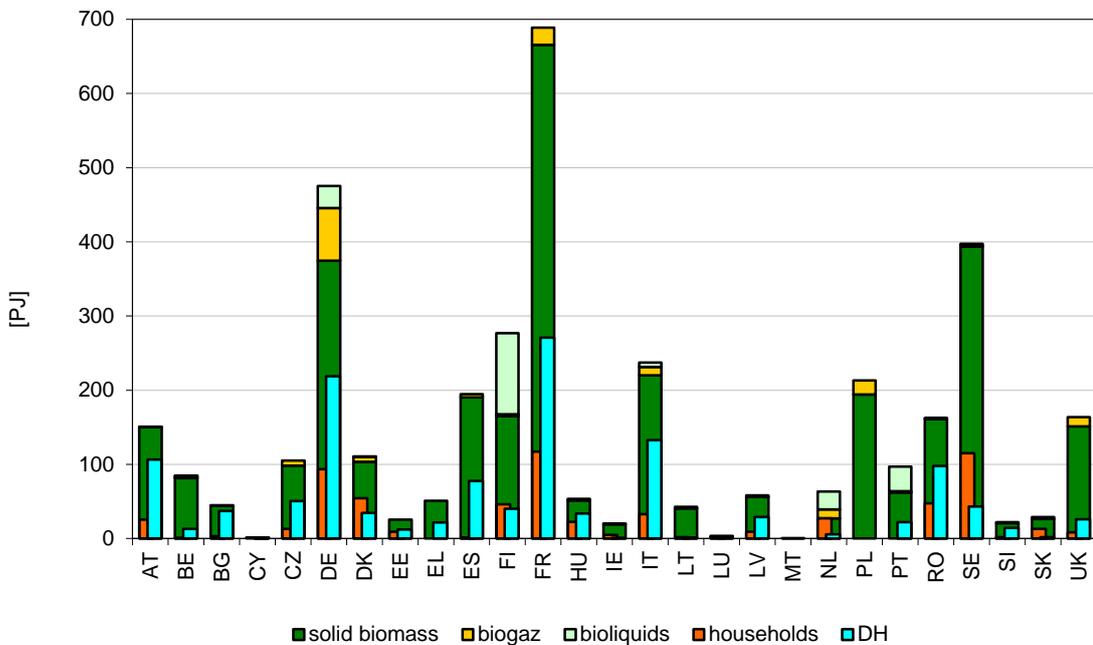
\* achieved, according to aggregated data of the Member States Progress reports

In 2020 biomass is projected to show the highest renewable energy contribution in this sector with 81.0% of renewable heating, a share which declines from the share of 96.8% in 2005. The biomass share in total heating and cooling demand is expected to increase from 9% in 2005 to 17.3% in 2020.

Significant progress was made in all sectors between 2005 and 2010, especially in biomass with 902 PJ (41%), heat pumps with 157 PJ (610%) and solar thermal with 34 PJ (117%). Biomass was the largest contributor in renewable heating and cooling in 2010 with 3109 PJ (74.3 Mtoe), which is 91.2% of the renewable heating, above the NREAP expected share of 90.9%.



**Figure 12: Biomass heating and cooling in the EU 27**



**Figure 13: Expected biomass heating and cooling in EU 27 in 2020**

The main contributor of biomass in renewable heating and cooling in 2005 was solid biomass with 2132 PJ (50.9 Mtoe), representing 96.6% of biomass heating and cooling. Although the use of solid biomass in heating and cooling will increase to 3379 PJ (80.7 Mtoe), its share is projected to decrease to 89.5% in 2020. The most important increase in the biomass heating is expected to come from biogas from 26 PJ (0.6 Mtoe) in 2005, to 62 PJ (2.0 Mtoe) in 2010 and 187 PJ (4.5 Mtoe) in 2020. The biogas share in biomass heating should increase from only 1.2% in 2005 to 5.0% in 2020. The use of bioliquids should increase from 49 PJ (1.1 Mtoe) in 2005, to 154 PJ (2.2 Mtoe) in 2010 and 209 PJ (5.0 Mtoe) in 2020 with a share in biomass heating raising from only 2.2% in 2005 to 5.5% in 2020.

Leading countries in biomass heat generation in 2010 were Germany with 521 PJ (12441 ktoe), France with 504 PJ (12027 ktoe), Sweden with 408 PJ (9752 ktoe), Finland with 271 PJ (6480 ktoe) and Italy with 230 PJ (5496 ktoe). In 2020, leading countries in geothermal heat are expected to be France with 689 PJ (16455 ktoe), Germany with 475 PJ (11355 ktoe), Sweden with 397 PJ (9491 ktoe), Finland with 276 PJ (6610 ktoe) and Italy with 237 PJ (5670 ktoe).

A small part of the heating and cooling is provided by district heating and cooling in 2005, with about 245 PJ (5.9 Mtoe) in 2005 and this is expected to increase to about 745 PJ (17.8 Mtoe). Biomass used in households, mainly used in the form of fuelwood and wood pellets is expected to increase to a limited extent from 1,175 PJ (28.0 Mtoe) in 2005 to 1,479 PJ (35.3 Mtoe) in 2020. Significant variations between member states (MS) are visible (Figure 13).

#### **2.4.2. Biomass use in households**

Biomass is largely used in households for heating in fireplaces and stoves. The contribution of biomass used in households is expected to have a limited increase from 1175 PJ (28.1 Mtoe) in 2005 to 1479 PJ (35.3 Mtoe) in 2020. The use of biomass in households increased since 2005 from 1175.0 PJ (28065 ktoe) to 1601 PJ (38250 ktoe) in 2010 (EC 2011d). Thus, the level achieved in 2010 is already 122 PJ (2916 ktoe) or 8.3% above the projected contribution of biomass in households in 2020. Biomass use in households shall represent 31.7% of the biomass used for heating in 2020 decreasing from 51.5% share of biomass used in households in 2005. Biomass use in households represented 47.1% of the biomass used for heating in 2010, in comparison with an expected share of 44.4% (Szabo et al 2011, Manja et al 2013).

From the point of view of the biomass use in households, France will have the leading role in 2020, with 134 PJ (3,200 ktoe) representing 18.0% of the biomass use in households. Other leading MS in the use of biomass in households are Sweden with 131.5 PJ (3,141 ktoe) Germany with 107.2 PJ (2,560 ktoe), Denmark with 62.2 PJ (1,486 ktoe), Romania with 54.4 PJ (1,300 ktoe) and Finland with 52.8 PJ (1,260 ktoe). The first three countries (France, Sweden and Germany) will use just more than 50% of the biomass used in households in the EU27.

Leading countries in biomass use in households in 2010 were France with 317 PJ (7581 ktoe), Germany with 262 PJ (9537 ktoe), Romania with 148 PJ (3526 ktoe), Estonia with 86 PJ (2055 ktoe) and Denmark with 78 PJ (1867 ktoe). In 2020, leading countries in biomass use in households are expected to be France with 309.8 PJ (7400 ktoe), Germany with 250.2 PJ (5975 ktoe), Italy with 151.6 PJ (3620 ktoe), Austria with 121.6 PJ (2905 ktoe), and Romania with 112.0 PJ (2676 ktoe).

### 2.4.3. Biomass use in district heating

Some countries, particularly in Scandinavia and New Member States, show a significant penetration of district heating. There is a significant potential for the expansion of DH to be used for cooling as well. The contribution of biomass from district heating plants is expected to have a more than three-fold increase between 2005 and 2020. District heating using biomass directly for heat from DH installations should increase from 245 PJ (5.9 Mtoe) in 2005 to 745 PJ (17.8 Mtoe) in 2020 and biomass from district heating will have a share increasing from 11.1% in 2005 to 19.7% in biomass heating in 2020 (Szabo et al 2011, Manja et al 2013).

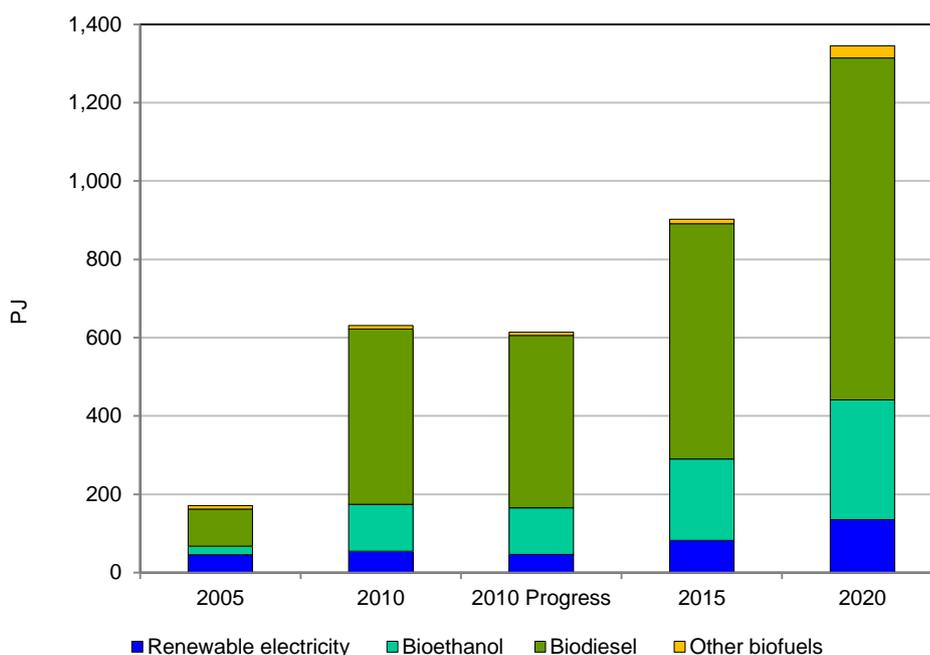
Leading country in district heating with biomass will be France with 309.8 PJ (7,400 ktoe), representing 18.2% of the district heating and cooling in the EU27. Other Member States with important district heating using biomass will be Germany with 250.2 PJ (5,975 ktoe), Italy with 151.6 PJ (3,620 ktoe), Austria with 121.6 PJ (2,905 ktoe) and Romania with 112.0 PJ (2,676 ktoe). The first three countries (France, Germany and Italy) will have a share of 48.2% of the district heating production from biomass.

### 2.5. Renewable energy in transport

The renewable energy share in the energy used in transport in the EU is expected to grow from 1.4 % in 2005 to about 11.4% by 2020, above the 10% binding target, if considering multiple counting for electricity and biofuels used in transport, as required by the Directive 2009/28/EC.

**Table 10: Expected trend in the use of renewable energy in transport in the EU**

	<b>2005</b>	<b>2010</b>	<b>2010*</b>	<b>2015</b>	<b>2020</b>
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Bioethanol</b>	22.5	119.9	118.9	208.0	305.9
<b>Biodiesel</b>	94.5	448.0	440.4	600.5	873.4
<b>Other biofuels</b>	8.3	8.8	7.8	11.2	31.1
<b>Biofuels</b>	125.4	576.8	567.2	819.7	1210.4
<b>RES electricity</b>	45.5	54.3	46.6	82.5	135.0
<b>Total RES</b>	170.8	631.1	615.9	902.3	1345.5
<b>Total RES (multiple counting)</b>	173.1	649.9	645.0	951.7	1496.4
<b>RES share in transport [%]</b>	1.3	5.0	5.0	7.2	11.4



**Figure 14: Expected trend in the use of renewable energy in transport in the EU**

According to the NREAPs projections (Szabo et al 2011, Banja et al 2013), biofuels contribution will reach around 1,210 PJ by 2020, growing from 125 PJ (1%) in 2005 and 586 PJ (4.8%) in 2010. In 2010, the renewable energy use in transport in the EU increased to 615.9 PJ, 2.4% below the NREAPs projected use of 631.1 PJ, considering multiple counting for electricity and biofuels used in transport. The share of renewable energy transport in the EU arrived at 5.0% in 2005 to about 11.4% by 2020, above the 10% binding target, which is about the expected share to be achieved (EC, 2011d).

The total contribution of renewable energy in transport, without multiple counting will be 1,346 PJ (32.1 Mtoe) and 1,496 PJ (35.7 Mtoe) with multiple counting of electricity use in road transport and biofuels from wastes, residues, non-food cellulosic material and lignocellulosic material (biofuels defined in the article 21.2 of the Directive 2009/28/EC).

The renewable electricity in transport is expected to increase from 45.5 PJ (1.1 Mtoe) in 2005 to 135 PJ (3.2 Mtoe) in 2020. Of this, the renewable electricity in road transport should have a significant increase, increasing from 0.5 PJ (12 ktoe) in 2005 to 29.3 PJ (701 ktoe) in 2020.

The leading MS in the use of renewable energy in transport in 2010 was Germany with 134 PJ (3.2 Mtoe), followed by France with 110 PJ (2.6 Mtoe), Italy with 69 PJ (1.7 Mtoe), Spain with 61.4 PJ (1.5 Mtoe) and UK with 50.4 PJ (1.2 Mtoe). In 2020 Germany remain the leading MS with 257.1 PJ (6.1 Mtoe) together with UK with 187.2 PJ (4.5 Mtoe), France with 134.6 PJ (4 Mtoe), Spain with 170.1 PJ (3.2 Mtoe) and Italy with 121.4 PJ (2.9 Mtoe) (Figure 15). According to the NREAPs, the country showing the highest renewable share in transport for 2020 will be Finland with 20% followed by Sweden with 13.8% and Germany with 13.2%.

### 2.5.1. Biofuels

The analysis of the NREAPs shows that biofuel use in transport is expected to reach about 1210 PJ (28.9 Mtoe) in 2020 in the EU. In comparison, according to the NREAPs, biofuel consumption was 130.0 PJ (3.1 Mtoe) in 2005 (Szabo et al 2011, Manja et al 2013). Biofuel use in transport increased to 566.8 PJ (13537 ktoe) in 2010, which is 10.0 PJ (240 ktoe) or 1.7% below the expected contribution of biofuels use in transport of 576.8 PJ (13777 ktoe) in 2010 (EC, 2011d).

**Table 11: Estimated contribution of biofuels in the transport sector in the EU**

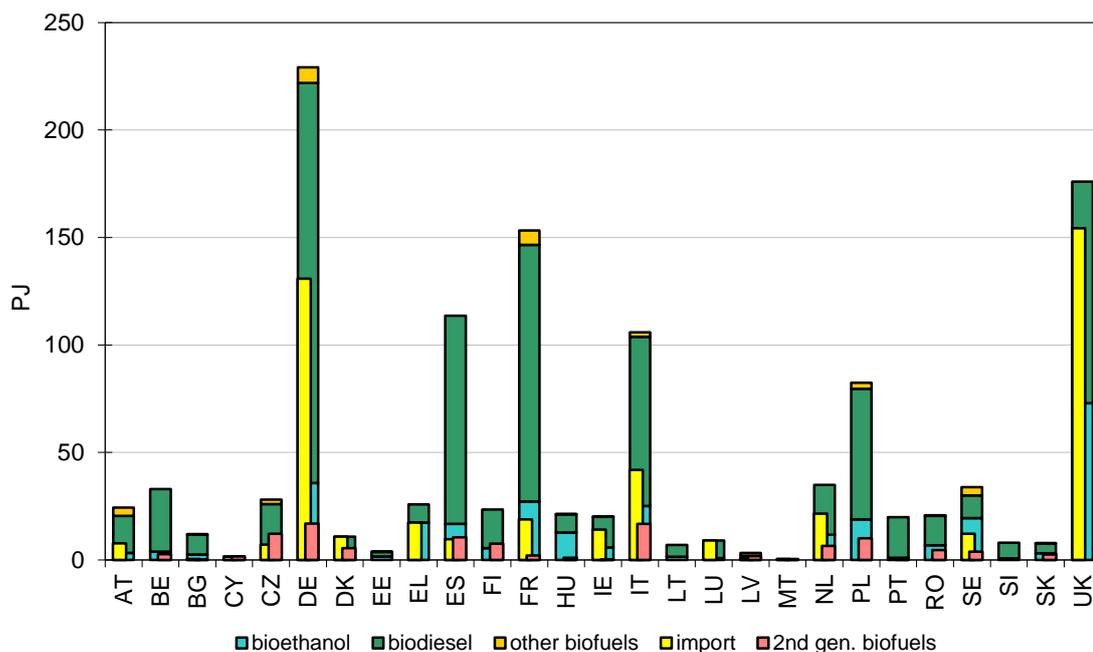
	2005	2010	2010*	2015	2020
	[PJ]	[PJ]	[PJ]	[PJ]	[PJ]
<b>Bioethanol/bio-ETBE</b>	22.5	119.9	118.9	208.0	305.9
<b>of which biofuels art 21.2</b>	0.0	1.5	3.9	7.8	28.3
<b>of which imported</b>	4.9	32.8	35.0	85.7	134.7
<b>Biodiesel</b>	94.5	448.0	440.4	600.5	873.4
<b>of which biofuels art 21.2</b>	0.9	14.1	22.4	27.0	61.9
<b>of which imported</b>	2.1	156.6	153.2	178.3	324.3
<b>Other biofuels</b>	8.3	8.8	7.8	11.2	31.1
<b>of which biofuels art 21.2</b>	0.6	1.9	2.3	5.2	17.2
<b>Total art 21.2</b>	1.4	17.6	28.6	40.0	107.3
<b>Total import</b>	7.0	189.3	188.2	264.0	459.0
<b>Total biofuels</b>	125.4	576.8	567.2	819.7	1210.4

Biofuel use in the transport sector is highly focused on first-generation biofuels that make up about 91.1% of all biofuels projected to be used by Member States. The greatest contribution in 2020 is expected to come from biodiesel with 873 PJ (20.9 Mtoe), followed by bioethanol/bio-ETBE with 306 PJ (7.3 Mtoe) and other biofuels (such as biogas/biomethane, vegetable oils, etc.) with 31 PJ (0.7 Mtoe). In 2020, first generation biofuels are still expected to provide the highest contribution to the total RES use in transport compared with a share of 25.3% bioethanol, 72.2% biodiesel and 2.6% other biofuels. In comparison, in 2005, first generation biofuels had a share of 18.0% bioethanol, 75.4% biodiesel and 6.6% other biofuels. With respect to the renewable energy use planned in transport in the EU in 2020 (single counting), the highest share should come from bioenergy (reaching 90.0% biofuels in 2020 will provide an energy amount representing 11.9% of the total renewable energy generation). Contribution of biofuels to the overall gross final energy consumption will change from 0.2% in 2005, 1.1% in 2010 to 2.4% in 2020.

**Table 12: Estimated share of RES and biofuels in the transport sector in the EU**

	2005	2010	2010*	2015	2020
	[%]	[%]	[%]	[%]	[%]
<b>Share of biofuels (single counting)</b>	1.0	4.4	4.4	6.2	9.2
<b>Share of art 21.2 in biofuels</b>	1.2	3.0	5.0	4.9	8.9
<b>Share of import biofuels</b>	5.6	32.8	33.2	32.2	37.9
<b>Share of biofuels (double counting)</b>	1.0	4.5	4.6	6.5	10.1
<b>Share of RES in transport</b>	1.3	5.0	5.0	7.2	11.4

Contribution of biofuels to the gross final energy consumption in transport has increased from 1.0% in 2010 to 4.7% in 2010, which is above the NREAPs expected contribution of biofuels of 4.5%. The contribution to the biofuels that will be consumed in 2020 in the transport sector only is projected to be 10.1%, biofuels contribution alone (without including renewable electricity) overcoming the 10% target imposed by the RES Directive.



**Figure 15: Biofuels used in transport in the EU in 2020**

The leading countries in the field of biofuel use in transport will be Germany with 229.1 PJ (5.4 Mtoe), UK with 176.1 PJ (4.2 Mtoe), France with 153.2 PJ (3.7 Mtoe), Spain with 146.7 PJ (3.5 Mtoe), Italy with 105.9 PJ (2.5 Mtoe) and Poland with 82.4 PJ (2.0 Mtoe). These MS will account for 73.7 % of the total biofuel use in transport in the EU.

The main biodiesel users will be Germany with 229.1 PJ (4.4 Mtoe), Spain with 129.8 PJ (3.1 Mtoe), France with 119.3 PJ (2.9 Mtoe), UK with 103.1 PJ (4.5 Mtoe), Italy with 78.7 PJ (1.9 ktoe) and Poland with 60.8 PJ (1.5 Mtoe). The main bio-ethanol users should be UK with 73.0 PJ (1743 ktoe), Germany with 35.9 PJ (0.9 Mtoe), France with 27.2 PJ (0.7 Mtoe), Italy with 25.1 PJ (0.6 Mtoe), Sweden with 19.5 PJ (0.5 Mtoe) and Poland with 18.9 PJ (0.5 Mtoe).

### 2.5.2. Biofuels from wastes, residues, ligno-cellulosic material

Biofuels produced from waste, residues, ligno-cellulosic material (biofuels defined in Article 21.2 of the Renewable Energy Directive) are expected to be available at commercial scale by 2020 and have a small contribution to the biofuels used in transport.

The use of biofuels Art 21.2 is expected to reach 107.3 PJ (2,564 ktoe) and a share of 8.9% of the biofuel use in the EU in 2020 in comparison with 1.4 PJ (35 ktoe) and a share of 1.2% in 2005 (Szabo et al 2011, Banja et al 2013). Until now, the use of Art. 21.2 biofuels was related to the biofuels produced from wastes and residues. Their use increased to 28.6 PJ (684 ktoe) in 2010, 11.1 PJ (265 ktoe) or 63.1% above the expected contribution of 17.6 PJ (419 ktoe) for 2010 (EC, 2011d). The contribution of Art 21.2 biofuels in the biofuels used in transport (single counting) increased from 1.2% in 2005 to 5.0% in 2010 and this is expected to increase to 8.9% in 2020. Their share to the gross final energy consumption in transport increased from 0.02% in 2005 to 0.5% in 2010 and this is projected to reach 1.6% in 2020.

The main contributor to biofuels from wastes, residues, non-food cellulosic material, and lignocellulosic material in 2020 should be biodiesel with a contribution of 57.7%, decreasing from 60.9% in 2005, followed by bioethanol with 26.4% and the other biofuels Art 21.1 that count for the remaining 16%, in comparison with 39.1% in 2005. Article 21(2) biofuels are expected to include in 2020: 61.9 PJ (1.5 Mtoe) as biodiesel produced from wastes, residues, non-food cellulosic material, and lignocellulosic material, with a share of 7.1% of biodiesel;

28.3 PJ (0.7 Mtoe) art 21.2 bioethanol, representing 9.2% of bioethanol use in 2020; and 17.2 PJ (0.4 Mtoe) other biofuels Art. 21(2), with a share of 55.3% of other biofuels.

Several countries, however, do not expect to have any contribution from biofuels from waste, residues, non-food cellulosic material and lignocellulosic material (Austria, Estonia, Greece, Lithuania, Luxembourg, Slovenia and UK) while others should have a negligible consumption (Germany, France, Ireland, Portugal). Denmark and Malta expect to have the entire consumption of biofuels coming from article 21.2 biofuels.

Although the contribution of biofuels from wastes, residues, non-food cellulosic material, and lignocellulosic material shall be considered to be twice that made by other biofuels, the availability of such biofuels will depend on the advancements in the technology and cost reduction. Therefore, in the next future, the majority of article 21.2 biofuels could be produced from wastes and residues.

### **2.5.3. Biofuels from import**

The NREAP data show that a significant amount of biofuels are expected to be imported in 2020 in order to reach the 10% binding target for renewable energy use in transport.

The amount of biofuels that are expected to be imported in 2020 will be 459 PJ (11.1 Mtoe) corresponding to 37.9% of the total biofuels that will be used that year and 3.5% of the energy that will be consumed in the transport sector. In comparison, the amount of biofuels imported in 2005 was 7 PJ (168 ktoe) corresponding to 5.6% of the total biofuels that were used that year and 0.1% of the energy that was consumed in the transport sector (Szabo et al 2011, Banja et al 2013). In 2010, the use of biofuels from import in transport reached 188.2 PJ (4414 ktoe) in 2010, which is only 1.1 PJ (108 ktoe) or 0.6% below the expected contribution of 189.3 PJ (4522 ktoe) in 2010 (EC, 2011d).

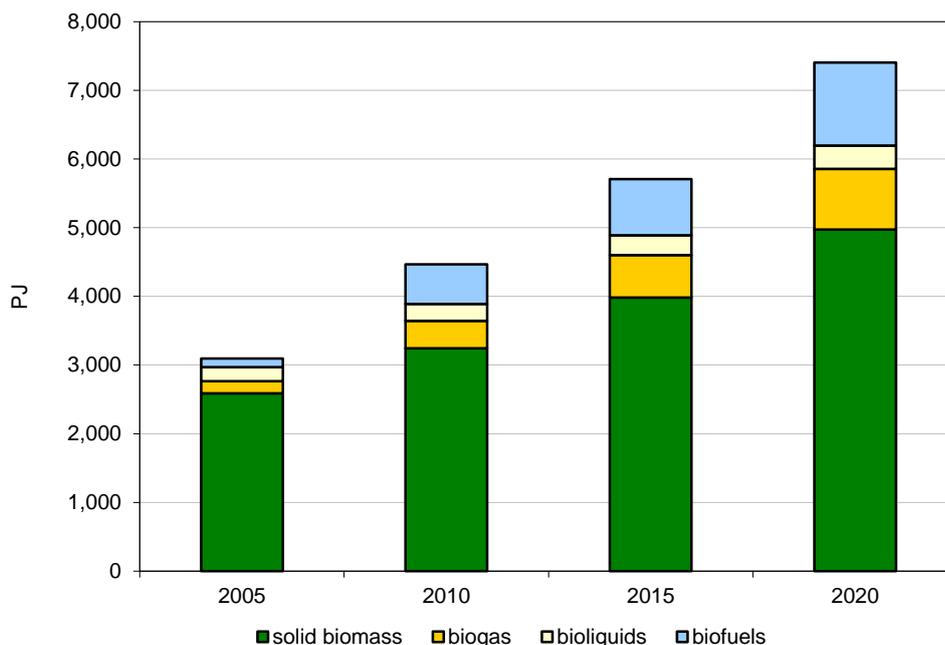
The contribution of imported biofuels to the gross final energy consumption in transport increased from 0.1% in 2005 to 1.5% in 2010, above the expected share of 1.4% in 2010. The contribution of biofuels from import to the energy that should be consumed in 2020 in the transport sector only is expected to be 3.5%. Biodiesel will remain the main contributor with a share decreasing to 92.0% in the total value of biofuels imports in 2020, while bioethanol imports will increase to reach a share of 29%. However, it is not clear how much biofuel should be domestically produced in the EU, how much should come from internal EU trade and how much should be imported as biofuels from third countries to the EU. Apart from this, some raw material is expected to be imported and afterwards processed within the EU.

The share of biofuels import at the level of MS is expected to vary from 0% in several countries (Belgium, Estonia, Finland, Hungary, Lithuania, Poland, Portugal, Romania, Slovenia and Slovakia) to 100% import in other countries (Denmark and Luxembourg). A number of countries should import more than 50% of their expected consumption of biofuels (Germany, Ireland, Malta, The Netherlands and the UK).

## **2.6. Biomass demand, supply and potential**

### **2.6.1. Biomass demand**

Biomass availability, competition between alternative use of biomass, as well as the environmental implications related to biofuels are major concerns for bioenergy deployment. There is a limited availability of biomass that can be used for energy. Furthermore, biomass can be used not only for electricity production, but also for heat and as transport fuels. It is therefore important to analyse the demand for biomass in relation to the existing potential.



**Figure 16: Expected trend in biomass demand in the EU**

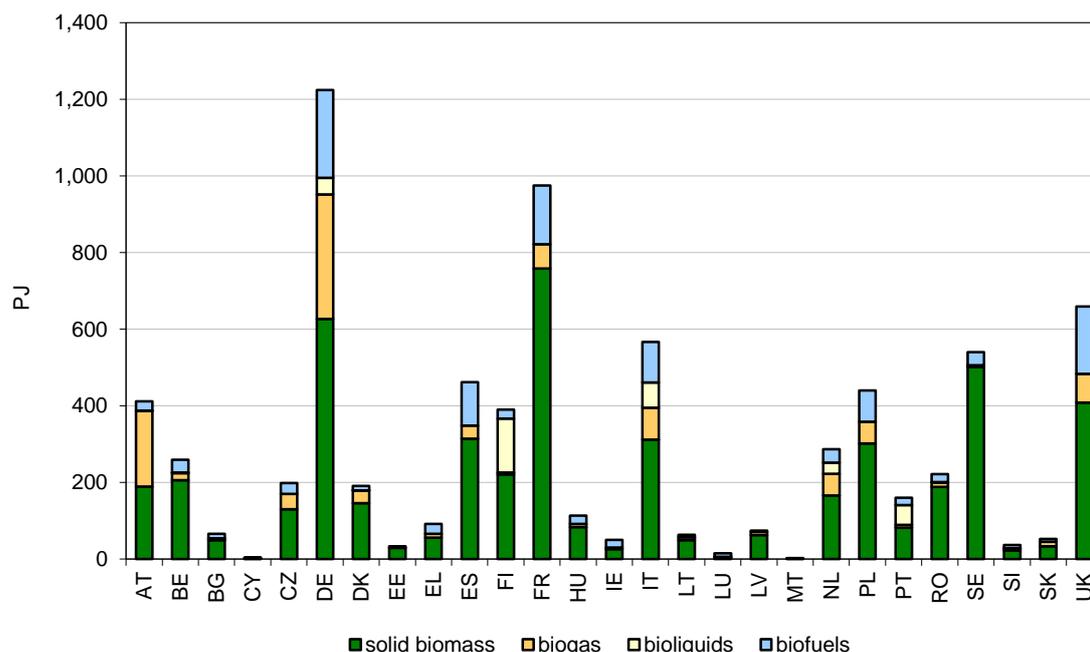
The biomass required for reaching the proposed 2020 targets for electricity, heating and transport was quantified for the whole EU and each Member State depending of the NREAPS projections on the electricity in CHP and electricity only plants, heating and cooling, biomass used in households and biofuels used in transport. The quantification of the biomass demand was done for the different categories: solid biomass, biogas, bioliquids and biofuels (Scarlat et al, 2013). In the estimation of biomass demand, the main sources of biomass were considered in accordance with the Member States projections for the availability of domestic biomass supply, as provided in the NREAPs.

Different conversion technologies exist today (JRC, 2011). Detailed information on the type of technologies likely to be deployed until 2020 as well as the plant capacities is not available, since their deployment depends on the market, the local biomass resources and local energy demand. Taking into account the variety of feedstock available, technologies and the range of plant capacities that can be used for bioenergy production, in the estimation of primary biomass demand we considered average conversion efficiency for solid biomass, biogas and bioliquids. In the calculations, we considered as final heat consumption the energy content of biomass before conversion when used in households, services and industry and the energy content of heat after conversion in DH and power plants.

The results show that in the EU, total biomass primary demand is expected to increase from 3,094 PJ in 2005 to 7,407 PJ in 2020. The major part is expected be delivered by solid biomass, with 4,959 PJ, followed by biofuels with 1,244 PJ, biogas with 883 PJ and bioliquids with 338 PJ (Scarlat et al, 2013). Table 13 shows the total biomass primary demand in the EU to meet the targets for electricity, heating and cooling and in transport in the EU estimated for solid biomass, biogas, bioliquids and biofuels. Figure 16 shows the biomass primary energy demand in all MS, differentiated between solid biomass, biogas, bioliquids and biofuels.

**Table 13: Total estimated biomass primary demand in the EU.**

	2005	2010	2015	2020
	[%]	[%]	[%]	[%]
<b>solid biomass</b>	2,590	3,244	3,986	4,976
<b>Biogas</b>	176	402	616	883
<b>Bioliquids</b>	202	246	289	338
<b>Biofuels</b>	125	577	820	1,210
<b>Total</b>	3,094	4,469	5,710	7,407



**Figure 17: Expected biomass demand in 2020**

### 2.6.2. Expected domestic biomass supply

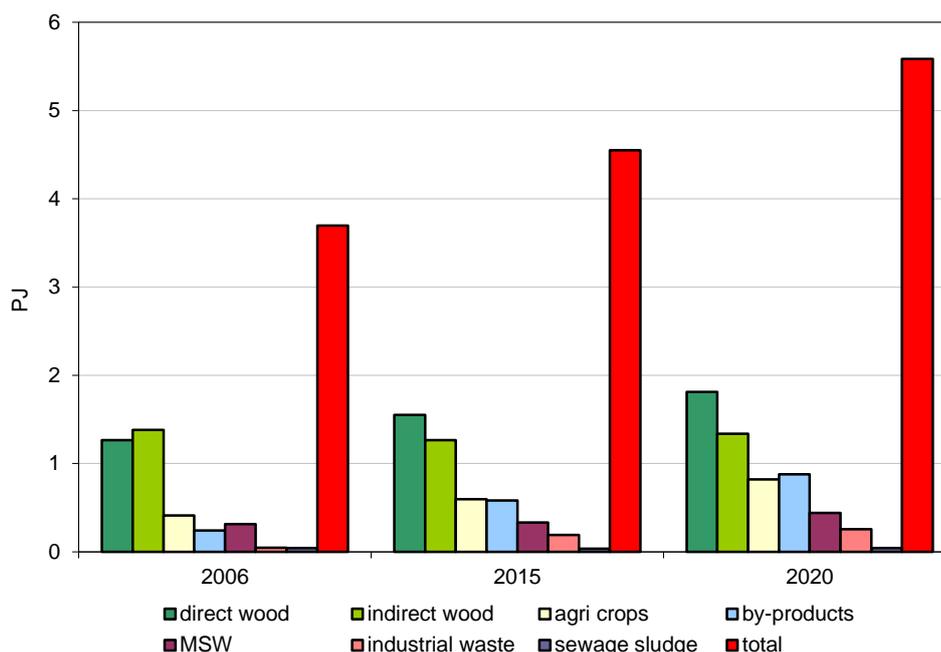
Biomass demand can be met from domestic supply or from import. The template for National Renewable Energy Action Plans under Directive 2009/28/EC, as defined by Commission Decision C(2009) 5174-1, required Member States to assess the supply of domestically available biomass as gross consumption and the need for imports in all relevant sectors (forestry, agriculture and fisheries and waste). The amount of raw biomass feedstock for biogas and biofuels had to be detailed as well (EC, 2009c).

According to the Member States data provided in their NREAPs, the domestic biomass supply in the EU is expected to increase to meet the demand for heat, electricity and transport biofuels from around 3,542 PJ in 2006 to around 5,454 PJ in 2020. The aggregated values from the NREAPs show that domestic biomass supply should come from forestry with 3,124 PJ, from agriculture and fisheries with 1,628 PJ and from waste 703 PJ (Szabo et al 2011, Banja et al 2013).

While the forest based biomass is expected to maintain its major role to biomass supply until 2020 (more than 57% of biomass supply), the biggest increase in supply should come from agriculture (with more than 150% increase compared with 2006).

Depending on the total primary biomass demand and the domestic available supply, a share of biomass might be imported. The difference between biomass domestic supply and biomass

demand could come as imports of biofuels and bioliquids as well as solid biomass (wood residues, wood pellets, etc.).



**Figure 18: Expected domestic biomass supply in the EU in 2020**

### 2.6.3. Future biomass demand and potential

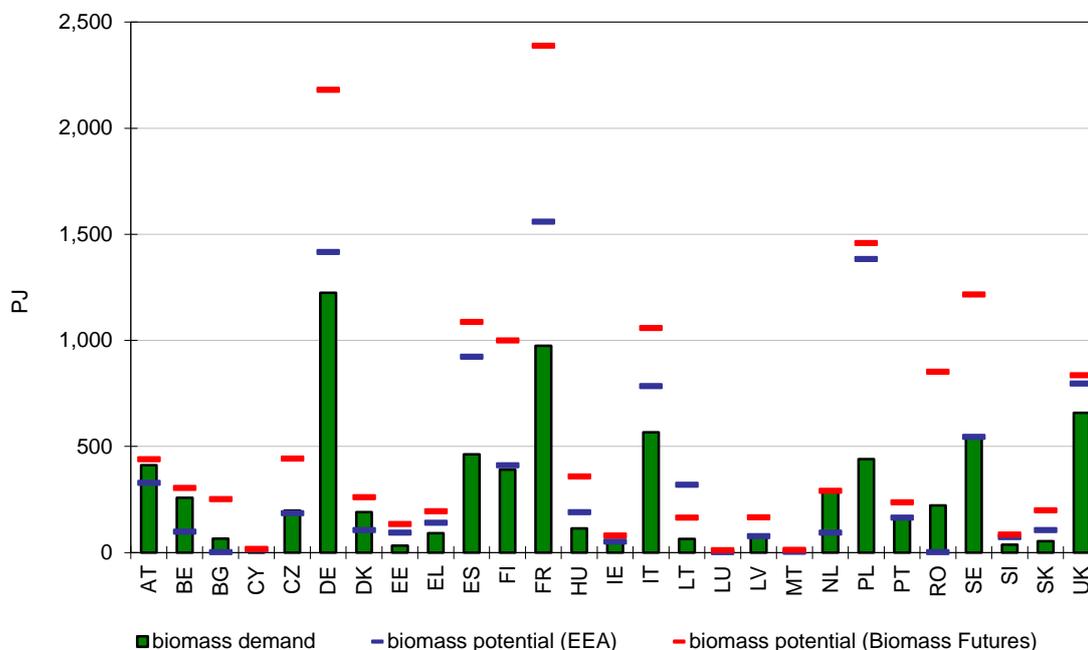
The biomass demand expected for 2020 was determined for all Member States then compared with the domestic biomass resources expected to be available and the biomass potential. This was used to identify the potential gaps in domestic supply that can be covered by import or additional measures for increasing biomass mobilisation, depending on existing potential.

Several studies provide estimates of the biomass potential in the EU covering forest, agriculture and waste to a different extent. The environmentally compatible biomass potential for the European Union (covering 25 Member States) was estimated at 9,839 PJ: 1,641 PJ from forestry, 4,007 PJ from agriculture and 4,181 Mtoe from waste (EEA, 2006). Another study, performed by the Biomass Futures project, shows that the biomass sustainable potential might be even larger in the EU27 in 2020, reaching 15,686 PJ, of which 7,006 PJ from forestry, 6,604 PJ from agriculture and 2,076 PJ from waste (Elbersen et al, 2012).

Thus, according to both studies, the biomass potential of the European Union is large enough to ensure the biomass demand of 7,424 PJ needed to reach the bioenergy targets at the EU level. The Figure 19 presents the expected primary biomass demand in the EU for all Member States, in comparison with the biomass potential established by the European Environment Agency and Biomass Futures project. This reveals the extent of the projected utilisation of domestic biomass in different MS in 2020 and that degree in which some MS could increase their contribution to the energy production from biomass, according to their biomass potential. The expected biomass demand and the available potential both show that further development of bioenergy in the European Union is possible, especially in some Member States. However, some biomass is expected to be imported, even if biomass potential is higher than the expected demand in 2020, due to economic considerations or adequate biomass mobilisation.

The biomass demand is higher than the environmentally compatible biomass potential (EEA) in several MS, such as Belgium, Denmark and the Netherlands, thus meaning they should rely on high extent on imports from other Member States or, most likely, from outside EU (Russia, Canada, etc.). In some other MS the expected biomass demand in 2020 is quite close to the

potential (Czech Republic, Ireland, Latvia, Portugal) and thus, limited increase of domestic biomass utilisation is expected. However, in some Member States the expected biomass consumption is below the biomass potential (France, Spain, Italy, Lithuania, Romania, Austria) and thus an increase of biomass use is possible. There are also Member States where the projected use of biomass in 2020 is well below the biomass potential: (e.g. Poland, Slovenia, Slovakia, Estonia, Lithuania) where significant development in bioenergy is possible.



**Figure 19: Primary biomass demand in 2020 and biomass potential**

However, the biomass sustainable potential, provided by the Biomass Futures project, is significantly higher and all MS can rely on domestic biomass to reach their bioenergy and biofuels targets for 2020. Biomass mobilisation is a key issue, especially where the biomass potential is close to sustainable potential.

### 3. Conclusion

Biomass is expected to contribute to about half of the EU Renewable Energy target in 2020. Biomass use in heating and cooling is expected to increase by about 47% and biomass use for electricity generation is projected to more than double between 2010 and 2020. Despite high growth rates in the Photovoltaic and wind sectors, bioenergy at EU level is expected to remain the main RES contributor. Within this framework, it is necessary to ensure that these expected increases in biomass use take place within a sustainable framework and biomass sustainability is thus a key issue. Even with a reduction of earlier EU objectives in the field of biofuels for transport, there are very ambitious targets for bio-heat and bio-electricity in the EU Member States Renewable Energy Action Plans presently implemented. In the EU, carbon accounting is being debated and related decisions will also affect future bioenergy development.

The biomass demand in the EU will be covered in the next few years by a combination of the use of domestic resources and imported feedstock (or products), for example from Latin America (e.g. Argentina and Brazil), North America (Canada and the USA, in the case of pellets), South East Asia (Indonesia and Malaysia for biofuels or bio-liquids).

An important issue to monitor is the competition of uses between traditional uses of biomass (e.g. food, feed and fiber), bioenergy, traditional forest industries (e.g. panel, pulp and paper)

and growing sectors such as biomaterials and green chemistry. This might open perspectives for an integrated use of biomass through a cascading approach or by setting up biorefineries. The future of bioenergy in the EU will also be affected by possible technological developments or improvements, for example in the field of torrefaction, second generation biofuels, use of algae for bioenergy or use of advanced biofuels for aviation.

## References

- **Banja M., Monforti-Ferrario F., Scarlat N.**, 2013, Review of Technical Assessment of National Renewable Energy Action Plans, EUR 25757 EN 2013.
- **Berndes G, Bird ND, Cowie A.**, 2010, Bioenergy, land use change and climate change mitigation. IEA Bioenergy 2010.
- **European Environment Agency (EEA)** 2006, How much bioenergy can Europe produce without harming the environment? Report No 7/2006 ISBN 92-9167-849-X2006.
- **European Commission (EC)**, 1997, Energy for the future: Renewable sources of energy. White Paper for a Community strategy and action plan, COM(97) 599 final.
- **European Commission (EC)**, 2001, Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity from renewable energy sources in the internal electricity market.
- **European Commission (EC)**, 2003 Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.
- **European Commission (EC)**, 2007a, An energy policy for Europe, Communication from the Commission to the the Council and the European Parliament, COM(2007) 1 final.
- **European Commission (EC)**, 2007b, Limiting Global Climate Change to 2 degrees Celsius. The way ahead for 2020 and beyond, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2007) 2 final.
- **European Commission (EC)**, 2007c, A European Strategic Energy Technology Plan (SET-PLAN), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2007) 723 final.
- **European Commission (EC)**, 2009a, Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
- **European Commission (EC)**, 2009b, Directive 2009/30/EC of the European Parliament and of the Council amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce GHG emissions and amending Directive 1999/32 as regard the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC.
- **European Commission (EC)**, 2009c, Commission Decision of 30 June 2009 establishing a template for National Renewable Energy Action Plans under Directive 2009/28/EC (2009/548/EC).
- **European Commission (EC)**, 2009d, Investing in the Development of Low Carbon Technologies (SET-Plan), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2009) 519 final.
- **European Commission (EC)**, 2010a, Europe 2020 A strategy for smart, sustainable and inclusive growth, Communication from the Commission COM(2010) 2020.

- **European Commission (EC)**, 2010b, Energy 2020 A strategy for competitive, sustainable and secure energy, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2010) 639 final.
- **European Commission (EC)**, 2010c, Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling. European Commission COM(2010)11 final.
- **European Commission (EC)**, 2010d, Report from the Commission on indirect land-use change related to biofuels and bioliquids, COM(2010) 811 final.
- **European Commission (EC)**, 2011a, A resource-efficient Europe–Flagship initiative under the Europe 2020 Strategy, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 21.
- **European Commission (EC)**, 2011b, A Roadmap for moving to a competitive low carbon economy in 2050, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 112 final.
- **European Commission (EC)**, 2011c, Energy Roadmap 2050, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2011) 885 final.
- **European Commission (EC)**, 2011d,  
[http://ec.europa.eu/energy/renewables/reports/2011\\_en.htm](http://ec.europa.eu/energy/renewables/reports/2011_en.htm), accessed May 2013.
- **European Commission (EC)**, 2012a, Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and Directive 2009/28/EC on the promotion of the use of energy from renewable sources, COM(2012)595.
- **European Commission (EC)**, 2012b, Renewable Energy: a major player in the European energy market, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2012) 271 final
- **European Commission (EC)**, 2012c, Impact Assessment on ILUC related to biofuels and bioliquids. Accompanying the Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70 relating to the quality of petrol and diesel fuels and amending Directive 2009/28 on the promotion of the use of energy from renewable sources, SWD (2012) 343.
- **European Commission (EC)**, 2013b, DG Energy,  
[http://ec.europa.eu/energy/renewables/action\\_plan\\_en.htm](http://ec.europa.eu/energy/renewables/action_plan_en.htm), accessed May 2013.
- **European Commission (EC)**, 2013, Renewable energy progress report, Commission staff working document accompanying the document Report from the Commission to the European Parliament and the Council, SWD (2013) 102 final.
- **Edwards R., Mulligan D., Marelli L.**, 2010, Indirect land use change from increased biofuels demand: comparison of models and results for marginal biofuels production from different feedstocks, EUR 24485 EN, 2010.
- **EIBI** 2013, <http://www.biofuelstp.eu/eibi.html> .
- **Elbersen B., Startisky I., Hengeveld G., Schelhaas M.J., Naeff H, BottcherH.**, Atlas of EU biomass potentials. Spatially detailed and quantified overview of EU biomass potential taking into account main criteria determining biomass availability from different sources,2012.
- **EurObserv'ER** (2011), The state of renewable energies in Europe, 11<sup>th</sup> EurObserv'ER report, 2011.
- **Eurostat**, 2013, <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

- **Fritsche U.R., Iriarte L., de Jong J., van Thuijl E., Lammers E., Agostini A., Scarlat N.** 2012, Sustainability Criteria and Indicators for Solid Bioenergy from Forests, Outcome paper of the Series of Workshops on Extending the RED Sustainability Requirements to Solid Bioenergy [http://www.iinas.org/tl\\_files/iinas/downloads/Joint\\_WS\\_Outcome\\_Paper\\_2012.pdf](http://www.iinas.org/tl_files/iinas/downloads/Joint_WS_Outcome_Paper_2012.pdf)
- **Joint Research Centre (JRC)**, European Commission, 2011, Technology Map of the European Strategic Energy Technology Plan (SET-Plan). Technology Descriptions, EUR 24979 EN – 2011.
- **Marelli L., Declan M., Edwards R.**, 2010, Critical issues in estimating ILUC emissions, Joint research centre of the European Commission, Ispra, Italy, EUR 24816 EN.
- **Scarlat N., Dallemand J.F.**, 2011, Recent developments of biofuels/bioenergy sustainability certification: a global overview. Energy Policy 39 (2011) 1630–46.
- **Scarlat N., Dallemand J.F., Banja M.**, 2013, Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals, Renewable and Sustainable Energy Reviews 18 (2013) 595–606
- **Swedish Energy Agency (SEA)**, 2009, SET Plan Conference 2009, Final Report. 21-22 October 2009, Stockholm, Sweden.
- **Szabo M., Jaeger-Waldau A., Monforti-Ferrario F., Scarlat N., Bloem H., Quicheron M, Huld., T, Ossenbrink, H.**, Technical assessment of the renewable energy action plans, EUR 24926 EN, 2011.
- **Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, Pacala S, Reilly J, Searchinger T, Somerville C, Williams R.**, 2009, Beneficial biofuels-the food, energy, and environment trilemma. Science 2009; 325:270–1.
- **Witcover J, Yeh S, Sperling D.**, 2012, Policy options to address global land use change from biofuels. Energy Policy 2012.

## Abbreviations

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania

SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
***	
EEA	European Environment Agency
EC	European Commission
EIBI	European Industrial Bioenergy Initiative
EU	European Union
FQD	Fuel Quality Directive
GHG	GreenHouse Gas
LUC	Land Use Change
ILUC	Indirect Land Use Change
JRC	Joint Research Centre, European Commission
Ktoe	Kilo tonnes of oil equivalent
Mtoe	Million tonnes of oil equivalent
MS	Member States
NREAP	National Renewable Energy Action Plans
PJ	Peta Joule
RED	Renewable Energy Directive 2009/28/EC
SEA	Swedish Energy Agency
T	tonne



# Bioenergy and water: challenges and opportunities<sup>1</sup>

G. Berndes  
Chalmers University of Technology  
Sweden

## Abstract

This paper provides an introduction to the discussion of challenges and opportunities related to bioenergy and water. Specific sections discuss bioenergy and its implications for water resource availability and use, its implications for water quality, as well as bioenergy systems improving the state of water or the governance of bioenergy development.

There is considerable scope for improving water productivity in many regions of the world, reducing the amount of water needed for crop production, and leaving more water for other uses. By simultaneously introducing efficient water management techniques and by providing a wider range of land-use options to optimize the use of land and water, bioenergy development provides opportunities to improve water productivity and increase access to water. One strategy for adaptation to water scarcity can be to use biomass production for energy as a tool for increasing the spatial and temporal accessibility of water resources and at the same time improving the quality of freshwater flows. Basin level planning could include biomass production as a land-use option with the potential for combining, for example, erosion control and flood prevention with income generation from carbon sink generation and biomass sales for energy.

Intelligently designed bioenergy systems can significantly offset greenhouse gas emissions associated with fossil fuel-based energy systems and at the same time lead to additional environmental benefits. Policy should be devised to promote the optimal use of land, water and biomass resources to meet needs for food, materials and energy. Design of policy for bioenergy need to balance multiple objectives and should be based on a holistic perspective recognizing the multiple drivers and effects of land use and land use change.

## 1. Introduction

The promotion of bioenergy offers considerable opportunities for the agriculture and forestry sectors, which can find new markets for their products and also make economic use of biomass flows earlier considered to be waste. But there has also been an increase in the number of reports expressing concern about possible negative environmental and socioeconomic impacts associated with bioenergy and the view that bioenergy represents an attractive alternative to conventional (primarily fossil) energy options has been challenged – particularly in the case of biofuels for transport (Chum et al., 2011). Agriculture accounts for about 70% of freshwater withdrawals from rivers, lakes and aquifers – up to more than 90% in some developing countries - and a growing population and changing dietary trends mean a rising demand for food and feed crop cultivation implying further growth in agriculture water use (Unesco, 2009). At the same time, freshwater is already scarce in some regions of the world and under the impact of climate change the population at risk of water stress could increase substantially; estimates of incremental water requirement to meet future demand for agricultural production under climate change indicate that 40–100 percent more water might be needed compared to a situation without global warming (Turrall et al., 2011). Water

<sup>1</sup> This part is partly based on Task 43 feature article included in the 2012 Annual Report of IEA Bioenergy (IEA Bioenergy, ExCo:2013:01)

scarcity can limit both intensification possibilities and the prospects for expansion of agriculture. Investments in increased irrigation can enhance water use competition in water scarce areas, but also rainfed cultivation can impact other production by reducing groundwater recharge and streamflows. Human land use and other activities also impact the quality of water in lakes, rivers, and aquifers, with consequences for aquatic ecosystem health and also for human water uses. Demand for bioenergy further adds to the growing pressure on water resources and signs of growing water scarcity in important agricultural areas in the world – including parts of China and India, western USA, Australia, and the Mediterranean – imply that water scarcity may become one of the major obstacles for bioenergy expansion (Berndes, 2002; Gerbens-Leenes et al., 2009; Service, 2009). However, there are many places where an expanding bioenergy industry is unlikely to be constrained by lack of water, and it has also been recognized that bioenergy demand might open up new opportunities to adapt to water related challenges and to improve the productivity of water use (Berndes, 2008).

## **2. Bioenergy and implications for water resource availability and use**

Different types of bioenergy systems will have different consequences for water and the net effects of establishing a bioenergy project depends on the local context including the previous land use. The use of organic post-consumer waste and residues and by-products from the agricultural and forest industries can mitigate land and water pressures: the water that is used to produce the food and conventional forest products is the same water as that which will also produce the organic waste, residues and by-products potentially available for bioenergy. However, residue extraction needs to consider tradeoffs with soil C management and extraction rates need to reflect what can be sustainably removed without severely impacting soils qualities such as texture and structure, which greatly influence water infiltration, permeability, and water-holding capacity (Blanco-Canqui and Lal, 2009; Ceschia et al., 2010).

Organic post-consumer waste and residues and by-products from the agricultural and forest industries presently contribute a major part of biomass for energy today. These biomass sources can give an important contribution also on the longer term, but they will not suffice to meet the anticipated levels of longer term biomass demand. To illustrate, a recent review by the Intergovernmental Panel on Climate Change (Edenhofer et al., 2011) of 164 long-term energy scenarios showed bioenergy deployment levels in year 2050 ranging from 80 to 150 EJ per year for 440–600 ppm CO<sub>2</sub><sup>eq</sup> concentration targets and from 118 to 190 EJ per year for less than 440 ppm CO<sub>2</sub><sup>eq</sup> concentration targets (25th and 75th percentiles). In comparison, the energy content of the present global industrial roundwood production is on the order 20 EJ per year and the energy content in the global harvest of major crops (cereals, oil crops, sugar crops, roots, tubers, and pulses) corresponds to roughly 60 EJ per year. Given that similar magnitudes of organic waste, residues and by-products are generated - and far from all will be available for bioenergy - it is clear that a substantial share of bioenergy feedstock supply would have to come from dedicated production if bioenergy demand grows to these levels in the future.

Beyond the energetic use of forest industry by-flows and residues from silvicultural treatments and final felling, changes in forest management and harvesting regimes may make more biomass available for the energy sector. In forests that are managed with long rotations these changes will not bring with them dramatic changes in water resource use (but might influence water quality - see further below). Water resource flows are to a larger degree influenced when expanding dedicated biomass production for energy is associated with land use change, in this context the change from a previous state (e.g., forest, grassland, agriculture land used for food and fiber production) into a new land use providing bioenergy feedstock, e.g., the

cultivation of annual and perennial plants similar to those used in agriculture today, tree plantations of the type used for pulp and paper production, or the cultivation of specific bioenergy feedstock plants such as various lignocellulosic plants grown in relatively short rotations.

As an illustration of possible magnitude implications in relation to the present land use, Figure 1 illustrates the cropland harvest increase required if a future supply of 1<sup>st</sup> generation biofuels were to grow to a level corresponding to 20% of the motor fuel consumption in 2005. Countries close to the diagonal line would roughly have to double their crop harvest in order to support such a level of biofuels use, based on domestic feedstocks, while countries far above the line would require less relative increase in harvest. Note that Figure 1 merely indicates the required effort in the agricultural sector and should be complemented with information about resources and competing demand; whether a specific country would be able to achieve the indicated increase depends on the availability of not yet utilized land and water resources, considering also the expected increase in food demand in the coming decades. In addition, technology development might bring about biofuels for transport based on lignocellulosic sources (e.g., forest wood, agricultural harvest residues and lignocellulosic crops) and biomass may also be used for heat and power production, increasing demand further.

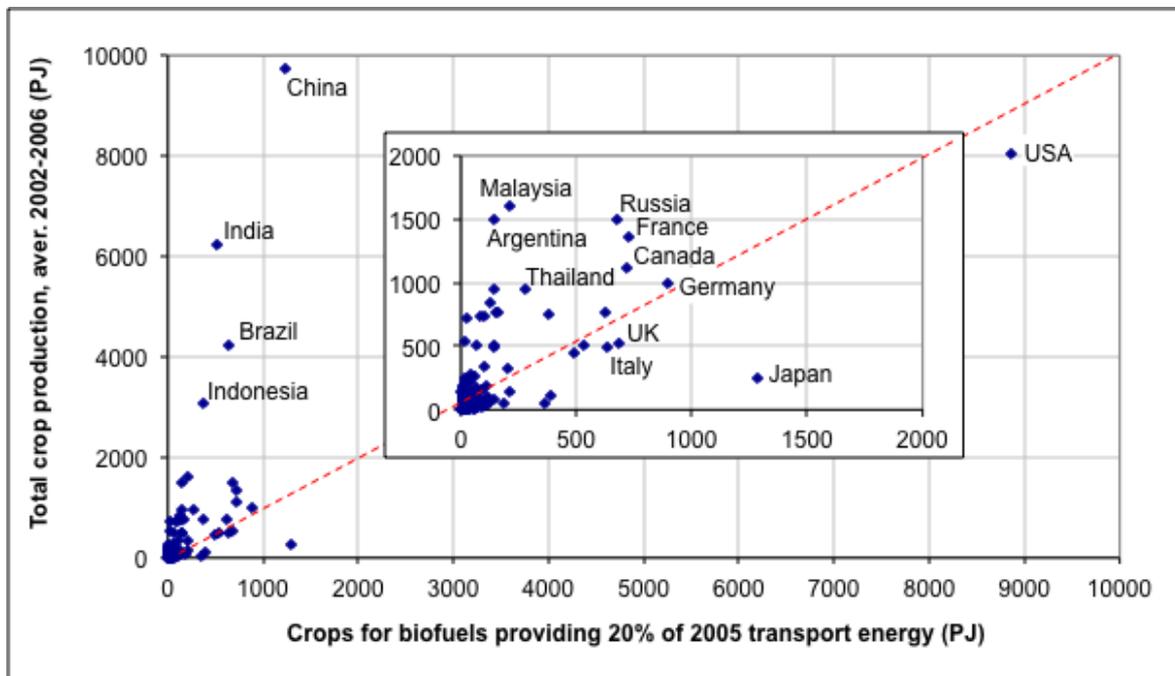
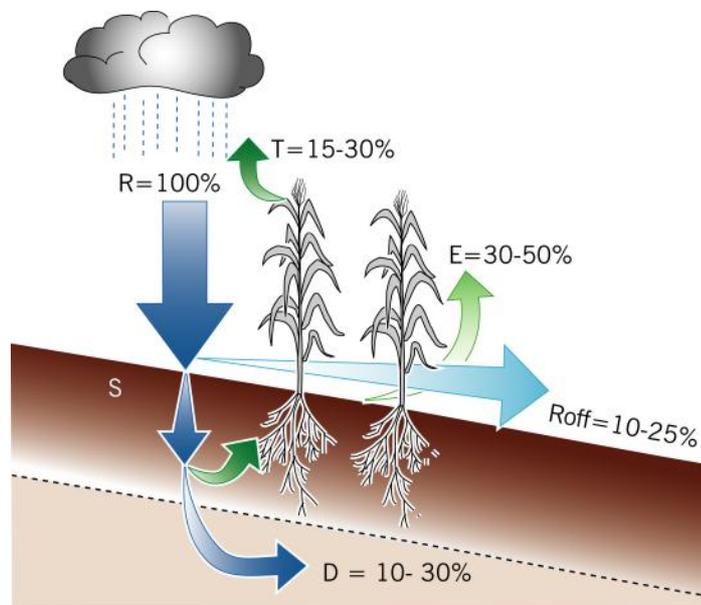


Figure 1. An illustration of the crop harvest required for 1<sup>st</sup> generation biofuels to make a substantial contribution in the world. The y-axis shows the average 2002-2006 domestic production of food and feed crops and the x-axis shows the amount of crops needed as feedstock for the production of 1<sup>st</sup> generation biofuels corresponding to 20 % of domestic transport fuel consumption in 2005. The red diagonal represents the situation where a country would have to double the domestic crop production in order to reach the 20 % biofuels share. It is assumed that the biomass is converted into biofuels at an average efficiency of 50 % (energy basis). The inset smaller diagram is an enlargement of the lower left part of the larger diagram. Source: (Berndes 2008).

Water scarcity can be partially alleviated through on-site water management and the productivity of agriculture can be improved in large parts of the world through improved soil and water conservation. Investment in agricultural research, development and deployment could produce a further increase in both the water productivity and land use efficiency. In this

context, bioenergy demand may offer new opportunities by opening for new types of crop production that utilizes the water flows more effectively.

As an illustration of possible options and associated consequences for water, Figure 2 shows water flows on the cropland level: if the non-productive evaporation (E) is reduced in favor of plant transpiration (T), total biomass production may increase without necessarily reducing the downstream availability of water. Capture and recirculation of runoff water to the fields can also increase the share of water going to plant transpiration and hence enhance yield levels where water limits crop growth. If, however, total evapotranspiration (ET, which is the sum of E and T) increases this can have consequences for both groundwater recharge and runoff. The ET can increase both as a consequence of measures to enhance the yields of presently cultivated crops, or as a consequence of land use change (LUC) such as when high-yielding biomass plantations are established on lands with sparse vegetation, e.g., degraded pastures. Such LUC may lead to substantial reductions in downstream water availability, which may become an unwelcome effect requiring management of a trade-off between upstream benefits and downstream costs. However, it should be noted that consequences of increased ET need not always be negative. Examples of positive consequences include when biomass plantations are used for salinity management or when plantation establishment on degraded lands reduces runoff intensity and the associated risks of flooding of cultivated areas (Garg et al., 2011).



**Figure 2. Overview of rainfall (R) partitioning. Runoff (Roff) and drainage (D) are lost from the field, but is potentially available for downstream use, although part of Roff is lost as evaporation as it flows through the landscape. Field evaporation (E) corresponds to a non-productive water loss, while transpiration (T) by the cultivated plants represents productive water use. The percentages shown correspond to conditions in the semi-arid tropics in Sub-Saharan Africa. Source (Rockstrom et al., 1999)**

The water use efficiency varies among crop types; the efficiency of a specific crop varies with climate, growing period and agronomic practice; and there are several options for modification of the water use efficiency. New crops and biomass production systems can also give access to previously little used water flows. Thus, bioenergy demand can be met in many ways that at the same time improves the situation concerning water resource availability and use:

- hardy and drought tolerant plants traits can be cultivated in areas where water scarcity prevents cultivation of conventional food and feed crops (Street et al., 2006 ; Oliver et al. 2009; Hamanishi and Campbell, 2011);
- salt-tolerant plants that can grow in conditions of high salinity are being studied as potential bioenergy crops with the ability to use saline water not suitable for most crops (Ruan et al., 2010; Sotiroudis et al., 2010; Abideen et al., 2011; Li and Qiu, 2012);
- the use of perennial plants and various agroforestry systems for food and bioenergy feedstock production can increase the productivity in rain-fed agriculture by capturing a larger proportion of the annual rainfall in areas where much of the rainfall occurs outside the normal growing season, although productivity of individual species may decrease due to competition for nutrients, water and light (Cesson, 2008, Cardinael et al., 2012, Jose and Bardhan, 2012; Susaeta et al., 2012).

To summarize, the biomass production for energy may grow to a scale similar to the present agriculture and forestry production. The use of organic post-consumer waste and residues and by-products from the agricultural and forest industries can mitigate land and water pressures, but may not suffice to meet the future biomass demand for energy. The requirement for dedicated bioenergy feedstock production may place a new large demand on water resources. However, bioenergy demand also presents new opportunities for using previously little used water resources and improving water use efficiency. One strategy for adaptation to water scarcity can be to use biomass production for energy as a tool for increasing the spatial and temporal accessibility of water resources.

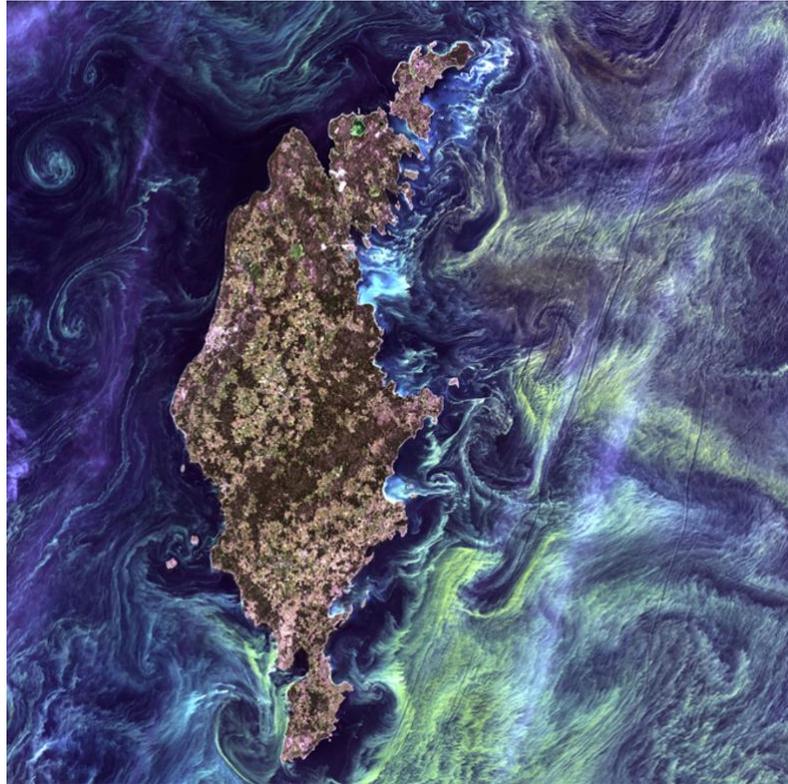
### **3. Bioenergy and implications for water quality**

Bioenergy projects can also affect the water quality. As with many other industrial activities, biomass conversion to energy products can require substantial volumes of water for the process. Most of this process water is returned to rivers and other water bodies and thus available for further use, albeit in changed (and sometimes degraded) states. These biomass conversion processes need to be monitored to minimise negative impacts that can occur due to pollution loading to the aquatic systems. This is not an issue affecting only the biomass-based industry but a general challenge for society, not the least in countries with less stringent environmental regulations or limited law enforcement capacity. However, the production of feedstocks for the conversion processes can also affect water quality in many ways.

In forests, water-quality impacts can occur at different phases during the forest rotation. Excluding large-scale disturbances such as fires, storm fellings and insect infestations, forest harvesting and the subsequent site preparation for forest regeneration (including road construction) are the largest disturbances in managed forests. But also the use of fertilizers, herbicides and other chemicals associated with intra-rotation silvicultural operations can have water quality impacts (Neary et al., 2012). Short term water quality effects are reported - most importantly increased sediment movement in streamflows but also increases of, e.g., nitrates, phosphates, and cations - but there is no evidence of long term adverse impacts in forest catchments subject to normal management operations (Neary and Koestner, 2012, Binkley and Brown, 1993; Stednick, 2000). Given use of existing best management practices that are designed for environmental protection and include nutrient management principles, forest bioenergy programs are judged compatible with maintaining forest productivity as well as high-quality water supplies in forested catchments (Neary and Koestner., 2012; Mead and Smith, 2012).

Due to the more intensive land use, water catchments where agriculture is the dominant land use generally produce lower quality water than forested catchments. Much of fertilizers, pesticides and other chemicals that are lost from croplands end up in waterways and

groundwater where they can have negative influence on water quality and aquatic ecosystem health as a result of eutrophication and other pollutant impacts (Diaz and Rosenberg, 2008; Simpson et al., 2009; Liu et al., 2012). Extraction of harvest residues as bioenergy feedstock can cause soil erosion resulting in increased sediment flows impacting aquatic ecosystems and also dams and other technical infrastructure.



**Figure 3. Algal blooms in the water around Gotland, a Swedish island in the Baltic Sea. Fertilizer run-off to the Baltic Sea from surrounding agriculture land contributes to a large nutrient load, primarily via river discharges. This run-off has changed it from an oligotrophic clear-water sea into an eutrophic marine environment experiencing summertime algal blooms. Photo credit: NASA's Goddard Space Flight Center/USGS.**

The cultivation of conventional agricultural crops such as cereals and oil seed crops for the production of so-called 1<sup>st</sup> generation biofuels for transport, will lead to the same water quality consequences as when such crops are produced for food and feed. But integration of other types of bioenergy plants into agriculture landscapes can instead mitigate some of the water quality impacts associated with conventional crop cultivation. Examples include perennial grasses and woody plants grown in multi-year rotations, which commonly require less fertilizer and other chemical inputs than conventional annual crops. The cultivation of such plants can help improving water quality and can also influence positively soils qualities such as texture and structure, which in turn improve water infiltration, permeability, and water-holding capacity. The possibility to combine biomass production for energy with the provision of additional environmental services is further discussed below.

#### **4. Bioenergy systems improving the state of water**

The integration of different perennial grasses and short rotation woody crops into the agriculture landscape has been suggested as a way of remediating many environmental problems. These perennial crops differ from most arable crops in physical traits and management practices. Results so far imply many positive environmental benefits associated with implementation of bioenergy feedstock production using such crops, although the effects on the environment depend on the existing or previous land use, the scale of planting and the management practices applied.

When bioenergy systems – through well-chosen localisation, design, management and system integration – offer additional environmental services, this creates added value for the systems. Some bioenergy systems provide environmental benefits of a more general nature, for instance, soil carbon accumulation leading to improved soil fertility and enhanced climate benefit. In general, planting of perennial grasses and short rotation woody crops also contribute to a more varied agriculture landscape, increased biodiversity and more animal life. Bioenergy systems can also be established to provide environmental benefits that are relevant in only specific conditions. Examples include trees that are established as a wind break to reduce wind erosion; plantations of suitable species that are used to remove cadmium and other heavy metals from cropland soils (Gomes, 2012, Berndes et al., 2004); plantations that are located in the agricultural landscape so as to provide ecological corridors that provide a route through which plants and animals can move between different spatially separated natural and semi- natural ecosystems. This way they can reduce the barrier effect of agricultural lands

Examples of bioenergy systems that are established for the purpose of providing specific environmental benefits relevant for water include soil-covering plants and vegetation strips located to limit water erosion, reduce evaporating surface runoff, trap sediment, and reduce the risks of shallow landslides; and tree plantations that are used for salinity management on land subject to productivity losses due to soil salinity induced by rising water tables (possibly leading to trade-offs due to reduced river stream flows) (Bann et al., 2006, Cacho et al., 2001, Finlayson et al., 2010). Specific bioenergy applications can also prove economically attractive compared to other approaches to address these problems (Rosenqvist and Dawson, 2005; Dimitriou and Rosenqvist, 2011; Börjesson and Berndes, 2006). As an example of this, shows a willow plantation that is irrigated with pretreated municipal wastewater. In this case, the municipality covered all costs of the storage ponds, pumps, automatic filters and irrigation pipes (which were lower than the estimated cost of installing improved conventional nitrogen treatment). The farmer/landowner planted the willows and is responsible for the cultivation including maintenance of the irrigation pipes. The willow producer has economic benefits from lower costs for conventional fertilizers and the irrigation contributes to higher yields and lower vulnerability to drought.

Plantations like the one shown in Figure 4 can also be used as vegetation filters for the treatment (via irrigation) of collected run-off water from farmlands and leachate from landfills. Plantations can also be located in the landscape and managed as buffer strips for capturing the nutrients in passing run-off water. Sewage sludge from treatment plants can also be used as fertilizer in vegetation filters.



**Figure 4: View of the Enköping municipal wastewater plant in Sweden, showing the water storage ponds and willows used as vegetation filter. A 75-ha willow plantation treats and utilizes decanted water from the dewatering of sewage sludge. The water contains approximately 25% of the N entering the wastewater treatment plant, but less than 1% of the water volume. By treating the water separately in the willow vegetation filter, instead of pumping it back into the treatment plant, the total N load is reduced by 25%. The biomass produced is used in the local district heating plant, contributing to the local supply of heat and electricity. Ash from the boiler is recycled back to the willow plantation. Photo credit: Per Aronsson, Swedish University of Agricultural Sciences, Sweden.**

## **5. Governance of bioenergy development**

Governance of bioenergy development is much about balancing trade-offs between partly incompatible environmental and socioeconomic objectives. Consequences of bioenergy production for water, soils and other resources will depend on which approaches to land use and biomass production that become established, and also on the willingness of national governments to protect natural ecosystems – and the effectiveness of legislation and other measures put in place. There are currently several initiatives to develop certification schemes intending to promote bioenergy systems that meet certain sustainability requirements (Goovaerts et al., Stupak et al., Goh et al., Pelkmans et al.).

Together with different governance mechanisms (e.g. local or state regulations, best management practices or international trade standards), these certification schemes may hedge against some of the undesired consequences of expanding bioenergy systems and promote a positive development where implemented effectively.

Complementary to establishing sustainability certification and other governance structures, competitive business cases need to be developed that are efficient along the entire bioenergy supply chain, from feedstock production to energy markets. Capturing the benefits of bioenergy requires that incentives are created that stimulate innovation in land use, including new ways to integrate bioenergy feedstock production in the agriculture and forestry landscapes so as to stimulate productivity growth, local development and sustainable land-use practices. One key issue will be to identify suitable mechanisms to put a premium on

additional environmental benefits associated with specific bioenergy systems. If additional revenues can be linked to the bioenergy systems, the competitiveness of the produced biomass on the market could be significantly improved. In some cases, actors can be identified that are willing to pay for a specific environmental service. In other situations, information campaigns and innovative government measures that credit the biomass producer may be required.

## 6. Conclusions and recommendations

It is not axiomatic that the use of biomass for energy is environmentally superior to the use of the fossil resources and water impacts is one of several possible impacts; both the feedstock production and the subsequent conversion to solid, liquid and gaseous biofuels can impact the state of water in many different ways. Thus, increasing biomass demand can be a challenge from the perspective of water and it is crucial that practices are found that ensure that negative impacts are avoided or mitigated as far as possible. We must always seek to develop new systems that are sustainable and that have significant beneficial outcomes when considered in the wider context.

There is considerable scope for improving water productivity in many regions of the world, reducing the amount of water needed for crop production, and leaving more water for other uses, including the environment. By concurrently introducing efficient water management techniques and by providing a wider range of land-use options to optimize the use of land and water, bioenergy development provides opportunities to improve water productivity and increase access to water. One strategy for adaptation to water scarcity can be to use biomass production for energy as a tool for increasing the spatial and temporal accessibility of water resources and at the same time improving the quality of freshwater flows. Basin level planning could include biomass production as a land-use option with the potential for combining, for example, erosion control and flood prevention with income generation from carbon sink generation and biomass sales for energy.

As have been described in this chapter, intelligently designed bioenergy systems can significantly offset greenhouse gas emissions associated with fossil fuel-based energy systems, and at the same time lead to additional environmental benefits. The environmental and socio-economic benefits from a large-scale establishment of such bioenergy systems could be substantial. Policy should be devised to promote the optimal use of land, water and biomass resources to meet needs for food, materials and energy. Design of policy for bioenergy need to balance multiple objectives and should be based on a holistic perspective recognizing the multiple drivers and effects of land use and land use change. There is otherwise a risk that policies will fail to promote optimal outcomes.

## References

- **Abideen Z., Ansari R., Khan M.A.**, 2011, Halophytes: Potential source of ligno-cellulosic biomass for ethanol production, *Biomass and Bioenergy* 35(5): 1818-1822
- **Bann G., Field J.** , 2006, The use of native (endemic) grass and tree species for dryland salinity mitigation, remediation and agronomy activities in south-east Australia. Proceedings of the 13th Australian Agronomy Conference. 10-14 September 2006 Perth, Western Australia.
- **Berndes G.**, 2002, Bioenergy and water -the implications of large-scale bioenergy production for water use and supply. *Global Environmental Change* 12(4):7-25
- **Berndes G.**, 2008, Water demand for global bioenergy production: trends, risks and opportunities. Report commissioned by the German Advisory Council on Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen -- WBGU)

- **Berndes G., Fredriksson F., Börjesson P.**, 2004, Cadmium accumulation and Salix based phytoextraction on arable land in Sweden. *Agriculture Ecosystems and Environment* 103:207–223.
- **Blanco-Canqui H., Lal R.**, 2009, Crop Residue Removal Impacts on Soil Productivity and Environmental Quality. *Critical Reviews in Plant Sciences* 28: 139-163.
- **Binkley D., Brown T.**, Forest practices as nonpoint sources of pollution in North America. *Water Resour Bull* 1993, 29:729–740
- **Börjesson P., Berndes G.** The prospects for willow plantations for wastewater treatment in Sweden. *Biomass & Bioenergy*, 2006, 30: 428–438.
- **Cacho O., Greiner R., Fulloon L.**, 2001, All economic analysis of farm forestry as a means of controlling dryland salinity. *Australian Journal of Agricultural and Resource Economics* 45(2): 233-256
- **Cardinael R., Thevathasan N., Gordon A., Clinch R., Mohammed I., Sidders D.**, 2012, Growing woody biomass for bioenergy in a tree-based intercropping system in southern Ontario, Canada. *Agroforestry Systems* 86(2): 279-286.
- **Ceschia E., Béziat P., Dejoux J. F., Aubinet M., Bernhofer C., Bodson B., Buchmann N., Carrara A.**, 2010, Management effects on net ecosystem carbon and GHG budgets at European crop sites. *Agriculture, Ecosystems & Environment* 139: 363-383.
- **Cesson E.**, 2008, Production of bioenergy on small farms: a two-year agroforestry experiment using *Eucalyptus urophylla* intercropped with rice and beans in Minas Gerais, Brazil. *New Forest* 35(3): 285-298.
- **Chum H., Faaij A., Moreira J., Berndes G., Dhamija P., Dong H., Gabrielle B., Goss Eng A., Lucht W., Mapako M., Masera Cerutti O., McIntyre T., Minowa T., Pingoud K.**, 2011: Bioenergy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- **Diaz R.J., Rosenberg R.**, 2008, Spreading dead zones and consequences for marine ecosystems. *Science* 321, 926–929.
- **Dimitriou I. and Rosenqvist H.**, 2011, Sewage sludge and wastewater fertilisation of Short Rotation Coppice (SRC) for increased bioenergy production—Biological and economic potential. *Biomass and Bioenergy* 35(2): 835-842
- **Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., von Stechow C.** [eds], IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; 2011.
- **Finlayson J., Bathgate A., Nordblom T., Theiveyanathan T., Farquharson B., Crosbie R., Mitchell D., Hoque Z.**, 2010, Balancing land use to manage river volume and salinity: Economic and hydrological consequences for the Little River catchment in Central West, New South Wales, Australia, *Agricultural Systems* 103(3): 161-170
- **Garg K., Karlberg L., Wani S., Berndes G.**, 2011, Biofuel production on wastelands in India: opportunities and trade-offs for soil and water management at the watershed scale. *Biofuels, Bioproducts and Biorefining* 5: 410-430
- **Goh C.S., Junginger M., Joudrey J., Chum H., Pelkmans L., Smith C.T., Stupak I., Cowie A., L. Dahlman L., O. Englund O., Goss A. and L. Goovaerts.** 2012. Task 3: Impacts of sustainability certification on bioenergy markets and trade. Strategic Inter-Task Study: Monitoring Sustainability Certification of Bioenergy. A cooperation between IEA Bioenergy Task 40, Task 43 and Task 38.
- **Gomes H.I.**, 2012, Phytoremediation for bioenergy: challenges and opportunities. *Environmental Technology*. DOI: 10.1080/09593330.2012.696715

- **Gerbens-Leenes, W., Hoekstra, A.Y., Van der Meer, T.H.,** 2009. Reply to Maes et al.: A global estimate of the water footprint of *Jatropha curcas* under limited data availability. Proceedings of the National Academy of Science (PNAS) (106) 40, E113
- **Goovaerts, L., L. Pelkmans, C.S. Goh, M. Junginger, J. Joudrey, H. Chum, T. Smith, I. Stupak, A. Cowie, L. Dahlman, O. Englund, and A. Goss** Eng. 2012. Task 1: Examining Sustainability Certification of Bioenergy. Strategic Inter---task Study: Monitoring Sustainability Certification of Bioenergy. A cooperation between IEA Bioenergy Task 40, Task 43 and Task 38.
- **Hamanishi E.T., Campbell M.M.,** 2011, Genome-wide responses to drought in forest trees. *Forestry* (2011) 84 (3): 273-283.
- **Jose S., Bardhan S.,** 2012, Agroforestry for biomass production and carbon sequestration: an overview. *Agroforestry Systems* 86(2): 105-111
- **Li R., Qiu G.,** 2012, *Spartina alterniflora*: Potential bio-energy source for biofuel production in China. *Applied Mechanics and Materials* 142 (3): 247-251.
- **Liu, C., Kroeze, C., Hoekstra, A.Y. and Gerbens-Leenes, W.** (2012) Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers, *Ecological Indicators*, 18: 42-49
- **Mead D., Smith T.,** 2012, Principles of nutrient management for sustainable forest bioenergy production. *WIREs Energy Environ* 2012, 1: 152–164 doi: 10.1002/wene.3
- **Neary D., Koestner K.A.,** 2012, Forest Bioenergy feedstock harvesting effects on water supply. *WIREs Energy Environ* 2012. doi: 10.1002/wene.26
- **Oliver R. J., Finch J. W. and Taylor G.,** 2009, Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO<sub>2</sub> and drought on water use and the implications for yield. *GCB Bioenergy*, 1: 97–114. doi:10.1111/j.1757-1707.2009.01011.x
- **Pelkmans, P., L. Goovaerts, T. Smith, J. Joudrey, I. Stupak, O. Englund, M. Junginger, C.S. Goh, H. Chum, A. Cowie.** 2012. Task 4: Recommendations for improvement of sustainability certified markets. Strategic Inter---task Study: Monitoring Sustainability Certification of Bioenergy. A cooperation between IEA Bioenergy Task 40, Task 43 and Task 38.
- **Rockström J., Gordon L., Folke C., Falkenmark M., Engwall M.,** 1999, Linkages among water vapor flows, food production, and terrestrial ecosystem services. *Conservation Ecology* 3(2): 5
- **Rosenqvist H. and Dawson W.M.,** 2005, Economics of using wastewater irrigation of willow in Northern Ireland. *Biomass and Bioenergy* 29(2): 83-92
- **Ruan C.J., Teixeira da Silva J.A., Mopper S., Qin P., Lutts S.,** 2010, Halophyte Improvement for a Salinized World. *Critical Reviews in Plant Sciences* 29(6): 329-359.
- **Service R.F.** Another Biofuels Drawback: The Demand for Irrigation. *Science* 23 October 2009: 516-517. DOI:10.1126/science.326\_516
- **Simpson T.W., Martinelli L.A., Sharpley A.N., Howarth R.W.,** 2009, Impact of ethanol production on nutrient cycles and water quality. Pages 153-167 in R.W. Howarth and S. Bringezu (Eds.) *Biofuels: Environmental Consequences and Interactions with Changing Land Use*. Proceedings of the Scientific Committee (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummertsbach Germany. Cornell University, Ithaca NY, USA (<http://cip.cornell.edu/biofuels/>)
- **Sotiroudis V.T., Sotiroudis T.G., Kolisis F.N.,** 2010, The Potential of Biodiesel Production from Fatty Acid Methyl Esters of Some European/Mediterranean and Cosmopolitan Halophyte Seed Oils. *Journal of ASTM International* 7(3)
- **Stednick J.D.,** Monitoring the effects of timber harvest on annual water yield. *J Hydrol* 2000, 176:79–95

- **Stupak, I., J. Joudrey, C.T. Smith, L. Pelkmans, H. Chum, A. Cowie, L. Dahlman, O. Englund, C.S. Goh, A. Goss Eng, M. Junginger and L. Goovaerts.** 2012. Task 2: Survey on governance and certification of sustainable biomass and bioenergy. Strategic Inter-task Study: Monitoring Sustainability Certification of Bioenergy. A cooperation between IEA Bioenergy Task 40, Task 43 and Task 38.
- **Street NR, Skogstrom O, Sjodin A et al.,** 2006, The genetics and genomics of the drought response in Populus. Plant Journal, 48, 321–341.
- **Susaeta A., Lal P., Alavalapati J., Mercer E., Carter D.,** 2012, Economics of intercropping loblolly pine and switchgrass for bioenergy markets in the southeastern United States. Agroforestry Systems 86(2): 287-298.
- **Turrall H., Burke J., Faurés J.-M.,** 2011, Climate change, water and food security. FAO Water Reports 36. Food and Agriculture Organization of the United Nations, Rome.
- **UNESCO,** 2009, The United Nations World Water Development Report 3: Water in a Changing World. Paris: UNESCO and London, Earthscan.

## Abbreviations

E	Non productive Evapotranspiration
EJ	Exa Joule
ET	Evapotranspiration
IEA	Internatio,nal Energy Agency
IPCC	International Panel on Climate Change
LUC	Land Use Change
T	Plant Transpiration

# Water footprint quantification of energy at a global level

W.P. Gerbens-Leenes, A.Y. Hoekstra  
University of Twente, The Netherlands

## Abstract

Agriculture is by far the largest water user. This chapter reviews studies on the Water Footprint (WF) of bioenergy (in the form of first generation bio-ethanol and biodiesel) and compares the results with the blue WF of fossil energy and other types of renewables (wind, solar thermal energy and hydropower). The WF of bioenergy varies, depending on crop type applied, production location and agricultural practice. The blue water footprints of bioenergy and hydropower are much larger than for fossil, nuclear, wind and thermal solar energy. The blue WF of hydropower shows a large variation, between 0.3 and 850 m<sup>3</sup> per GJ, with an average probably somewhere between 20 and 70 m<sup>3</sup> per GJ.

The most water-efficient way to generate bioenergy is to use the total biomass, including parts without a large economic value, and generate heat. The generation of electricity is the second best option. Much research is presently done to develop the so termed second generation biofuels, biofuels generated from biomass waste. When this technique becomes available, large amounts of waste biomass can be converted into second generation biofuels. Also the development of third generation biofuels, biofuels from algae, is an interesting development that might decrease the WFs of biofuels.

When comparing different first generation biofuel practices, in general, it is more water efficient to produce bio-ethanol than biodiesel. The green WF of a typical biodiesel energy crop, rapeseed, is two times larger than the WF of ethanol from sugarcane and four times larger than ethanol from sugar beet. The blue WFs that have a larger environmental impact on water systems show a different pattern, however. For the dominant biofuel feedstocks, the global weighted average blue WFs increase in the following order: palm oil (0 m<sup>3</sup>/GJ), ethanol from maize (8 m<sup>3</sup>/GJ); ethanol from sugar beet (10 m<sup>3</sup>/GJ), soybean oil (11 m<sup>3</sup>/GJ), rapeseed oil (20 m<sup>3</sup>/GJ), sunflower oil (21 m<sup>3</sup>/GJ) and ethanol from sugar cane (25 m<sup>3</sup>/GJ). Grey WFs related to water pollution are smallest for soybean and palm oil and for ethanol from sugar cane (6 m<sup>3</sup>/GJ) and largest for rapeseed oil (29 m<sup>3</sup>/GJ).

Our results provide new insights into the impacts of energy on the use and pollution of freshwater. This knowledge is a valuable contribution to future research and for policies concerning energy needs, freshwater availability and the choice whether to allocate water to food or to energy production.

## 1. Introduction

Fresh water of adequate quality is essential for the functioning of society and nature. Fresh water is a scarce natural resource. Most water on the planet earth is saline and cannot be used for societal needs. The oceans contain about 97.5 percent of available water in the form of salt water. Of the remaining 2.5 percent of fresh water, most is not accessible, because it forms part of ice or snow covers (Shiklomanov, 1997). Although the amount of water on the planet is constant, the annual freshwater supply in the form of precipitation is limited. Human activity consumes and pollutes great amounts of water, particularly through agricultural production (Hoekstra and Chapagain, 2007). Water use in agriculture, industry and households has increased sharply in the 20th century (Shiklomanov, 1997). Today, the

increasing food demand, in combination with the shift towards a larger fraction of bioenergy in total energy supply, results in still increasing freshwater use (UNEP, 2009).

Natural precipitation is the main provider of water for agriculture. This is the so termed green water (Hoekstra et al., 2011). When precipitation is insufficient, farmers can apply irrigation, the so termed blue water. The irrigation sector has increased enormously in the past decades and is currently the largest water user, accounting for 61 percent of total water withdrawal globally. Between 1900 and 1995, the irrigated area expanded fivefold, from 50 to 250 million ha. Half of these irrigated areas are located in just four countries: China, India, the US and Pakistan (Shiklomanov, 1997). Today, about 80 percent of the agricultural water requirements are met by precipitation with the rest withdrawn from other sources, such as rivers and lakes (De Fraiture and Berndes, 2009). These withdrawals account for 70 percent of all human water use (UNEP, 2009).

Fresh water is becoming, more and more, a global resource, because water-intensive products are traded on global markets. International trade results in a spatial disconnection between consumers and the water resources used for making consumer products. Water footprint (WF) research shows the relationship between consumer goods and water consumption along supply chains, thereby addressing the link between consumption and production. By doing this, WF research offers a new perspective on how a consumer or producer relates to the use of freshwater systems (Hoekstra et al., 2011). The WF concept provides a tool to calculate water needs for consumer products and provides an indication of the total amount of freshwater used, directly and indirectly, along product supply chains (Hoekstra et al., 2011). The WF of a product, for example bio-ethanol, is the volume of freshwater used to produce the ethanol, measured over the complete supply chain. Important water-intensive products are crop and livestock commodities, natural fibers and bioenergy.

The next decades will see an increased demand for food (Tilman et al., 2002; FAO, 2003), as well as an increased demand for biofuels (See Eisenstraut in this publication, Stromberg et al., 2010). The corresponding necessary growth of agricultural output can be achieved in three ways: (a) an increase of agricultural land areas, (b) an increase of yield levels per unit of land (increase of land productivity), or (c) an increase of cropping intensities (e.g. by increasing multiple cropping and shortening the fallow periods). If agricultural land areas are increased, water use will probably increase by the same factor given that water input per unit of land usually remains the same. The increase of yield levels or cropping intensities might also increase water use in those cases where water is the limiting factor for crop growth.

Bioenergy production may divert land, water and other resources away from the production of food and feed (Fischer et al., 2009). In many countries, agricultural water use competes with other uses, such as urban supply and industrial activities (Falkenmark, 1989), causing the aquatic environment to show signs of degradation and decline (Postel et al., 1996). Crop growth (for biomass production) requires freshwater; and agricultural activity associated with feedstock production is by far the largest user of water, followed by industrial activities (WWAP, 2009). In general, increased biofuel production will probably require more water (Berndes, 2002; De Fraiture et al., 2008) and a shift from fossil energy towards bioenergy might put additional pressure on freshwater resources.

Today, some of the world's most important agricultural areas show signs of water scarcity (De Fraiture and Berndes, 2009) such as North India, Pakistan and North China (Shah et al., 2007). Water shortages are the result of a mismatch between demand for fresh water and its availability over space and time. China and India will account for one third of the world population and will demand one third of the world's energy supply by 2030 (De Fraiture and Berndes, 2009) so they aim to partly replace transport fuels from fossil sources by biofuels, such as bio-ethanol and biodiesel (Yang et al., 2009). This is expected to increase water scarcity, because China and India have already overexploited their natural water resources

(De Fraiture et al., 2008; Muller et al., 2008). Sufficient water for agriculture is available in Latin America and Sub-Saharan Africa (Muller et al., 2008), excluding South Africa (Jewitt et al., 2009). All of the above suggest that biofuel-related water consumption might aggravate water scarcity in many countries. In all, about thirty developing countries face water scarcity and it is expected that by 2050, over fifty developing countries will suffer from water shortages (Fischer et al., 2009). It is therefore important to have insight into the relationship between agricultural output, water consumption and water availability in order to properly allocate the water to food or to bioenergy (e.g. biofuels).

Biofuel production does not only affect the quantity of water resources but can also affect the quality of such resources (Stromberg et al., 2010). Apart from water, other important agricultural inputs for feedstock production include nutrients (such as nitrogen and phosphorus) and agrochemicals for controlling pests, diseases and weeds. When agricultural yields increase, the demand for nutrients expressed per unit area also increases (De Wit, 1992). Part of these inputs leach to water bodies and cause water pollution (UNEP, 2009; Simpson et al., 2009; Stromberg et al., 2010). Ethanol production, for example, has serious implications for coastal water quality and will almost certainly worsen already serious hypoxic conditions in many locations around the world (Simpson et al., 2009). Sugarcane expansion is one of the main drivers of increased fertilizer and agrochemical use in Brazil which has been linked to water pollution and ecosystem deterioration (Martinelli and Filoso, 2008).

In this chapter, we present the WF concept to assess the water requirements of different biofuel production practices. Initially, we summarize the WF methodology and review the recent bioenergy WF studies that have estimated WFs per unit of bioenergy ( $\text{m}^3/\text{GJ}$ ). Next, we compare WFs of bioenergy with WFs of fossil energy carriers, nuclear energy and the WFs of renewables (wind, solar thermal and hydropower). The chapter gives WFs of various types of bioenergy in  $\text{m}^3$  per unit of energy (GJ) and covers the main producing countries, including developing countries, transition countries and industrialized countries.

## **2. The Water Footprint**

The water footprint (WF) is a multi-dimensional indicator, giving water consumption volumes by source and polluted volumes by type of pollution. The WF of a product is defined as the volume of freshwater used for its production at the place where it was actually produced (Hoekstra et al., 2011). In general, product's actual water contents are negligible compared with their WF. For many products, such as bioenergy, the water used (or consumed) during the agricultural production stage makes up the bulk of the product's total life-cycle water use.

The WF concept includes three components—green, blue and grey water—and distinguishes between direct and indirect water use, taking into account the water use along supply chains. The components of WFs are specified geographically and temporally. Green water refers to the precipitation on land that does not run off or recharge the groundwater, but is stored in the soil as soil moisture and water that stays on top of the soil and on the vegetation. Green water eventually evaporates or transpires through plants. It can be made productive for crop growth. The green WF in crop growth is equal to the volume of evapotranspiration from the field from sowing to harvesting plus the volume of water incorporated into the crop.

The blue WF refers to consumption of blue water resources, i.e. fresh surface and groundwater. Water consumption does not mean that the water disappears, because it remains within the hydrological cycle and always returns somewhere. Blue water consumption refers to the following four cases: (i) water evaporates; (ii) water is incorporated into products; (iii) water does not return to the same catchment area where it came from; and (iv) water does not return in the same period.

The grey WF refers to pollution and is defined as the volume of freshwater required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra et al., 2011). The grey component of the WF is:

$$\text{Grey WF} = [(\alpha \times \text{AR}) / (\text{cmax} - \text{cnat})] / Y \quad (1)$$

where AR is the chemical application rate to the field per ha (kg/ha),  $\alpha$  is the leaching-runoff fraction, cmax, is the maximum acceptable concentration of the pollutant (kg/m<sup>3</sup>), cnat, is the natural concentration for the pollutant considered (kg/m<sup>3</sup>) and Y is the crop yield (ton/ha).

The pollutants generally consist of fertilizers (nitrogen, phosphorus, etc.) and agrochemicals. One has to consider only the 'waste flow' to freshwater bodies, which is generally a fraction of the total agricultural application to the field. One needs to account for only the most critical pollutant, that is the pollutant for which the above calculation yields the highest water volume (Hoekstra et al., 2011).

The method is the global standard for water footprint assessment, which is the most comprehensive method for assessing water consumption and pollution along supply chains (Hoekstra et al., 2011). The method is supported by the Water Footprint Network that includes over 150 partners, including for example WWF, the World Business Council for Sustainable Development and many universities.

### 3. Bioenergy

Bioenergy is energy derived from biomass, material of organic origin in non fossilized form, e.g. agricultural crops, forestry products, agricultural and forestry wastes and by-products, manure, microbial matter, and wastes from industry or households (FAO, 2006). Bioenergy includes different forms of energy, e.g. heat and electricity from the burning of biomass, or biofuels, for example, bio-ethanol and biodiesel. In general, a distinction is made between first, second and third generation biofuels. First generation biofuels are the presently available biofuels produced using the starch, sugar, or oil fraction of a crop. Applying conventional techniques, these fractions are converted into ethanol by fermentation or into biodiesel by extracting and processing the oil (Worldwatch Institute, 2007).

Future developments in the area of biofuels are, for example, the development of so termed second generation and third generation biofuels, such as biodiesel from algae (see also Gerbeens-Leenes et al. in this publication). For the second generation biofuels, cellulosic biomass of, for example, crop wastes or woody residues from forestry, is applied as a feedstock. There are two basic conversion technologies, thermo-chemical conversion, e.g. pyrolysis, and biochemical conversion, e.g. biological conversion into ethanol (Worldwatch Institute, 2007). At present, research is done to develop second generation biofuels from agricultural waste, such as pyrolysis oil and ethanol. Pyrolysis oil, however, still misses the quality of first-generation biodiesel, because it contains hundreds of different components formed during the decomposition of the cellulosic biomass in the feedstock. Pyrolysis oil has a low quality, is unstable, has a high acidity and viscosity and it has a relatively low energy content. Moreover, it is not miscible with petrol and is corrosive to engines (De Miguel Mercader et al., 2010). Another problem is the instability of pyrolysis oil, especially during storage, referred to as "aging" (Oasmaa and Czernik, 1999). Aging causes greater viscosity and a possibly unwanted change in chemical composition of pyrolysis oil. Biological conversion into ethanol, e.g. by fermentation, also finds itself in an experimental stage (Worldwatch Institute, 2007, Park et al., 2010). When the production of second generation biofuels is technically and economically possible, large amounts of feedstocks are available.

A second interesting development is the production of biodiesel from algae, the so termed third generation biofuels. To date, microalgae-based biofuel production has not yet been

commercialized to a large scale, but there is a wide interest for this new biofuel, for example from the US army for aviation (Cullom, 2010) and from the aviation industry (Holmgren, 2009). Biodiesel from algae can reduce WFs compared to presently applied biodiesel (Yang et al., 2010).

### **3.1 Bio-ethanol**

Bio-ethanol is a liquid biofuel. Globally, 75 percent is used for transportation (Worldwatch Institute, 2007). Industry produces 95 percent of the bio-ethanol by fermenting sugar and starch (carbohydrates), mainly from sugar cane, sugar beet and maize (Berg, 2004). Sugar cane is a perennial crop growing in tropical climates. Over the period 1998-2007, Brazil produced 30 percent of the global sugar cane, India 21 percent, China 7 percent, and Thailand and Pakistan 4 percent each (FAO, 2011). Sugar beet is a root crop growing in temperate climates. The main producers are France (12 percent of global production), the US (11 percent), Germany (10 percent), the Russian Federation (8 percent), Turkey (6 percent), the Ukraine (6 percent), Poland (5 percent), Italy (4 percent) and China (4 percent) (FAO, 2011). Although sugar beet has high ethanol yields per hectare (Rajagopal and Zilberman, 2007), the use for bio-ethanol is limited compared to sugar cane. Maize grows in moderate and subtropical climates. The US (40 percent of global production) and China (20 percent of global production) are the main producers (FAO, 2011). About half of the maize is used for animal feed, the other half for industrial purposes, such as bio-ethanol. In 2019, bio-ethanol production is expected to require 40 percent of the maize grown in the US (Economic Research Service/USDA, 2009).

### **3.2 Biodiesel**

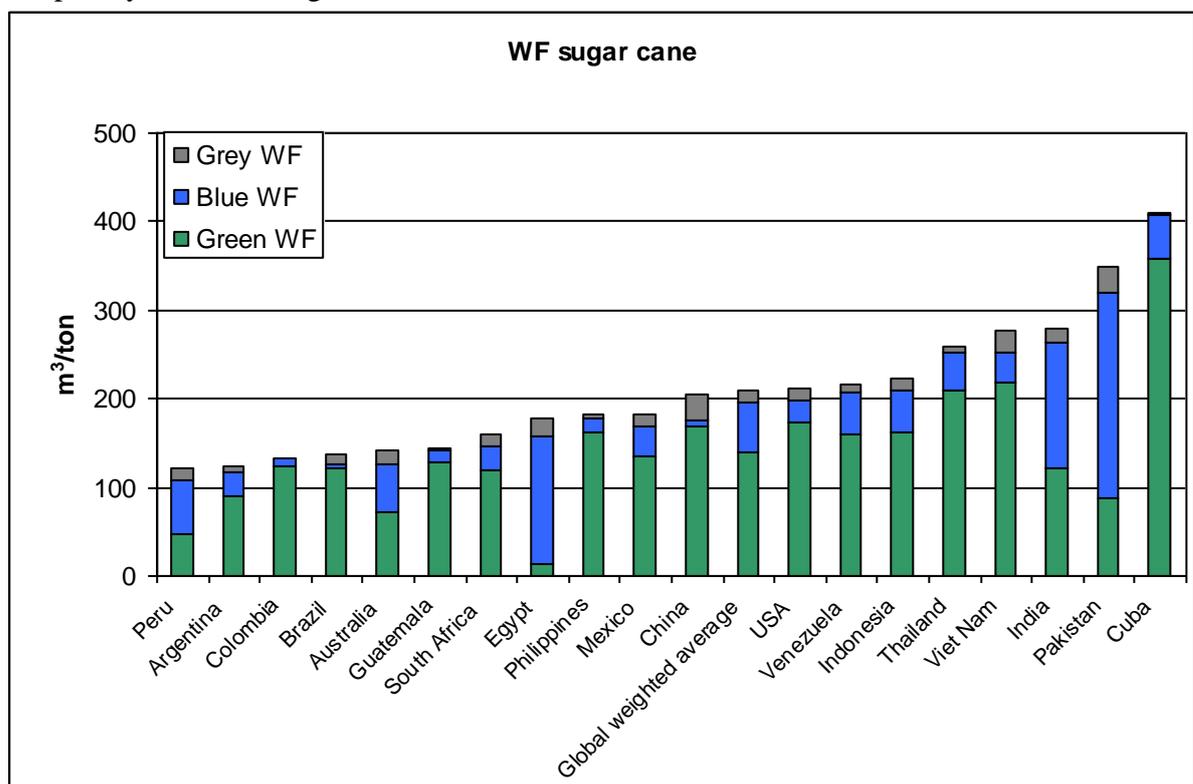
First generation biodiesel is produced from oilseed crops, e.g. rapeseed, soybean, sunflower, palm, coconut or jatropha. The vegetal oil is extracted. Sometimes it can be used directly, in the form of straight vegetable oil, sometimes a conversion step is needed, especially in temperate climates, because straight vegetable oil has a high viscosity at low temperatures (Worldwatch Institute, 2007). The biodiesel is manufactured by applying transesterification, in which oil reacts with an alcohol giving an alkyl ester of a fatty acid with a higher viscosity. In Europe, rapeseed is the main feedstock for biodiesel, with some sunflower. In the US, soybean is the main feedstock. In tropical countries, the main feedstocks are palm, coconut and jatropha oil.

## **4. Water footprint of first generation biofuels**

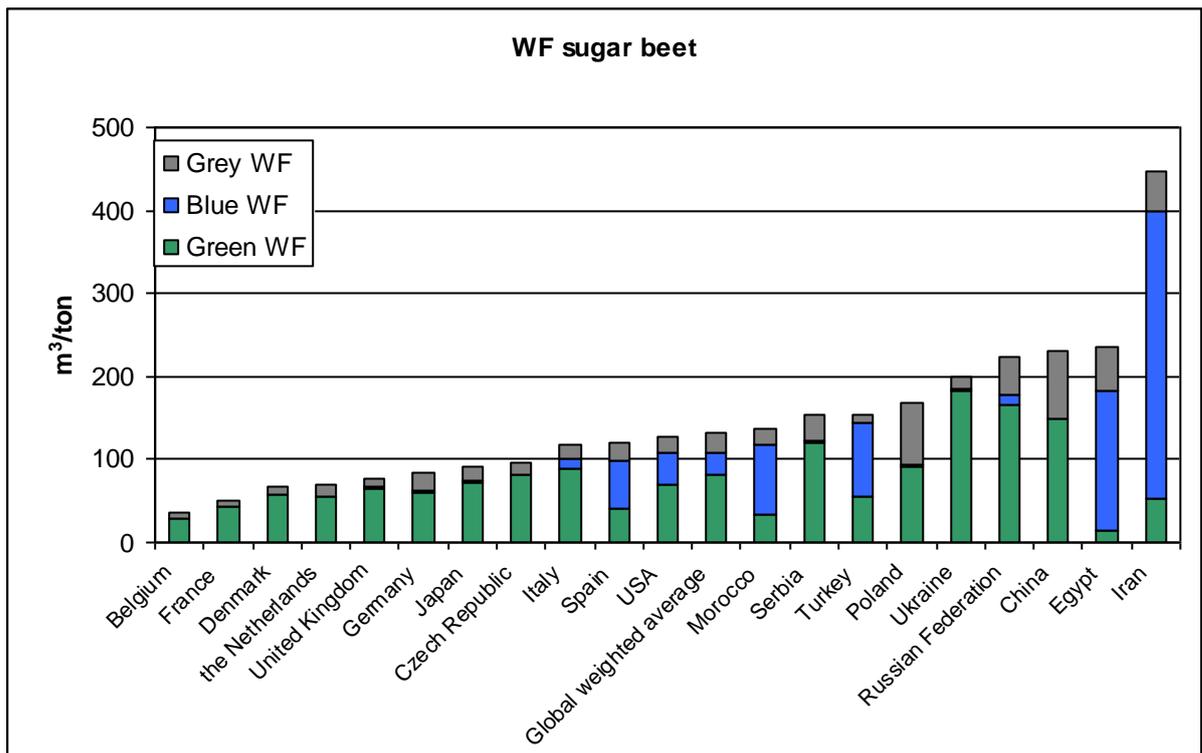
Recently, Mekonnen and Hoekstra (2010) have developed a new method of estimating green and blue water consumption at a high spatial resolution. That method takes actual irrigation rather than irrigation requirements into account. Earlier studies calculated blue WFs as differences between crop water requirements and effective rainfall, assuming irrigation requirements are met. In many cases, this leads to an overestimation of blue water use. The new method is a large improvement of water use estimates compared to the earlier WF calculations. The study provides a comprehensive global database of green, blue and grey WFs of crops and derived crop products, including bio-ethanol and biodiesel, at a spatial resolution of 5 by 5 arc minute. Gerbens-Leenes and Hoekstra (2012) derived data from that study and performed a detailed study of bio-ethanol WFs for the main producing countries as well as the main producing US states.

#### 4.1 Water footprint of sugar cane, sugar beet and maize

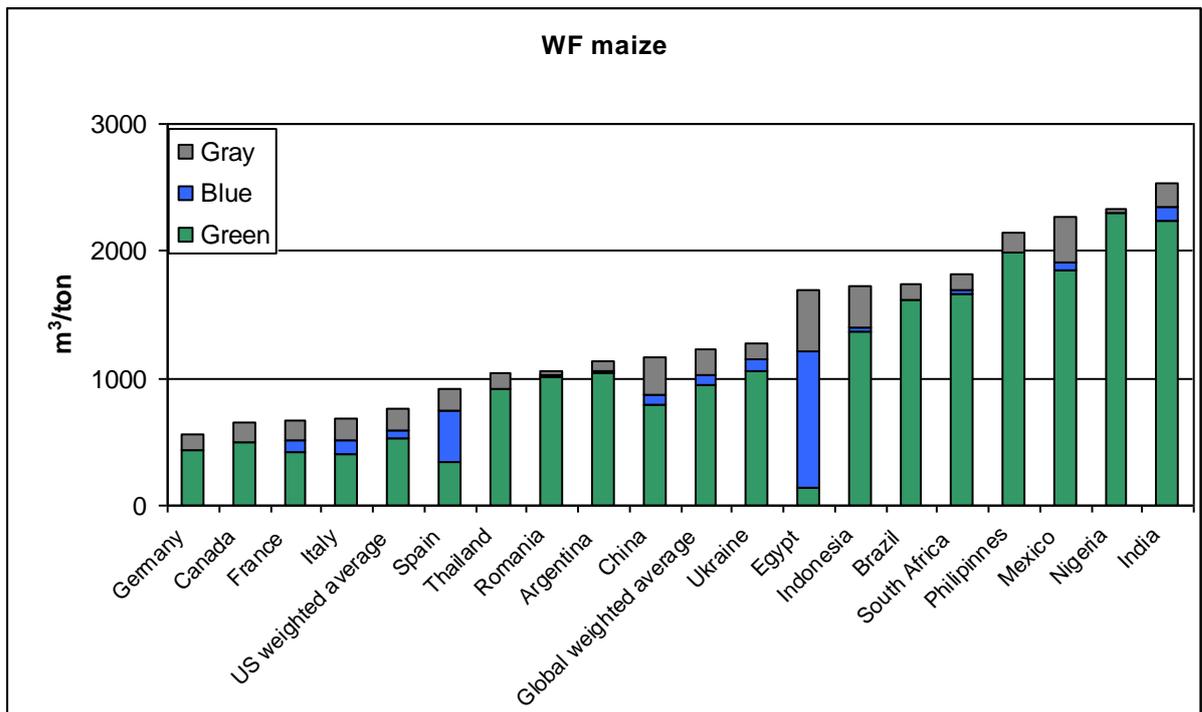
The WF of biofuels, e.g. bio-ethanol from sugar cane, sugar beet or maize, is dominated by the agricultural phase, i.e. feedstock production. Process water use varies between 0 m<sup>3</sup> per ton (in the case of sugar beet where the water from the beet itself is used) to 21 m<sup>3</sup> per ton (Gerbens-Leenes and Hoekstra, 2012). Other processes during the biofuel's life cycle, such as feedstock transportation and processing, are much less water intensive. Figure 1 shows the WFs of sugar cane (m<sup>3</sup>/ton), Figure 2 the WFs of sugar beet and Figure 3 the WFs of maize. There are large differences for similar crops that are caused by differences in climate and differences in yields (ton per ha). Some countries have unfavourable WFs, far above the global average. For example, for sugar cane production in Cuba, Pakistan, India, Vietnam and Thailand. Egypt, India and Pakistan heavily rely on blue water for irrigation. For sugar beet, Iran, China, Egypt and Ukraine have WFs far above the global average, while western European countries have WFs below the global average. Especially grey WFs are great for Poland and China, indicating that much nitrogen is leaking or applied in too large amounts, polluting water bodies. For maize, developing countries like India, Nigeria, Mexico and the Philippines have relatively great WFs, while developed countries like Germany, France, the US, Canada and Spain have relatively small WFs. For all three crops, Egypt almost completely relies on irrigation.



**Figure 1: The water footprint of sugar cane for the main producing countries including the weighted global average value (Source: Gerbens-Leenes and Hoekstra, 2012)**



**Figure 2: The water footprint of sugar beet for the main producing countries including the weighted global average value (Source: Gerbens-Leenes and Hoekstra, 2012)**



**Figure 3: The water footprint of maize for the main producing countries including the weighted global average value (Source: Gerbens-Leenes and Hoekstra, 2012)**

Table 1 gives the WFs for maize in the main producing states in the US, as well as the US weighted average. The Table shows that variation among the states is small, with Nebraska and Illinois the only exceptions. Nebraska uses a relatively great amount of blue water, while Illinois has a great grey WF. In this way, these states influence the average US values. US values, however, are much smaller than global averages, indicating relatively favourable production and climatic circumstances.

US State	Green WF	Blue WF	Grey WF
	m <sup>3</sup> per ton	m <sup>3</sup> per ton	m <sup>3</sup> per ton
Illinois	578	5	192
Indiana	526	7	172
Iowa	553	2	177
Michigan	466	14	163
Minnesota	525	4	165
Nebraska	443	191	153
North Carolina	528	4	152
Pennsylvania	458	3	158
Wisconsin	465	3	158
US weighted average	522	63	176
US SD	± 127	± 63	± 78

**Table 1: Green, blue and grey WFs for maize in the main producing states in the US, US weighted average values and standard deviations (Mekonnen and Hoekstra, 2010)**

The WFs of bio-ethanol are a function of crop WFs, product and value fractions, and process water use. Table 2 gives the product and value fractions that determine the WF multiplication ratio. It shows that for the production of bio-ethanol, maize is the most favourable crop with a multiplication ratio of 4.3. Sugar cane is the most unfavourable crop, requiring fifteen times the crop WF to produce bio-ethanol (m<sup>3</sup> per ton). Results for WFs of crops indicate that process water use is almost negligible compared to crop WFs.

Product	Product fraction	Value fraction	WF multiplication ratio
Cane bio-ethanol	0.06	0.89	14.8
Beet bio-ethanol	0.09	0.92	10.2
Maize bio-ethanol	0.15	0.65	4.3

**Table 2: Product fractions, value fractions and WF multiplication ratios for bio-ethanol from sugar cane, sugar beet and maize (Source: Gerbens-Leenes and Hoekstra, 2012)**

Table 3 gives the weighted global average green, blue and grey WFs of bio-ethanol (m<sup>3</sup>/GJ ethanol) from sugar cane, sugar beet and maize (Mekonnen and Hoekstra, 2010), indicating that green WFs increase from sugar beet to sugar cane to maize. Sugar cane requires most blue water per unit of ethanol, however, whereas pollution is greatest in the production of bio-ethanol from maize.

	<b>Green WF</b>	<b>Blue WF</b>	<b>Grey WF</b>
	m <sup>3</sup> /GJ ethanol	m <sup>3</sup> /GJ ethanol	m <sup>3</sup> /GJ ethanol
Sugar beet	31	10	10
Sugar cane	60	25	6
Maize	94	8	19

**Table 3: Weighted global average green, blue and grey WFs of bio-ethanol from sugar cane, sugar beet and maize (Source: Mekonnen and Hoekstra, 2010)**

#### 4.2 Water footprint of biodiesel

Mekonnen and Hoekstra (2010) have calculated the WFs of biodiesel from oilcrops for the main producing countries. For jatropha, Gerbens-Leenes et al. (2009c) and Hoekstra et al. (2009) have calculated green and blue WFs for locations distributed over the *Jatropha curcas* belt (between 300 N and 350 S), including Brazil, Indonesia, Nicaragua, Guatemala and India. For the purposes of this chapter, we adopt the WF estimates of biodiesel from Mekonnen and Hoekstra (2010) and Gerbens-Leenes et al. (2009c). Table 3 (a Source: Gerbens-Leenes et al. 2009c and b Source: Mekonnen and Hoekstra, 2010) gives the green, blue and total WFs of jatropha for five different locations and their average values, of palm oil, rapeseed, sunflower oil and soybean oil for some large producing countries and global weighted average values. The blue WFs of biodiesel from jatropha oil are greatest. The green WFs of biodiesel from rapeseed oil and palm oil are smallest. The Table also shows that differences among locations and averages for countries are large.

When WFs for bio-ethanol are compared to WFs for heat (m<sup>3</sup> per GJ), in general, it is much more favorable to generate heat rather than produce biofuels. Depending on crop type, WFs for heat generation are much lower than bio-ethanol WFs. For example, the WFs of bio-ethanol from cassava are 50 percent higher than the WFs of heat generated from cassava while the WFs of ethanol from barley are four times the WF of heat from barley (Gerbens-Leenes et al., 2009b). However, there are differences in the quality of the energy. Biofuels can be used directly for transportation purposes, for example, while heat is energy of a lower quality. It can be applied for space heating, or needs to be converted into another energy carrier, for example into electricity. In an earlier study, we estimated the WF of bio-electricity from the WF of total crop biomass, including stems and leaves, assuming a maximum efficiency of 59 percent for the conversion of heat into bio-electricity (Gerbens-Leenes et al., 2009a). This means that part of the energy is lost in the conversion process.

		<b>Green WF</b>	<b>Blue WF</b>	<b>Grey WF</b>
		m <sup>3</sup> /GJ oil	m <sup>3</sup> /GJ oil	m <sup>3</sup> /GJ oil
Jatropha oil a	India	575	1116	
	Guatemala	156	174	
	Nicaragua	120	187	
	Indonesia	184	109	
	Brazil	160	91	
	Average	239	335	
Rapeseed oil b	India	141	129	20
	China	118	0	42
	Germany	86	0	21
	Global weighted average	145	20	29
Soybean oil b	United States	250	15	2
	Argentina	335	1	2
	Italy	185	21	0
	Brazil	349	0	2
	Global weighted average	326	11	6
Palm oil b	Philippines	144	0	13
	Thailand	97	0	8
	Indonesia	128	0	9
	Malaysia	117	0	5
	Honduras	102	0	4
	Global weighted average	150	0	6
Sunflower oil b	France	175	2	74
	Germany	227	0	199
	United States	446	16	54
	Global weighted average	428	21	28

**Table 3: Green, blue and grey WFs of jatropha, palm oil, rapeseed, soybean oil and sunflower oil biodiesel for different locations and weighted global averages**

### 4.3 Water Footprints of conventional energy carriers

At present, important energy carriers include fossil energy carriers (petroleum, coal and natural gas), uranium, and electricity from hydropower (IEA, 2006). Promising renewables are solar and wind energy. We also give the blue WFs for these important energy carriers. For petroleum, coal, natural gas and uranium, we derived data from literature (Argonne National Laboratory, 2011; Gleick, 1994). For electricity from hydropower, we estimated the global blue WF by dividing the global evaporation of reservoirs (Shiklomanov, 2000) by the hydroelectric generation (Gleick, 1993) for the year 1990. Next, we compared these results with information on blue WFs of hydropower from Mekonnen and Hoekstra (2012). Table 4 gives an overview of the blue WFs of different energy forms other than bio-energy. Although most data are rather old, they give at least an indication. WFs of petroleum, coal, natural gas, nuclear energy, solar thermal energy and wind electricity generation are all smaller than the WFs of first generation biofuels.

For hydropower, Gerbens-Leenes et al. (2009b) have found an average global blue WF of 22 m<sup>3</sup>/GJ, while Mekonnen and Hoekstra (2012) have arrived at an average value of 68 m<sup>3</sup>/GJ. WF values per unit of generated electricity, however, show enormous variation. For example, the Lubuge power plant in China uses only 0.5 m<sup>3</sup>/GJ of generated electricity. On the other hand, the Akosombo dam and Kpong power plant in Ghana use 850 m<sup>3</sup>/GJ of generated electricity, which is the highest WF for any energy source discussed in this chapter so far. In general, blue WFs of hydropower are much greater than the WFs of other energy sources.

For fossil fuels, it should be noted that the water required over time to grow the vegetation that finally has accumulated and turned into fossil fuel, is excluded from the figures presented. For a fair comparison between the water footprint of bioenergy and fossil fuels, this historically accumulated water consumption, i.e. the green WF, should be accounted for. Another issue is that at present we lack data on water pollution for the conventional energy carriers. This also makes it impossible to make a fair comparison between bioenergy, for which we calculated the grey WFs, and the conventional energy carriers.

	Average blue WF (m <sup>3</sup> /GJ)
Energy carrier	
Petroleum a	0.06-0.14
Coal b	0.2
Natural gas b	0.1
Nuclear energy b	0.1
Solar thermal energy b	0.3
Wind energy b	0.0
Hydropower c,d	0.3–850

**Table 4: Average blue water footprints of different energy carriers (m<sup>3</sup>/GJ)**

**a Source: Argonne National Laboratory, 2011**

**b Source: Gleick (1994)**

**c Source: Gleick (1993) and Shiklomanov (2000)**

**d Source: Mekonnen and Hoekstra (2012)**

## 5. Discussion

In assessing the WFs of bioenergy, the WF of the gross energy output from crops was taken into account. Energy inputs in the production chain, such as energy requirements in the agricultural system (e.g. energy use for the production of fertilizers and pesticides) or the energy use during the industrial biofuel production process were excluded. For high-input agricultural systems, energy input is substantial (Giampietro and Ulgiatti, 2005; Pimentel and Patzek, 2005), so that net energy yields are smaller than presented here. This means that this overview underestimates the WF of bioenergy from agricultural systems with relatively large energy inputs. Future studies should take this aspect into account.

The WFs presented in this chapter are based on rough estimates of freshwater requirements in crop production, in combination with theoretical maximum conversion efficiencies in heat, bio-electricity and biofuel production. The studies have integrated data from several sources, each adding a degree of uncertainty. Meteorological data, for example, are averages over several years rather than data for a specific year and do not reflect annual variations. Calculations of crop water requirements are sensitive to input of climatic data and assumptions concerning the start of the growing season. The data on energy carriers from the literature (Gleick, 1994) give an indication of blue water requirements, but are probably outdated. Therefore, results are indicative. However, the differences among the WFs of different energy carriers are so great that they support general conclusions with respect to relative WFs of different types of bioenergy, crops and countries.

It is worth mentioning that the WF of second generation biofuels will be higher than the WFs of heat generation, because the biomass needs to be converted into biofuel which will have a conversion efficiency of less than 100 percent. How much of the WF of a crop that delivers both food and second-generation energy will be allocated to the energy component, depends on the value of the energy derived from one kilogram of harvested crop relative to the value of food coming from the same kilogram of crop.

Especially the WFs of bioenergy and hydropower are large. A policy relevant question is whether (and to what extent) water should be used for food, fibers or fuel. This is especially relevant in developing countries with increasing populations, such as China and India, where the demand for food will increase. Large biofuel and hydropower programs may need large amounts of water, making it unavailable for food production. Another issue is the sustainability of energy with large water requirements. Whether the WF related to the production of bioenergy and hydropower is sustainable or not depends on two criteria: the geographic context and the characteristics of the production process itself (Hoekstra et al., 2011). A WF is unsustainable when the process is located in a so termed hotspot, a catchment where during a certain period of the year environmental water needs are violated or when pollution exceeds waste assimilation capacity. For example, when ethanol from sugarcane is produced in North India, an area where water stress occurs, this is unsustainable. A WF is also considered unsustainable when the WF of the process can be reduced or avoided altogether. One could argue that allocating water to bioenergy or hydropower with large WFs is unsustainable, because other renewables (e.g. sun and wind) have much smaller WFs. If the choice is made to produce bioenergy, however, the agricultural practices chosen should produce the feedstock in the most water-efficient way. The reduction of green WFs can be achieved by increasing land productivity. Blue WFs can be reduced with more efficient irrigation or by selecting alternative crops. Grey WFs can be reduced by applying fewer chemicals (thanks, for example, to the use of precision agriculture). We have shown the large differences in grey WFs among countries. An example of this is provided by Eastern Europe countries which have relatively large grey WFs indicating an inefficient use of chemicals. Large improvements are possible under such scenarios.

## 6. Conclusions

The blue water footprints of fossil and nuclear energy and renewables like wind and thermal solar energy are much smaller than the blue WFs of hydropower and bioenergy. For hydropower, blue WFs show a large variation, between 0.3 and 850 m<sup>3</sup> per GJ. On average, the blue WF of hydropower lies between 20 and 70 m<sup>3</sup> per GJ.

The most water-efficient way to generate bioenergy is to use total biomass, including parts without a large economic value, and generate heat. The generation of electricity is the second best option. Much research is presently done to develop the so termed second generation biofuels, biofuels generated from biomass waste. When this technique becomes available, large amounts of waste biomass can be converted into second generation biofuels. Also the development of third generation biofuels, biofuels from algae, is an interesting development that might decrease the WFs of biofuels.

When comparing different first generation biofuel practices, in general, it is more water efficient to produce bio-ethanol than biodiesel. The green WF of a typical biodiesel energy crop, rapeseed, is two times larger than the WF of ethanol from sugarcane and four times larger than ethanol from sugar beet. The blue WFs that have a larger environmental impact on water systems show a different pattern, however. For the dominant biofuel feedstocks, the global weighted average blue WFs increase in the following order: palm oil (0 m<sup>3</sup>/GJ), ethanol from maize (8 m<sup>3</sup>/GJ); ethanol from sugar beet (10 m<sup>3</sup>/GJ), soybean oil (11 m<sup>3</sup>/GJ), rapeseed oil (20 m<sup>3</sup>/GJ), sunflower oil (21 m<sup>3</sup>/GJ) and ethanol from sugar cane (25 m<sup>3</sup>/GJ). Water pollution is smallest for soybean and palm oil and for ethanol from sugar cane (6 m<sup>3</sup>/GJ) and largest for rapeseed oil (29 m<sup>3</sup>/GJ).

Our results provide new insights into the impacts of bioenergy on the consumption and pollution of freshwater. This knowledge is a valuable contribution to future research and for policies concerning energy needs, freshwater availability and the choice whether to allocate water to food or to energy production.

## References

- **Argonne National Laboratory**, US Department of Energy, 2011. Consumptive water use in the production of ethanol and petroleum gasoline-2011 update. ANL/ESD/09-1 update.
- **Berg C.**, 2004. World fuel ethanol, Analysis and outlook. Presentation prepared for the Ministry of Economy, Trade and Industry of Japan. [www.meti.go.jp/report/downloadfiles/g30819b40j.pdf](http://www.meti.go.jp/report/downloadfiles/g30819b40j.pdf)
- **Berndes G.**, 2002. Bioenergy and water, the implications of large-scale bioenergy production for water use and supply. *Global Environ Chang.* 12, 253-271.
- **Chiu Y., Walseth B., Suh S.**, 2009. Water embodied in bio-ethanol in the United States. *Environ. Sci. Technol.* 43, 2688-2692.
- **Cullom P.**, 2010. Navy leadership in clean energy. Key note presentation held at the World Algae congress USA 2010, December 6-8, San Francisco, CA.
- **De Fraiture C. Giordano M., Liao Y.**, 2008. Biofuels and implications for agricultural water use: blue impacts of green energy. *Water Policy* 10, Supplement 1, pp. 67-81.
- **De Fraiture C. and Berndes G.**, 2009. Biofuels and water. *Biofuels : Environmental Consequences & Implications of Changing Land Use*. R.W. Howarth and S. Bringezu, editors, 139-152
- **De Miguel Mercader F., Groeneveld M.J., Kersten S.R.A., Venderbosch R.H., Hogendoorn J.A.**, 2010. Pyrolysis oil upgrading by high pressure thermal treatment. *Fuel* 89 (10), 2829-2837.

- **De Wit C.T.**, 1992. Resource efficiency in agriculture. *Agricultural Systems* 40 (1-3), 125-151.
- **Economic Research Service/ USDA**, 2009. [www.ers.usda.gov/data](http://www.ers.usda.gov/data)
- **Falkenmark M.**, 1989 Comparative hydrology – a new concept, in Falkenmark, M., Chapman, T. (Eds.), *Comparative hydrology. An ecological approach to land and water resources.*, Unesco, Paris, France, pp. 10-42.
- **FAO**, 2003. *World agriculture: towards 2015/2030. An FAO perspective.* J. Bruinsma (eds). Earthscan Publications Ltd, London.
- **FAO**, 2006 *Introducing the international Bioenergy Platform.* FAO, Rome, Italy.
- **FAO**, 2011. FAOSTAT, Food and Agriculture Organization. Rome, Italy, <http://faostat.fao.org/default.aspx>.
- **Fischer G., Hiznyik E., Prieler S., Shah M., Van Velthuizen H.**, 2009. Biofuels and food security. International Institute for Applied Systems Analysis, Laxenburg, Austria. Available at <http://www.iiasa.ac.at> (Accessed at 21 June 2010).
- **Gerbens-Leenes P.W., Hoekstra A.Y., Van der Meer Th. H.**, 2009a. The Water footprint of bioenergy and other primary energy carriers. *Ecol. Econ.* 68 (4), 1052-1060.
- **Gerbens-Leenes W., Hoekstra A.Y., Van der Meer Th. H.**, 2009b. The water footprint of bioenergy. *Proc. Natl. Acad. Sci.* 106 (25), 10219-10223.
- **Gerbens-Leenes W., Hoekstra A.Y., Van der Meer T.H.**, 2009c. Reply to Maes et al.: A global estimate of the water footprint of *Jatropha curcas* under limited data availability. *Proc. Natl. Acad. Sci.* (106) 40, E113.
- **Gerbens-Leenes P.W., Hoekstra A.Y.**, 2012. The water footprint of sweeteners and bioethanol. *Environment International*, 40: 202-211.
- **Giampietro M., Ulgiati S.**, 2005. Integrated assessment of large-scale biofuel production. *Crit Rev Plant Sci.* 24(5), 365-384.
- **Gleick P.H.**, 1993. Water and energy. In *Water in crisis. A guide to the world's freshwater resources.*, Oxford University Press, New York, Oxford, pp. 67-79
- **Gleick P.H.**, 1994. Water and energy. *Annu. Rev. Energy Environ.* 19, 267-99.
- **Hoekstra A.Y., Chapagain A.K.**, 2007 Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resour. Manage.* 21, 35-48.
- **Hoekstra A.Y., Chapagain A.K., Aldaya M.M. and Mekonnen M.M.**, 2011. *The Water Footprint Assessment Manual: Setting the Global Standard*, Earthscan, London, UK.
- **Hoekstra A.Y., Gerbens-Leenes W., Van der Meer Th.H.**, 2009. Reply to Jongschaap et al.: The water footprint of *Jatropha curcas* under poor growing conditions. *Proc. Natl. Acad. Sci.* (106) 42, E119.
- **Holmgren I.**, 2009. Creating alternative fuel options for the aviation industry: the role of biofuels. ICAO Workshop on aviation alternative fuels, Montreal, Canada.
- **International Energy Agency (IEA)**, 2006. *World Energy Outlook 2006.* OECD/IEA Paris, France.
- **Jewitt G.P.W., Wen H.W., Kunz R.P., Van Rooyen A.M.**, 2009. Scoping study on water use of crops/trees for biofuels in South Africa. Report to the water research commission. School of bioresources Engineering and environmental hydrology, University of KwaZulu-Natal, Pietermaritzburg, South Africa.
- **Martinelli L.A., Filoso, S.**, 2008. Expansion of sugar cane ethanol expansion in Brazil: environmental and social challenges. *Ecological Applications*, 18, 885-898.
- **Mekonnen M.M. and Hoekstra A.Y.** (2012) The blue water footprint of electricity from hydropower, *Hydrology and Earth System Sciences*, 16(1): 179-187.
- **Mekonnen M.M., Hoekstra A.Y.**, 2010. The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series No. 47, IHE, Delft, The Netherlands.

- **Muller A.J., Schmidhuber J., Hoogeveen P., Steduto**, 2008. Some insights in the effect of growing bioenergy demand on global food security and natural resources. *Water Policy* 10 (S1): 83–94.
- **Oasmaa A, Czernik S.**, 1999. Fuel oil quality of biomass pyrolysis oils-state of the art for the end users. *Energy Fuels* 13, 914–921.
- **Park I., Kim I., Kang, K., Sohn H., Rhee I., Jin I., Jang, H.**, 2010. Cellulose ethanol production from waste newsprint by simultaneous saccharification and fermentation using *Saccharomyces cerevisiae* KNU5377. *Process Biochemistry* 45, 487-492.
- **Pimentel D, Patzek T.W.**, 2005. Ethanol production using corn, switch grass, and wood: biodiesel production using soybean and sunflower. *Natural Resources Research* 14(1), 65-76.
- **Postel S.L., Daily G.C., Ehrlich P.R.**, 1996. Human appropriation of renewable freshwater. *Science* 271, 785-788.
- **Rajagopal D. and Zilberman D.**, 2007. Review of environmental, economic and policy aspects of biofuels, policy research, Working Paper 4341. The World Bank, Washington, D.C., US.
- **Shah T., Burke J., Villholth K.** 2007. Groundwater: a global assessment of scale and significance, Chapter 10. In Molden, D. (eds.). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. Earthscan, London; International Water Management Institute, Colombo..
- **Shiklomanov I.A.** 1997. Assessment of water resources and availability in the world. In *Comprehensive assessment of the freshwater resources of the world*. Stockholm, Stockholm Environment Institute.
- **Shiklomanov I.A.**, 2000. Appraisal and assessment of world water resources. *Water International* 25 (1), 11-32.
- **Simpson T.W., Martinelli L.A., Sharpley A.N., Howarth R.W.**, 2009. Impact of Ethanol Production on Nutrient Cycles and Water Quality: The United States and Brazil as Case Studies. In: *Biofuels: Environmental Consequences & Implications of Changing Land Use* (R.W. Howarth and S. Bringezu, eds), 153-167.
- **Stromberg P.M., Gasparatos A., Lee J.S.H., Garcia-Ulloa J., Koh L.P., Takeuchi K.**, 2010. Impacts of liquid biofuels on ecosystem services and biodiversity. *UNU-IAS Policy Report*. United Nations University, Yokohama, Japan.
- **Tilman D., Cassman K.G., Matson P.A., Naylor R., Polasky S.**, 2002. Agricultural sustainability and intensive production practices. *Nature*, 418: 671-677.
- **UNEP**, 2009. *Towards sustainable production and use of resources: assessing biofuels*. United nations environment programme, Paris, France.
- **Worldwatch Institute**, 2007. *Biofuels for transport. Global potential and implications for sustainable energy and agriculture*. Earthscan, London, Sterling, VA.
- **WWAP**, 2009. *The United Nations World Water Development Report 3: Water in a changing world*. World Water Assessment Programme, UNESCO Publishing, Paris/Earthscan, London.
- **Yang J., Xu M., Zhang X., Hu Q., Sommerfeld M., Chen Y.**, 2010. Life Cycle Analysis on Biodiesel Production from Microalgae: Water Footprint and Nutrients Balance, *Bioresource Technology* 102 (1), 50-56.



# **Agrofuels and water in Argentina**

**A.Anschau<sup>1</sup>, A.Acevedo<sup>2</sup>**

**<sup>1</sup>Instituto de Clima y Agua**

**<sup>2</sup>Instituto de Suelos**

**Centro de Investigación de recursos Naturales**

**Las Cabañas y Los Reseros s/n**

**1712 Castelar, Buenos Aires, Argentina**

## **Abstract**

In order to reflect the level of sustainability in the production or consumption of goods and services of societies, several indicators have been developed over the last years. Among them, the concepts associated with "footprints" have served as a tool for quantifying the level of humankind appropriation of natural resources. The water footprint concept was created to develop an indicator that illustrates the pressure that society exerts on water resources in order to maintain their levels of production and consumption.

Worldwide, the incorporation of renewable energy supply has been undertaken as a way to reduce the different footprints. In this context, Argentina has in place a regulatory framework that aims at incorporating renewable energies to the national grid. National Law 26093 mandates an obligatory mix of ethanol in gasoline and biodiesel in diesel. In 2011, 210000 cubic meters of ethanol from sugarcane feedstock were produced and consumed by the domestic transportation sector. Also, more than 3 million cubic meters of biodiesel from soy oil were produced, of which approximately 1 million cubic meters was internally consumed and more than two thirds were exported.

This investigation is aimed at analyzing the effects of the incorporation of agrofuels to the liquid fuels supply, on the basis of their water footprints and their impact on the water resources available in the country.

## **1. Legislative framework**

In Argentina, the generation and usage of biofuels, as well as management of water resources, have regulatory frameworks that establish limits and scopes. The following is a summary of the main regulations concerning biofuels, water and their interrelationships. In the country, the regulatory framework on biofuels is based on the Law No. 26,093, enacted in April 2006, which regulates the production and sustainable use of biofuels and establishes a regime for its production. It is supplemented with the Law No. 26,334 which establishes the promotion system for bioethanol production. Among the promoting actions, the norm establishes a mandatory cutting consisting of the obligation to mix fossil fuels (diesel oil and gasoil) that are commercialized in the country with biofuels at a rate of 5% or more, measured over the total quantity of the final product. In 2010, the Secretariat of Energy of the Nation established the quotas that the biodiesel producers should have in order to supply the cutting (Resolution

7/10) that was raised to 7% (Resolution 554/10). These resolutions also establish the export quota of the biodiesel producers (Hilbert et al., 2011).

Regarding the protection of water resources, biofuels production enterprises must have an authorization to operate which is granted by the Secretariat of Energy of the Nation. This authorization is only granted when the enterprises fulfill the requirements related to quality of biofuels and sustainable production. In order for this to occur, the project must undergo an environmental impact assessment that includes effluent treatment and waste management. This procedure is performed according to the provincial legislation where the industrial enterprise settles down (Saulino, 2011).

### **1.1 Legislation Concerning Water**

The outlook for the regulation of water resources in Argentina is complex, since it includes legislation at the federal, provincial and municipal levels (Saulino, 2011). To address this complexity, the National Law No. 26,438, enacted in December 2008, created the Federal Water Council (CoHiFe), an inter-jurisdictional agency comprised of the Argentine provinces, the Autonomous City of Buenos Aires and the Nation, where national and provincial water agencies are represented. This organization stands as federal body for consultation and coordination of federal water policy and harmonization of policies, legislation and water management in the respective jurisdictions, respecting the original ownership of water resources that correspond to the provinces (Del Campo, 2009).

Argentina is organized on the basis of a federal system, where the faculties retained by the Provincial Governments are not delegated to the Federal Government. In environmental matters, while the constitutional reform of 1994 gave the nation the authority to issue rules on minimum environmental protection, the provinces had the authority to approve those that were necessary to complement them. Thus, the provinces retain their territorial competition to complement the national legislation on the basis of the particular circumstances of their territory and environmental problems they face, but without being able to provide less protection than the one established by the national standard (Esain, 2008).

In addition, the Constitution recognizes municipalities as political entities, and states that the provinces have the duty to ensure their autonomy and regulate their scope. In many cases, the provinces have delegated responsibility to municipalities for the management of water resources, such as authorization and operation of industrial and commercial establishments, and the prevention and elimination of pollution in watercourses (del Castillo, 2007).

The outlook for the regulation of water resources in Argentina is therefore complex, since it includes legislation at the federal, provincial and municipal levels (Saulino, 2011). To address this complexity, the National Law No. 26,438, enacted in December 2008, created the Federal Water Council (CoHiFe), an inter-jurisdictional agency comprised of the Argentine provinces, the Autonomous City of Buenos Aires and the Nation, where national and provincial water agencies are represented. This organization stands as federal body for consultation and coordination of federal water policy and harmonization of policies, legislation and water management in the respective jurisdictions, respecting the original ownership of water resources that correspond to the provinces (del Campo, 2009).

The National Law No. 25,688 of 2002 establishes minimum environmental assumptions for water preservation and its rational use, which can then be supplemented by provincial and municipal regulations. This rule that regulates the use of water is part of all surface water and groundwater, as well as those contained in aquifers, underground rivers and the atmosphere.

It is necessary to have permission from competent provincial or municipal authority to use the waters mentioned by the law. In the case of inter-jurisdictional watershed, the approval of the

corresponding Watershed Committee will be taken into account if the authorization has a significant environmental impact on other jurisdictions.

Most provincial legislations about water regulate the right to use public water and establish priorities for water usage based on the characteristics of their territories and economic activities (Del Castillo, 2007). Generally, these rules prioritize water for human consumption and favor the most interesting economic activities when water resource supply is limited. In addition, they fix the concession to the payment of a fee and reserve the right to revoke the concession due to public interest or breach of the terms.

## **1.2 Legislation related to biofuels**

Regarding environmental quality standards, the law determines the Secretariat of Environment and Sustainable Development as the implementing authority.

Concerning the production of biofuels, bioethanol production is concentrated in the provinces of NWA, Tucumán (62.6%), Salta and Jujuy (35.9%), whereas the Province Santa Fe concentrates 76% of biodiesel production capacity in the country.

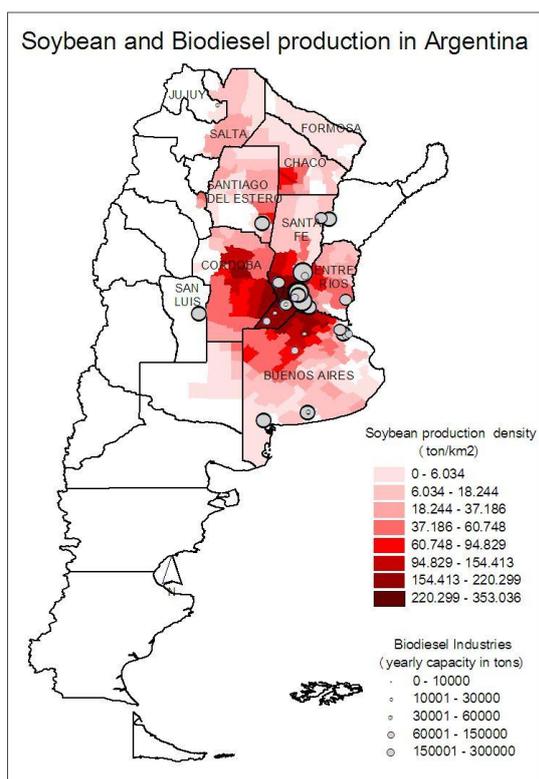
The effluents from sugar/bioethanol production processes stand as one of the major constraints facing the expansion of its production in the province of Tucumán. Even though provincial legislation prohibits the discharge of effluent pollutants to surface water and groundwater, the Sali River basin is facing serious pollution problems. To address this problem, in 2007 the Secretariat of Environment and Sustainable Development signed an Industrial Restructuring Plan with the sugar mills operating in the province of Tucumán (SAyDS, 2007). Based upon this plan, the sugar companies and distilleries were committed to discharge zero quantity of filter cake and vinasse to the Sali River. Four years later, five mills signed a new agreement under the aforementioned Industrial Restructuring Plan, which allowed them to access funding in order to improve their facilities for better environmental performance (SAyDS, 2011). The agreement also states that the companies will avoid all possible overturning of vinasse, which may be used for fertirrigation or disposal in saline lands with potential subsequent recovery (MSAL, 2011).

## **3. Agrofuels production in Argentina**

### **3.1 Soybean and biodiesel production**

Transesterification of soybean oil is the main source of Argentine biodiesel production. While soybean production is concentrated in the Pampa provinces (Buenos Aires, Santa Fe and Córdoba), its industrialization is closely related to the distribution of the mill/oil factories that are concentrated in the provinces of Santa Fe (50%) and Buenos Aires (29%) . The 21% remaining is distributed among the provinces of San Luis, Neuquén, Entre Ríos and Santiago del Estero.

In 2011, the Argentine Chamber of Renewable Energies reported that biodiesel consumption in the country reached a volume of 1 million cubic meters (CADER, 2011). This occurred in Argentina just one year after entering into force Law 26,093. Even though the law establishes that from 2010 onwards the diesel should be mixed with 5% of biodiesel, this mandatory mixture had an enlargement up to 7% (B7) of biodiesel, and it is expected to increase until 10% (B10). In 2011, the installed capacity exceeded 3 million tons (Hilbert et al., 2011).

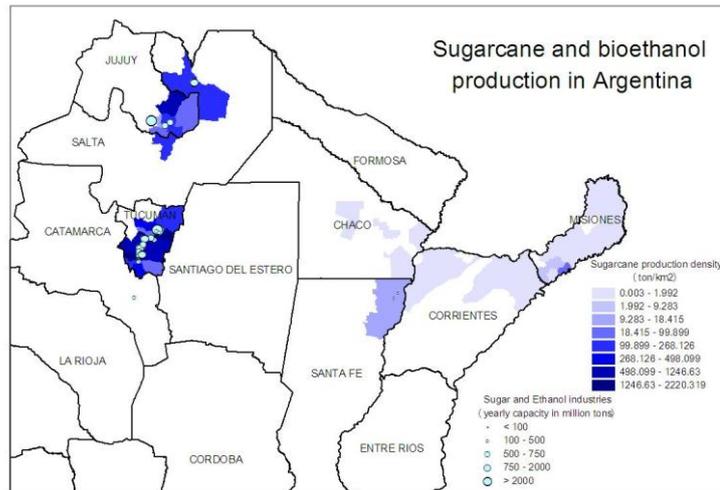


**Figure 1: Soybean production and Biodiesel industries in Argentina**

### 3.2 Sugar cane and bioethanol production

Bioethanol production is concentrated in the northwest of Argentina (NWA), a region of historical development of the sugar industry. Three provinces are responsible of 98.5% of the national production of sugar, i.e., Tucumán (62.6%), Jujuy (24.7%), and Salta (11.2%) (EEAOC, 2011). Even though 23 sugar mills are spread in the national territory, 20 are situated in the NWA, and 15 out of these 20 are located in Tucumán. Moreover, 16 out of the 20 sugar mills distributed in the NWA are distilleries as well, and 10 out of these 16 are able to manufacture anhydrous alcohol. In 2009, 2 distilleries manufactured 2.1 million tons of bioethanol, but the production dramatically increased next year with the incorporation of 6 distilleries more. In 2011, the Secretary of Energy established a quota of 170,000 tons.

Currently, several northeastern provinces of Argentina (NEA) have joined the traditionally producing sugar cane provinces with the intention to develop this activity. In this respect, in November 2011 the province of Chaco signed a project agreement for the establishment of 50,000 hectares of sugar cane to be used for the production of bioethanol. Formosa also seeks to establish this crop for energy purposes. As for 2012, three distilleries situated in the provinces of Chaco, Córdoba, and Santa Fe, have predicted to produce bioethanol from grains. Last year, the national production of bioethanol did not cover the mandatory quota established by law, and the mixing ratio almost reached 3%.



**Figure 2: Sugarcane production and sugar and ethanol industries in Argentina**

#### 4. Irrigation in Agriculture and Bioenergy

The national area under irrigation over the last 25 years averaged 1.5 million hectares, representing 5% of the total cultivated area in the country. This percentage is far from being evenly spread throughout the country because 99% of the cultivated area in the provinces of Cuyo (Mendoza and San Juan) is under irrigation, whereas in Entre Rios, Formosa, Chaco, Santa Fe, Buenos Aires and Córdoba, the relationship varies between 1 and 2%. Middle term situations are observed in La Rioja, Jujuy and Río Negro, where the ratio is about 60%, and in Catamarca, Neuquén and Santa Cruz where the irrigated area is close to 40% of all the cultivated land (IICA, 2010).

There is a wide range of irrigated crops in Argentina. Among the most representative crops, fruits account for 31%, cereals for 22%, industrial crops (includes sugar cane) for 10% and oilseeds for 7%. These data originate from the last National Agricultural Census (INDEC-CNA, 2002), and although no updated official data are available, estimates of reliable organisations indicate that the total irrigated area could have reached 1.8 million hectares in 2008 (Table 1) and show an increasing tendency nowadays. This growth in the total irrigated area may be attributed to fruit crops, and to a lesser extent, to the expansion of soybean area outside the nucleus Pampa (Prieto, personal communication).

1986 (a)	1988 (b)	1990 (c)	1995 (d)	2002 (e)	2008 (f)
1.532.188	1.246.748	1.760.000	1.347.070	1.355.241	1.800.000

**Table 1: Trends in agricultural land under irrigation in Argentina.**

(Source: (a) INTA, 1986; (b) INDEC-CNA, 1988; (c) FAO, 1990; (d) PROSAP, 1995; (e) INDEC-CNA, 2002; (f) INTA-PROSAP, estimates)

The soybean area under irrigation is about 90,000 hectares (INDEC-CNA, 2002), representing 0.5% of the nearly 1.9 million hectares sown in the last campaign (SIIA, 2012), and the final destination of the grains is geared to the production of seeds (Carballo, personal communication).

Sugar cane is a very water efficient crop yielding 2.0-2.7g dry matter and 0.6-1.0 g of sugar per kg of consumed water (Romero et al, 2009). The irrigated area in the producing provinces

reaches 91,000 hectares (INDEC-CDA, 2002), representing 25% of the national sugarcane area (SIIA, 2012). In the case of Tucumán, the irrigated sugar cane area covers 25-30% of the area cultivated with this crop; thus, a majority of the sugarcane grows under non-irrigated conditions. This area varies from year to year depending on rainfall characteristics and water availability, which is usually low. Not only this information reveals that irrigation is not integrated into the production system but it also shows that most sugar cane producers turn to irrigation when water deficit is critical. Consequently, each year the yield is as variable depending on the rainfall (Romero et al, 2009).

## **5. Water Footprint of Agrofuels in Argentina.**

The water footprint (WF) of a product is the volume of freshwater used to produce the product, measured over the fully supply chain (Hoekstra et al, 2011). In other words, in addition to the water that the product (in this case, agrofuels) itself contains, there is a much larger volume of water associated with its production process.

The terms virtual water and WF also give an indication of the (virtual) water transfers among countries or regions. This indicates that the product or service generates a WF in the country of origin that corresponds to a virtual water transfer from the country that exports the product to the country that imports it.

The calculation of the WF of an agricultural product takes into account the effective precipitation (green WF) and the surface and groundwater provided by supplemental watering for the production of a crop (blue WF). No losses are taken into account in irrigation since it is assumed that water somehow returns to the source and it is available for reuse. The calculation also considers the amount of water needed to assimilate the pollutants, e.g. pollutants provided by the usage of agrochemicals generating a grey WF.

### **5.1 Water Footprint of Soybean Biodiesel**

In Argentina, the WF of soybean biodiesel (Table 2) was calculated as described by Civit et al., (2011) considering the complete set of tasks of the agricultural stage necessary for obtaining the crop, and the industrial processes that involve grain drying, vegetable oil extraction and biodiesel production. Two different agro-productive systems were analyzed: (1) no-till farming of soybean under supplementary irrigation in the south of Córdoba, and (2) no-till farming of soybean under non-irrigated conditions in the central region of Córdoba. The investigation was performed along three years that exhibited different climatic conditions: year 2002 (wet period), year 2003 (dry period) and year 2009 (average).

Soybean	Period	Blue WF	Green WF	Grey WF	Total WF
Irrigated	Wet (2002)	1.702	2.783	753	5.239
	Dry (2003)	2.904	2.005	753	5.662
	Average (2009)	2.293	2.358	753	5.405
Non irrigated	Wet (2002)	0,23	3.923	856	4.779
	Dry (2003)	0,23	3.702	856	4.558
	Average (2009)	0,23	3.846	856	4.702

**Table 2: Water footprint (WF) of soybean biodiesel production (m<sup>3</sup>/ton). (Source Civit et al., 2011)**

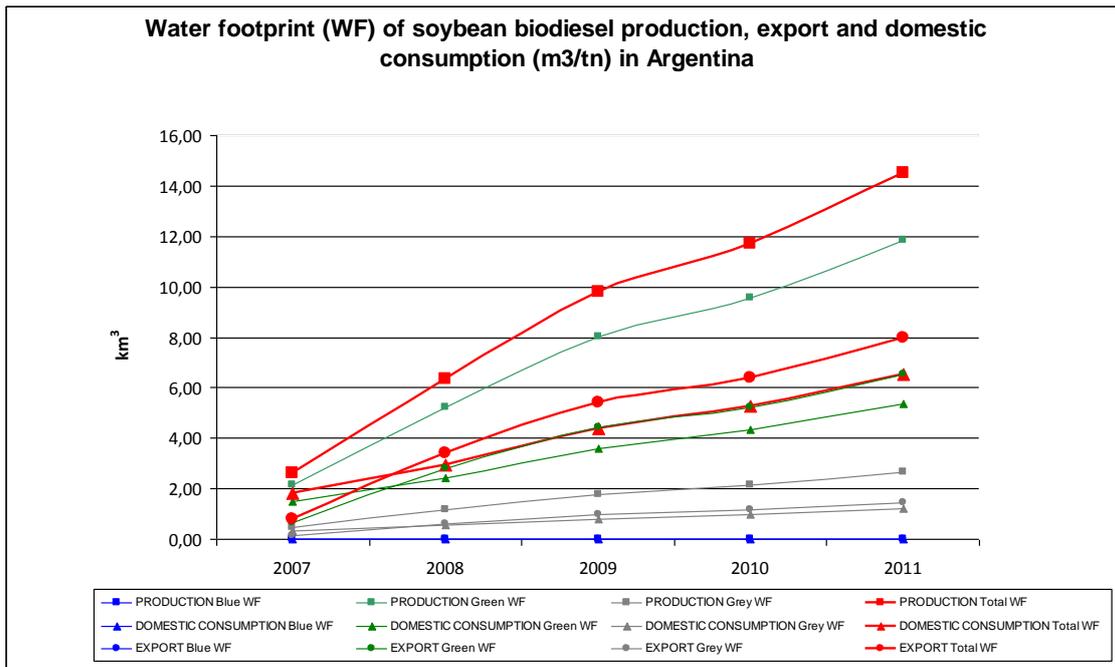
The growth rate of the biodiesel industry in Argentina has been dramatically high throughout the last five years. Table 3 shows that the production of biodiesel in 2007 was 560,000 tons, increasing fivefold to 3 million tons in 2011 (Hilbert et al., 2011).

Year	Installed capacity of biodiesel production* (tons / year)	Domestic consumption** (tons / year)	Biodiesel exports*** (tons / year)
2007	560.000	391.635	168.365
2008	1.353.500	628.708	724.792
2009	2.087.100	937.437	1.149.663
2010	2.487.000	1.123.493	1.363.507
2011	3.084.000	1.391.109	1.692.891

**Table 1: Installed capacity, domestic consumption and exports of biodiesel, Argentina, 2007-2011.(Sources: \*INTA, 2012; \*\*Secretary of Energy; \*\*\*CADER, 2012)**

Interestingly, biodiesel production supplied an emerging domestic market in 2007. However, due to the application of different withholdings to soybean, almost 35% to grains and 20% to biodiesel, in 2008 the export volumes started to exceed the domestic consumption and the country became the largest exporter of biodiesel.

The aforementioned data not only contribute to calculate the WF of the production, the consumption and export of soybean biodiesel in Argentina, but they also show the changes over the past five years. Figure 1 shows the development of the WF of soybean production, export and domestic consumption in Argentina between 2007 and 2011. The Figure clearly shows the increasing trends.



**Figure 3: Water footprint of soybean production, export and domestic consumption in Argentina, 2007-2011**

## 5.2 Water Footprint of Sugar Cane Bioethanol

Since sugar cane is predominantly cultivated in Tucumán, Jujuy, and Salta, Mekonnen and Hoekstra (2010) calculated the WF related to sugar cane bioethanol production for three Argentine provinces, Tucumán, Jujuy and Salta (Table 4). The blue WF in Jujuy is more than five-fold the blue WF value estimated for Tucumán, whereas the green WF for Tucumán is twice the green WF value estimated in Jujuy. However, the total WF values are fairly similar for the three provinces (Table 4).

Province	Blue WF	Green WF	Gray WF	Total WF
Tucumán	117	1.047	83	1.247
Jujuy	613	546	55	1.214
Salta	451	800	79	1.330

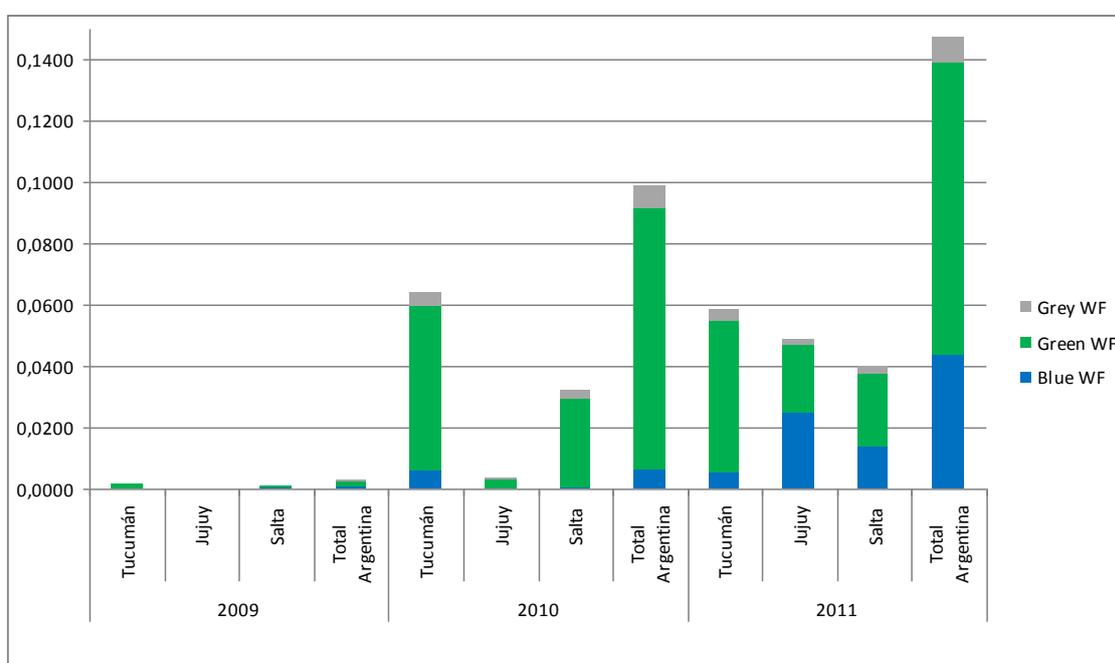
**Table 2: Water footprint (WF) of bioethanol production from sugar cane ( $m^3/m^3$ ). (Source Hoekstra and Mekonnen, 2010)**

Bioethanol from sugar cane was initially produced in the country in the 1080's, with the program named "Alco-nafta". However, it was discontinued and it was not until 2009 that bioethanol production from sugar cane started primarily in Tucumán because it was the province where sugarcane was traditionally cultivated. Later on, distilleries settled in Jujuy and Salta promoted the establishment of the crop in those areas. This promising scenario was responsible for the significant increase of bioethanol production in the past three years (Table 5).

Year	Tucumán	Jujuy	Salta	Total Argentina
2009	1.201		914	2.115
2010	51.349	5.379	36.040	92.769
2011	47.044	40.334	30.090	117.468

**Table 3: Bioethanol delivered to oil companies in the period 2009-2011 (tons / year). (Source Chamber of Alcohols)**

The aforementioned data not only contributed to the estimation of the WF of bioethanol production from sugar cane in Tucumán, Jujuy, and Salta, but also showed the evolution over the past five years (Figure 2). Initially, the province of Tucumán led the bioethanol production from sugar cane that was grown almost entirely under non-irrigated conditions. Nevertheless, after the sequential establishment of distilleries in Salta (2010) and Jujuy (2011), the ratio between blue and green WF changed dramatically at the national level (Figure 2).



**Figure 4: Water footprint of the production and consumption of bioethanol from sugar cane in Argentina (2009-2011)**

## 6. Analysis of Sustainability

To understand the impact of agrofuels production from two major commodities (soybean and sugar cane), it is necessary to compare the volumes of water consumed to produce them with the availability of renewable water resources of the country, or watershed in which they are produced.

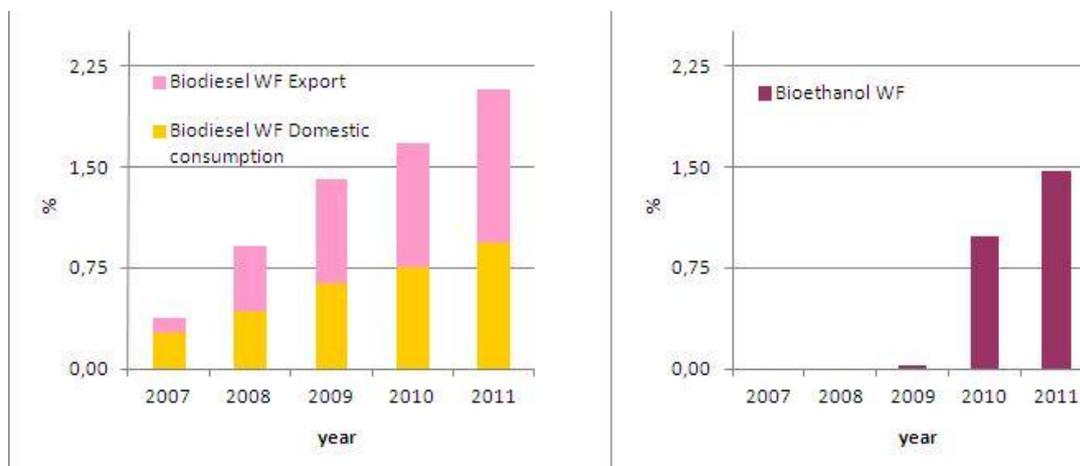
In Argentina, surface water resources have an average flow of 26,000 m<sup>3</sup>/s (815 km<sup>3</sup>/year). However, this average is not representative of the real spatial and temporal distribution of water resources, since 85% of these resources correspond to the Platine basin (30% of the territory and 22,000 m<sup>3</sup>/s), whereas basins of arid and semiarid areas have less than 1% of the

entire surface water resources (11% of the territory and 223 m<sup>3</sup>/s) (Table 6). In other words, over 75% of the country has arid and semiarid conditions, and there are extensive regions where water availability is below the water stress index (1,000 m<sup>3</sup>/year/capita) published by the UNDP (INA, 2006).

Basin	Surface water resources	%
Platine	699,41	86
Center	5,87	0,7
Cuyo/NWA	10,06	1,2
Colorado/Negro	34,53	4,2
Patagonia	26,68	3,3
Pacific slope	38,22	4,7
Total	814,76	100

**Table 4: Surface water resources (km<sup>3</sup>/year) by basin.**  
(Source: INA, 2006)

The WF of biodiesel production from soybean, which is mostly produced in the River Plate Basin, has been steadily increasing throughout the past 5 years (Figure 3). In 2007, it represented 0.4 % of the renewable water resources of the basin and overcame the 2% last year. Similarly, the WF of bioethanol shows an increasing tendency, since in 2009 it barely represented 0.03% of the annual flow of the basins from the sugarcane producing region (NWA) and in 2011 it almost reached 1,5% (Figure 3).



**Figure 5: Relationship between water footprint (WF) of agrofuels and renewable water resources**

Assuming that the volume of water consumed for domestic purposes by the population of Argentina was 4.7 km<sup>3</sup> (Hoekstra and Chapagain, 2004), it is interesting to note that biodiesel exports accounted for 8 km<sup>3</sup> of water in 2011, which is almost twice the national domestic consumption of water.

## 7. Perspectives for bioethanol

Sugar cane stands as the main source of raw material for bioethanol production in Argentina, and its cultivated area is concentrated in Tucumán, and to a minor extent in Jujuy and Salta. Presently, there is a demand focused on the expansion of the cultivated area to the North West (NWA) and North East of Argentina (NEA) for bioethanol production purposes. However, the fact that current sugar cane cultivars have poor performance in the regions of potential expansion has moved researchers from the Agricultural Experimental Station Famaillá, (Tucumán, INTA) to start developing cultivars for bioethanol production more suitable for the NWA and NEA regions.

The aforementioned demand has also been addressed by sugary sorghum breeders from the EEA Manfredi, Córdoba, INTA, since the species is characterized by high sugar content and low lignin stem and grain production. In addition, its wide adaptability to different environments and climates is underscored by the fact that it grows faster and is more water efficient than sugarcane.

Researchers at the Obispo Colombes Experimental Station (EEOC), Tucumán, have calculated an energy balance of 5-8 for sugary sorghum (Romero et al, 2012). Because sugary sorghum bioethanol system shows a highly positive energy balance and the species may grow in non-traditionally producing sugarcane areas, it may supplement sugarcane production during downtime processing distillery mills.

The construction of two new bioethanol production factories in Córdoba is in progress. This situation has driven maize breeders from the Pergamino Agricultural Experimental Station (INTA Buenos Aires) and producers to test maize hybrids for bioethanol generation. Preliminary results reveal a yield of 484 liters of bioethanol per ton of maize.

The Institute of AgroBiotechnology of Rosario (INDEAR) and Fiscal Petroleum Reservoir (YPF) have subscribed to an agreement to develop technological solutions for production of second-generation bioethanol. This type of bioethanol differs from the first-generation one, in that it is obtained from the conversion of fermentable sugars from the lignocellulose of agri-forest waste. The agreement foresees the creation of a platform for the production of cellulolytic enzymes based on an agricultural crop designed specifically for this purpose. YPF, the main energy company in the country, will provide its expertise for the characterization of the product and the selection of the technologies for industrial scaling up.

## References

- **CADER**, 2011, Cámara Argentina de Energías Renovables. Estado de la industria argentina de biodiesel. Reporte Cuarto Trimestre 2010. Buenos Aires, Argentina.
- **Cámara de Alcoholes**. Estadísticas 2009-2011, <http://www.camaradealcoholes.org.ar>.
- **Civit B., Arena P., Piastrellini R., Curadelli S, Silva Colomer J.**, 2011, Comparación entre la huella hídrica de biodiesel obtenido a partir de aceite de colza y aceite de soja. AVERMA (Avances en Energías Renovables y Medio Ambiente) Vol. 15.
- **Del Campo C.**, 2009, El agua ya tiene su organismo federal, Hydria 22 (5), Editorial Proxar, Buenos Aires, Argentina.
- **Del Castillo L.**, 2007, La gestión del Agua en Argentina. Buenos Aires, Ediciones Ciudad Argentina. 425 pp.
- **EEOC**, 2011, Estación Experimental Agroindustrial Obispo Colombes, Boletín N° 52, Reporte Agroindustrial, Estadísticas y márgenes de cultivos tucumanos, Tucumán, Argentina. Junio de 2011. 9 pp.
- **Esain J.A.**, 2008, Competencias Ambientales, Buenos Aires, Argentina, Editorial Abeledo Perrot, 898 pp.

- **Hilbert J., Sbarra R., López Amorós M.**, 2011, Soy Market and Derivates—Context and Recent Evolution, Buenos Aires, Argentina. Ediciones INTA, 141 pp. ISBN 978-987-679-051-2
- **Hoekstra A., Chapagain A., Aldaya M & Mekonnen M.**, 2011, The Water Footprint Assessment Manual, Setting the Global Standard, Water Footprint Network. Earthscan London, UK. 228 pp.
- **Hoekstra A., Chapagain A.**, 2004, Water footprints of nations, Volume 2: Appendices, Value of Water Research Report Series N° 16. UNESCO-IHE. Institute for Water Education.
- **IICA**, 2010, Instituto Interamericano de Cooperación para la Agricultura. El riego en los países del Cono Sur. Montevideo. Uruguay. 112 pp.
- **INA**, 2006, Instituto Nacional del Agua. Subsecretaría de Recursos Hídricos de la Nación. Bases para un plan nacional de recursos hídricos de la República Argentina. Septiembre de 2006
- **INDEC-CNA**, Instituto Nacional de Estadísticas y Censos, Censo Nacional Agropecuario 2002, Buenos Aires.
- **INDEC-CNA**, 2002, Instituto Nacional de Estadísticas y Censos, Censo Nacional Agropecuario 2002, Buenos Aires.
- **MSal**, 2011, Avanza la reconversión industrial de empresas azucareras en la Cuenca Salí Dulce, Ministerio de Salud de la República Argentina.
- **Romero R., Digonzelli P., Scandaliaris J.**, 2009, Manual del cañero. 1° edición. . Estación Experimental Agroindustrial Obispo Colombres Las Talilas. Tucumán. Argentina. 232 pp.
- **Saulino F.**, 2011, Implicaciones del desarrollo de los biocombustibles para la gestión y el aprovechamiento del agua, Santiago de Chile, CEPAL (Comisión Económica para América Latina y el Caribe), 67 pp.
- **SAyDS**, 2007, Cuenca Salí Dulce. Componente Industria. Síntesis de lo actuado. Dirección Nacional de Gestión del Desarrollo Sustentable. Secretaría de Ambiente y Desarrollo Sustentable de la Nación.
- **SAyDS**, 2011, Ingenios tucumanos firman convenio para cuidado de medio ambiente. Coordinación de Prensa y Difusión. Secretaría de Ambiente y Desarrollo Sustentable de la Nación. 3 de octubre de 2011.
- **SIIA**, 2012, Sistema Integrado de Información Agropecuaria. Estimaciones Agrícolas, MAGyP, por Departamento. Ministerio de Agricultura, Ganadería y Pesca. <http://www.sii.gov.ar/index.php/series-por-tema/agricultura>

## Abbreviations

CADER	Argentine Chamber of Renewable Energies
CAN	Censo Nacional Agropecuario
EEAOC	Estación Experimental Agroindustrial Obispo Colombres
IICA	Instituto Interamericano de Cooperación para la Agricultura
INA	Instituto Nacional del Agua
INDEAR	Institute of AgroBiotechnology
INDEC	Instituto Nacional de Estadísticas y Censos
INTA	Instituto Nacional de Tecnología Agropecuaria
NEA	North East of Argentina
NWA	North West of Argentina
SIIA	Sistema Integrado de Información Agropecuario
UNDP	United Nations Development Programme
YPF	Fiscal Petroleum Reservoir
WF	Water Footprint

# Bioenergy and water: Brazilian sugarcane ethanol

Fábio Vale Scarpere

Brazilian Bioethanol Science and Technology Laboratory (CTBE/CNPENM)

Caixa Postal 6192, 13083-970 Campinas, São Paulo, Brazil.

## Abstract

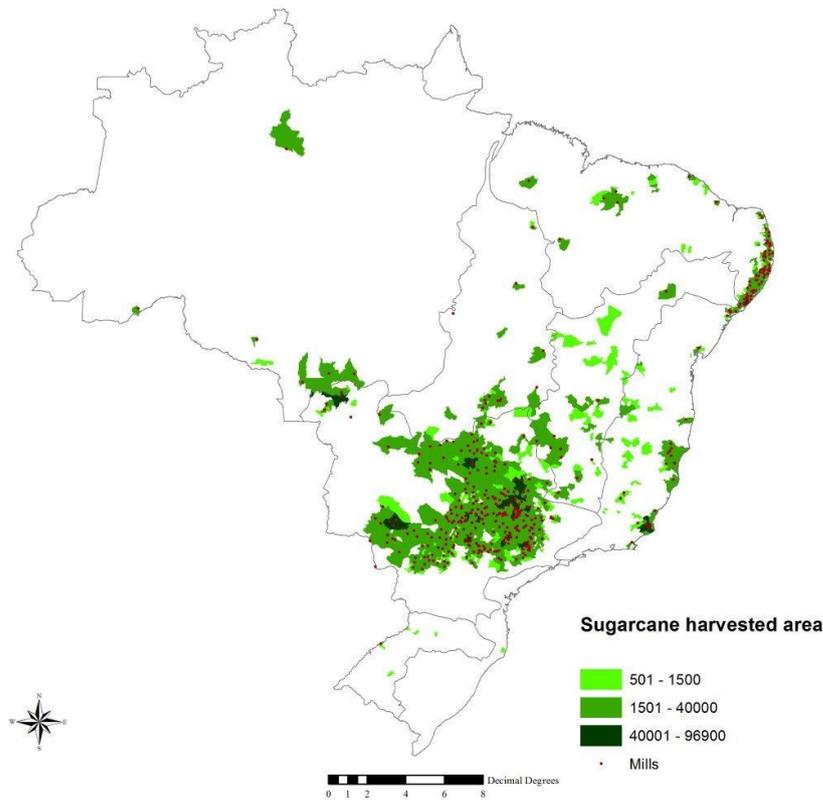
The aim of this paper is to give an overview of Brazilian biofuel programs evolution, specially, regard to sugarcane ethanol water use since sugarcane is nearly the exclusive feedstock source for it. Although the Brazil has several advantages due to its large territory, geographical position, solar radiation and abundant water resources, the processing and converting of sugarcane to ethanol requires large amounts of water. Due to the increasing demand for ethanol and the high prices, sugarcane is expanding to the Cerrado regions (savannahs), where irrigation would be needed to complement successive dry spell. Indeed, in recent years the irrigation potential has expanded substantially, following recent advances in soil management and irrigation techniques applicable in that region. During industrial processes, several improvements have been made indicating that the sugarcane industry effectively minimizes water use, both through rationalization and as the implementation of lower water demand technologies.

## 1. Introduction

Brazilian fresh water availability has been estimated in  $5,660 \text{ km}^3 \text{ year}^{-1}$ , approximately 12% of the world's total due to its privileged location both on the surface and in water tables (Asad et al., 1999). The surface fresh water (rivers and lakes) covers  $50,000 \text{ km}^2$ , whereas the main water table, the Guarani Aquifer, extends over 1.2 million  $\text{km}^2$ , 70% of which is in Centre-West and South of Brazil. This aquifer stores approximately  $40,000 \text{ km}^3$  of water, which is equivalent to the world's total annual runoff (Macedo, 2005). In 2000, the water withdrawals for consumptive uses totaled  $1,592 \text{ m}^3 \text{ s}^{-1}$ , being about 53% of this total ( $841 \text{ m}^3 \text{ s}^{-1}$ ) actually consumed and with  $751 \text{ m}^3 \text{ s}^{-1}$  returning to the watershed (Borsoi & Torres, 1997). However, due to the naturally uneven distribution of these resources, combined with rapid population growth and industrialization, conflicts over water use have been intensified (Asad et al., 1999).

Regarding biofuels production, Brazil has several advantages due to its large territory, geographical position, solar radiation and abundant water resources. Since the implementation of the Brazilian National Alcohol Program (the start of the Brazilian ethanol program), the sugarcane production increased from 80 million Mg in 1970 to 734 million Mg in 2011, while the harvested area increased from 1.7 to 9.6 million hectares (IBGE, 2006). Concomitantly by sugarcane land cover expansion, sugarcane yield also increased dramatically from  $46 \text{ Mg ha}^{-1}$  in 1970 to  $83 \text{ Mg ha}^{-1}$  in 2010 (IPEADATA, 2013). This increase in productivity,  $\sim 930 \text{ kg ha}^{-1} \text{ year}^{-1}$ , was due to better agricultural techniques and an important genetic breeding program promoted both by the Brazilian Government and by the private sector, particularly in the 1970s and 1980s (Walter et al., 2013). Nowadays, Brazil is the largest world cane producer and the main exporter of fuel ethanol. In 2011, Brazil exported approximately 2 billion liters but surpassed 5 billion liters in 2008 (Walter et al., 2013). In this context, the aim of this chapter is to give an overview of Brazilian biofuel programs evolution, specially, regard to sugarcane ethanol water use along last century till now. Thus, the review attempts to answer the research question: Is Brazilian biofuel production sustainable?

Sugarcane geographic distribution and hence, plant locations are concentrated in two main regions: the North-Northeast, where the cane harvest extends from September to March, and the Central-South, where harvests occur from April to November (Figure 1). The largest national producer, São Paulo State contributes with more than 50%, which is equivalent to 80% of India's production, and it also represents an output larger than the four other major world producers combined: China, Thailand, Pakistan and Mexico (Rudorff et al., 2010).



**Figure 1: Sugarcane harvest area distribution on the main Brazilian river basins**

The Paraná River basin, situated in the Brazilian Central-South, is the most industrialized and urbanized region of the country. With 88 million hectares, it concentrates more than 85% of the total sugarcane production (CONAB, 2012). Furthermore, this region is where sugarcane expansion is occurring in order to meet the domestic increasing demand for ethanol due to a recent and substantial increase of the flex-fuel vehicles (FFV) fleet.

Studies based on satellite images covering the Central-South region show that between 2000 and 2010 sugarcane expansion occurred mostly over pastures (70%), followed by annual crops (25%), citrus (1.3%), forest (0.6%) and sugarcane land under crop rotation (3.4%) (Adami et al., 2012). The land use change alters the water balance by affecting the infiltration, runoff and also evapotranspiration (ET). It should also be noted that the ET is generally lower in cropland compared to grassland or natural vegetation, but this impact can be compensated by runoff increase (Smeets et al., 2008).

Aiming to establish a sustainable sugarcane expansion and investments in the biofuel sector, the Brazilian Government has recently conducted a study resulting in the Sugarcane Agro-Ecological Zoning, launched in 2009, which considers environmental, economic, and social aspects. The eleven areas not considered suitable for sugarcane cropping were: (1) Lands with slopes greater than 12% (due to unburned cane mechanical harvest); (2) Areas with native vegetation; (3) Amazon and Pantanal biomes; (4) Environmental protection areas; (5) Indigenous lands; (6) Forest remnants; (7) Dunes; (8) Mangroves; (9) Cliffs and rock outcrops; (10) Reforestation and (11) Urban and Mining areas.

Land estimations show that Brazil has about 65 million ha of suitable areas for sugarcane expansion, out of which 19.3 million ha were considered with high yield potential, 41.2 million ha as medium and 4.3 million as a low cultivation potential.

## 2. Brazilian biofuel programs

The economic crises that struck along last century afforded the Brazilian production of liquid biofuel to enlarge its share in the energy matrix for the purposes of improving energy security, fostering rural development and climate change mitigation. Brazil's governmental interest for ethanol began in the early 20<sup>th</sup> century due to the surplus of sugar and to the heavy burden of gasoline imports on the economy. In the 1970s, oil prices reached high records, doubling Brazil's oil import payments. The impact of the oil shock on the balance of payments and on the inflation motivated the launch in November 1975 of the National Alcohol Program (Programa Nacional do Álcool – ProÁlcool) (Nass et al., 2007; Walter et al., 2013). However, in 1988, the ProÁlcool program was officially extinct, mainly because the ethanol production was still expensive and the subsidies required a burden for the government (Nass et al., 2007; BNDES, 2008). In the early 2000s, oil prices began to raise, making ethanol production once again marginally profitable and competitive vis-à-vis gasoline prices. In 2003, the FFV were launched (in Brazil, they are able to run with any fuel mix between gasohol - 18 to 25% ethanol, volume basis - and pure hydrated ethanol - 100%) and since then have been the main driving force of the domestic consumption. Nowadays, all car manufacturers in Brazil have at least one FFV model, and there are more than 100 models available on the national market. FFV represents more than 90% of the new cars sold (Walter et al., 2013). Today, both anhydrous and hydrated ethanols are produced in large quantities. Hydrated ethanol is used directly in FFV cars, whereas anhydrous ethanol can be used to produce gasohol. Ethanol production (anhydrous and hydrated) rose from 14.8 million cubic meters in the 2003/2004 season to 22.7 million cubic meters in the 2011/2012 season (UNICADATA, 2013).

Another Brazilian biofuel program is the National Program of Biodiesel Production and Use (PNPB). Launched in 2004, the PNPB has created considerable national demand for biodiesel, stimulating the Brazilian production from different oleaginous plants (oil seeds), aiming at promoting social inclusion through the generation of income for small producers. The PNPB defined biodiesel as an alkyl esters of vegetable oils or animal fat and established the target of 2% of biodiesel in blends with fossil diesel in 2008 (volume basis) and 5% in 2013 (Nass et al., 2007). The 5% target was anticipated due to the large growth of biodiesel production.

In principle, the oilseed crops for biodiesel include a variety of crops grown in different regions of Brazil. Crops include *Glycine max* (soybean), *Helianthus annuus* (sunflower), *Gossypium hirsutum* (cotton), *Ricinus communis* (castor bean), and *Brassica* spp. (colza) in the South, Southeast, and Central regions; *Elaeis guineensis* (African palm), *Attalea speciosa* (babassu), soybean, and castor bean in the Northeast and North regions (Nass et al., 2007). However, soybean is currently the single-largest source for biodiesel production (77%) followed by animal tallow (16%) and cotton seed (4%) (ANP, 2013).

At present, biodiesel production remains regulated by the government. In 2011, the production was 2.7 billion liters. For 2013, the total Brazilian biodiesel production is forecasted at 2.8 billion liters, assuming that the mandatory biodiesel mixture remains unchanged at five percent (ANP, 2013).

Comparing the ethanol and biodiesel programs, it is clear that early ethanol production in Brazil was driven primarily by economic factors, whereas biodiesel production involved at least three driving forces: (i) *economic*, by the influence of oil prices; (ii) *social*, by the need to generate jobs and new opportunities for permanent settlement of families in the countryside

and (iii) *environmental*, by the production of a sustainable, renewable and friendly fuel (Nass et al., 2007).

### 3. Sugarcane as a biofuel feedstock

Renewable energy sources account for over 44% of the energy matrix in Brazil. The sugarcane industry plays a key role, since it was responsible for 16% of the entire primary energy supply in 2011 (UNICADATA, 2013). Bioethanol may be produced based on any biomass that contains significant amounts of sugar or starch, derived from corn, wheat or other cereal grains. Sugar-based bioethanol production from sugarcane and sugar beet is a simple process and requires one step less than the production of starch-bioethanol, since sugars are already present in the biomass (BNDES, 2008). Therefore, this additional stage for starch-bioethanol production reduces the yield of the process and increases production costs. For example, whilst the USA spends 1 unit of equivalent fossil fuel energy to generate 1.3 ethanol energy units, in Brazil, the same unit of fossil energy produces around 8 sugarcane ethanol energy units (CTBE, 2013).

In Brazil, sugarcane is nearly the exclusive feedstock source for bioethanol production. Moreover, this crop is also an excellent energy feedstock due to its high primary energy content per Mg of cane. Based on the average Brazilian cane quality with 70% moisture content, the higher heating value of the whole sugarcane, including 140 kg of straw (dry basis), is 7.4 GJ per Mg of cane stalks. The products providing energy, ethanol and bagasse, however, give only 2.2 GJ Mg<sup>-1</sup> or less than 30% of the primary energy (Leal, 2007). Bagasse, the industrial fibrous residue from the juice extraction, is completely consumed in the mill boilers to provide energy for the mill. The boilers supply enough electricity and steam for the process to be self sufficient. In some cases, electricity can even be delivered to the grid. The fiber in the sugarcane leaves and tops (straw, also termed trash) is normally burned in the pre-harvest (Leal et al., 2013). However, due to environmental and economic reasons, there are on-going programs to phase out the burning, with the gradual replacement of the manual harvest with burning by unburned mechanized harvest; this action is motivated by a Federal law and Environmental Protocols already in progress in São Paulo and the Minas Gerais States that accelerates the law time schedule.

The unburned cane harvest, also known as green cane management, includes a large deposition of straw on the soil after each harvest (Figure 2), ranging from 10 to 20 Mg of dry matter per ha (Walter et al., 2013).



**Figure 2: Sugarcane straw on the ground after unburned cane harvest in São Paulo State - Brazil**

Under Brazilian conditions, sugarcane straw represents approximately one third of the total primary energy of sugarcane in the field. Studies have estimated that when 40-50% of the straw available in the field is used as additional fuel for bagasse, the total electricity surplus from the sugarcane mills cane reaches 468-670 MJ Mg<sup>-1</sup> (130-186 kWh Mg<sup>-1</sup>) of cane (Leal et al., 2013). Besides being used as a fuel in boilers for steam and electricity production, sugarcane bagasse and straw may be used as a feedstock for cellulosic ethanol production, termed second generation ethanol. Since it is composed of cellulose, hemicelluloses and lignin, it may be converted into fermentable sugars through pretreatment and hydrolysis processes (Dias et al., 2011). The deployment of bagasse-based technologies in Brazil would be favored because the production process could be attached to the mills, requiring lower investments, less additional infrastructure, logistics and energy supply. Furthermore, bagasse is available at the industrial facility, free of transportation costs (Soccol et al., 2010). However, the use of lignocellulosic materials as feedstock for second generation ethanol production has not yet become a commercial reality due to the lack of efficient and low cost technologies (Dias et al., 2011).

Another process that has stimulated new research is the biodigestion of vinasse residue left after the ethanol distillation. As a byproduct of the digestion process, methane (CH<sub>4</sub>) and other gases are produced in large quantities and provide electricity to the ethanol plants. For now, the elevated costs associated with biodigestion of vinasse have limited the interest in this process (BNDES, 2008). Regarding sugarcane ethanol, this product is one of the most promising biofuels because its energetic balance is generally positive, meaning that sugarcane absorbs more carbon than it emits when the ethanol is burned as fuel (Oliveira et al. 2005). Moreover, the production cost is relatively cheap, around 0.37 \$ L<sup>-1</sup> (Dias et al., 2012). In addition, the use of sugarcane ethanol in flex motorcycles, small planes and buses is on the rise. For instance, in São Paulo, there are already sixty ethanol-powered buses (UNICADATA, 2013). In the near future, ethanol could also be used in trucks and farm equipment.

#### **4. Water use for cane production**

In tropical areas, the combination of high solar energy incidence with abundant rainfall brings favorable conditions for bioenergy production. Besides, the availability of areas for agro-energy activities, without reducing the farm area for food production, highlights the Brazilian advantage regarding biofuel production (Nass et al., 2007). Especially sugarcane that is well adapted to high brightness and temperature conditions and relative water scarcity. However, the water availability plays an important role in cane production, as there is a straight correlation between water consumption and yield. Sugarcane growers in the São Paulo State consider water availability to be the major cause of inter-annual yield variation and yield differences. Major yield reductions are blamed on dry spells of more than two weeks during the hot rainy season, from November to March (van den Berg et al., 2000). Moreover, additional factors conditioning water availability are the soil water retention characteristics and limited rooting caused by acid subsurface soil with large aluminum saturation (the fraction of effective cation exchange capacity occupied by Al<sup>3+</sup>). The sugarcane water requirement is larger during the first periods of the growth cycle, i.e., sprouting, tillering and establishment, while during vegetative growth period, the water demand decreases, and is almost negligible during maturation. Therefore, the best climate for growing sugarcane is a warm and wet climate to encourage germination and vegetative development; followed by a cool, dry season to promote ripening and consequent accumulation of sucrose in the stalks (Meyer et al., 2011). Moreover, the development of the crop stand (plant or ratoon<sup>1</sup>) and

---

<sup>1</sup> Ratoon: cane sprout after it has been cropped.

variety patterns is also responsible for the large variation of sugarcane water consumption that may range from 1.2 to 8.6 mm d<sup>-1</sup> (Scarpore, 2011).

Several methods have been used to assess the sugarcane water consumption. Scarpore et al. (2012) used the Water Productivity approach (WP), the ratio between biomass produced per unit of evapotranspired water, to assess the amount of water used under rainfed and subsurface drip irrigation with and without nitrogen fertilization. As a result, the interaction of irrigation and nitrogen (fertirrigation) in ratoon cane provided the best WP, 28 kg mm<sup>-1</sup> against 15 kg mm<sup>-1</sup> under rainfed and without nitrogen condition. This suggests high synergy between water and nitrogen application. However, the majority of the sugarcane plantations in Brazil are rainfed, which may in some cases be complemented by partial fertirrigation carried out mainly by residual water from industrial processes and vinasse. For this reason, most plantations limit their production to regions with reasonable rainfall (Moreira, 2007). Due to the increasing demand for ethanol and the high prices, sugarcane is expanding to the Cerrado regions (savannahs), where irrigation would be needed to complement successive dry spell (Goldemberg et al., 2008). Although sugarcane has a high drought tolerance, it is a real challenge to determine which water stress levels are possible without compromising high yields. This analysis is critical because the sugarcane production areas are huge, which makes irrigation projects an investment of high implementation costs, associated with a large energy and water consumption (Corrêa et al., 2013). Irrigation can be economically feasible, especially with efficient application methods such as drip irrigation. Besides direct benefits, i.e., yield increase and crop longevity, the indirect benefits include the reduced need of new cultivation areas, decreased transport distances and transportation costs, which represent about 10% of total cane production cost.

The Brazilian irrigation potential is estimated at 29 million ha, with only 10% effectively explored, including areas where irrigation can be developed and excluding areas of high ecological value, e.g. in the Northern region (Amazonas and Tocantins Basins). In the Center-West region, where most of the Cerrado is located, in recent years the irrigation potential has expanded substantially, following recent advances in soil management and irrigation techniques applicable in that region (FAO, 2013). Through questionnaires, a large number of mills were consulted and it was estimated that sugarcane irrigation has increased during the last two crop seasons (2010/2011 and 2011/2012). The pure water irrigation increased from 9.4 to 12.6%, whereas pure vinasse irrigation increased from 8.0 to 8.3% and diluted vinasse from 20.1 to 22.1% (Pinto et al., 2012). Regardless the application methods used, sugarcane irrigation can be divided into three groups: (1) "salvage irrigation", (2) "supplementary irrigation" and (3) "full irrigation". Salvage irrigation is performed after the planting or harvesting time, where one or two irrigation amounts are normally applied to ensure the plant survival. In this case, it is important to know the soil properties to ensure the maximum capacity of water retention. Supplementary irrigation normally applies between five to ten irrigation amounts at the most critical development stages, aiming to mitigate water shortages. Full irrigation consists of daily or every other day irrigation application, aiming to replace all the water demand during the season. Generally, the amount of applied water is inversely proportional to the covered irrigated area. Thus, salvage irrigation can be performed over larger areas.

Despite the irrigation benefits, some environmental problems, such as soil salinization and fresh water resource depletion, may emerge. In other sugarcane producing countries, groundwater withdrawals are reported that exceed natural recharge rates of aquifers, leading to lowering water tables, potential salinization and land subsidence (Gopinathan & Sudhakaran 2009). NASA's Gravity Recovery and Climate Experiment (GRACE) Satellites have revealed the fast depletion of 18 billion m<sup>3</sup> year<sup>-1</sup> groundwater stocks in India, especially in the North and Northwestern parts of the country (Shrivastava et al., 2011).

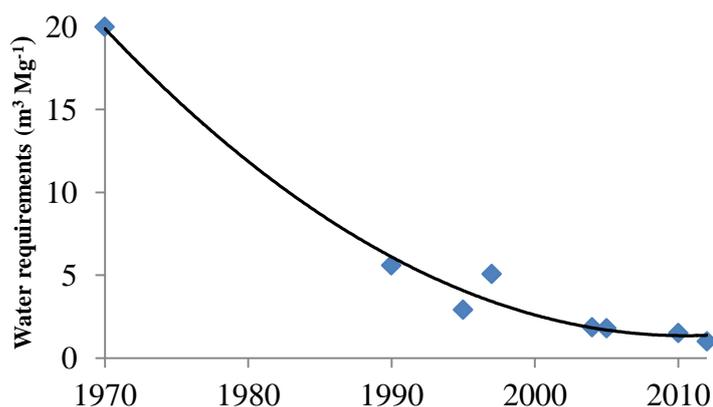
In Brazil, for supplementary and full irrigation, the surface water is the main source for irrigation; therefore, a water stream dam is normally built (Figure 3).



**Figure 3: Water reservoir of Coruripe's sugarcane mill in Alagoas State - Brazil**

### 5. Water use and effluent produced during industrial processes

The processing and converting of sugarcane to ethanol requires large amounts of water. This water is used mainly (about 87%) in four processes: (1) cane washing; (2) juice evaporation; (3) fermentation cooling and (4) ethanol distillation condenser cooling (Walter et al., 2013). Four decades ago, the water requirement for industrial use was around  $20 \text{ m}^3 \text{ Mg}^{-1}$  for processed sugarcane stalks due to water open circuits. In the 1990s, the water reuse by closing the circuit was largely responsible for a four times decrease of water requirements (Smeets et al., 2008). Besides that, the substitution method of wet cane washing by dry cane cleaning contributed to this evolution. Currently, due to high reuse rates that may reach 95%, the average water requirement of the sugarcane industry stays around  $1.5 \text{ m}^3 \text{ Mg}^{-1}$  (Elia Neto et al., 2010). However, in some modern mills, which use a high technical level of closed water circuit, the standard goal for the sugarcane industry of  $1.0 \text{ m}^3 \text{ Mg}^{-1}$  can be reached (Hernandes et al., 2012) (Figure 4).



**Figure 4: Evolution of sugarcane industry water requirements ( $\text{m}^3 \text{ Mg}^{-1}$  of cane stalks) in Brazil**

Source: Smeets et al. (2008); ANA (2009); Elia Neto (1995)

Considering the water requirement of  $1.0 \text{ m}^3 \text{ Mg}^{-1}$  of cane, with a 95% reuse rate and an average cane yield of  $85 \text{ Mg ha}^{-1}$  (IBGE, 2012), there are around  $80 \text{ m}^3$  of waste water available for fertirrigation use per hectare cultivated.

The industrial production of sugar and ethanol generates large amounts of waste with impacts on the aquatic systems, with the vinasse the most important waste. Vinasse is a residue of alcoholic solution during the distillation process that is rich in organic matter and nutrients. For each liter of ethanol produced, around 12 liters of vinasse are generated. The physical and chemical characteristics of vinasse vary widely, depending on the raw material and the operating conditions of the fermentation and distillation. However, it usually has a low pH, is highly corrosive and rich in organic matter (ranging from 20,000 to 35,000 mg L<sup>-1</sup>) promoting the increase of water biochemical oxygen demand (BOD) and hence, anoxia and also eutrophication (Meyer et al., 2011). Nowadays, the residual water from industrial processes generating vinasse is normally used as fertirrigation. However, before the 1960s, almost all vinasse was directly released into water streams causing serious contamination problems. With the boom of ethanol production in Brazil in the early 1980s, new legislation was created to ban the direct discharge of vinasse into surface waters. Since then, the vinasse is recycled back to the sugarcane fields as organic fertilizer (Gunkel et al. 2007). To a certain extent, this solution has helped to protect aquatic ecosystems. Since the 1980s, this practice has brought economic benefits in replacing part or all of the mineral fertilizer, improving the physical and chemical characteristics of the soil, increasing agricultural productivity and eliminating the immediate problem of pollution of water ecosystems. A yield increase of 73 Mg ha<sup>-1</sup> was found during six seasons, which corresponds to an additional harvest, when compared to the standard mineral fertilization, 57-28-115 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O (Donzelli, 2005). The application of vinasse as a fertilizer adds a significant amount of organic matter to the soil and modifies the physical soil conditions, such as the infiltration capacity, water retention, formation of aggregates and the reduced susceptibility to erosion (ANA, 2009). However, the vinasse dosage application for agricultural soil enrichment should be calculated considering the soil depth and fertility, besides the concentration of potassium in vinasse and the average extraction of this element by the plants. Usually, the fertirrigation is conducted in the areas nearby to the industrial plant, which are equipped to receive wastewater and vinasse by rain guns equipment (Figure 5).



**Figure 5: Rain guns equipment**

The maximum soil potassium concentration may not exceed 5% of the cationic exchange capacity (cmolc dm<sup>-3</sup>). When this limit of 185 kg of K<sub>2</sub>O ha<sup>-1</sup> is reached, the vinasse application is restricted (ANA, 2009).

## 6. Deterioration of aquatic systems

In Brazil, the majority of the water supplied to cities, rural areas and to electrical power plants comes from dammed rivers and reservoirs with large consequences for the sedimentation of aquatic ecosystems (Martinelli & Filoso, 2008). Sediments transported downhill across the landscape in sugarcane fields are generally limited compared to conventional agricultural crops such as maize and soybeans, since there the canopy rapidly closes, providing soil cover, and soil disturbance is limited to the replanting period (once every five or six years). However, soil losses from sugarcane may vary dramatically depending on many factors, such as the slope, the annual rainfall, the management and the harvesting system (Figure 6).



**Figure 6: Soil erosion caused by runoff in sugarcane lane (left) and on crop field (right) in São Paulo State, Brazil**

In the São Paulo sugarcane fields, Sparovek and Schnug (2001) estimated soil erosion rates of up to 30 Mg of soil ha<sup>-1</sup> year<sup>-1</sup>. For comparison, erosion rates in forests and pastures did not exceed 2 Mg ha<sup>-1</sup> year<sup>-1</sup>. The evolution of crop management from unburned to green cane harvest was responsible for soil erosion rates decreasing from 20.2 Mg ha<sup>-1</sup> year<sup>-1</sup> to 6.5 Mg ha<sup>-1</sup> year<sup>-1</sup> and runoff of 8 to 2.5 % of rain fall, respectively (Macedo, 2005). An example of a sedimentation problem linked to sugarcane cultivation in one small watershed in Piracicaba (traditional industrial and important cane production region in São Paulo State) was reported by Fiorio et al. (2000). In 1978, when a reservoir was built to supply water for a small town nearby, the watershed had 25% of sugarcane land cover. During 20 years, the watershed enlarged the sugarcane land cover up to 70%; the reservoir could no longer be used as a water supply losing around 50% of its capacity because of sedimentation.

The severity of sedimentation may be aggravated even further by the agrochemicals contaminants transport into aquatic systems. Sugarcane in Brazil uses a lower level of fertilizers compared to other countries and also lower agrochemicals than citric, corn, coffee and soybean crops (Martinelli & Filoso, 2008). However, some studies found contaminants, such as organochlorides and atrazine tracers, in sediment and fish samples collected in streams that drain a sugarcane region.

Vinasse discharge in open water systems has disastrous effects on the water quality, due to the high temperature, BOD and salt content level. The high levels of organic load with high temperature in the water stream result in a significant drop of dissolved oxygen causing fish dying off. The BOD discharges are, for easier comparison, often expressed in terms of inhabitant's equivalents, i.e. the equivalent amount of domestic sewage from an average inhabitant (Moreira, 2007). Thereby, the potential pollution of a small Brazilian mill with a crushing capacity of 1 million Mg of cane per year along the whole season is equivalent to a

city with about 1.5 million inhabitants (ANA, 2009). Several studies (Ometto et al, 2000; Gunkel et al., 2007) analyzing sugarcane mill downstream water samples reported significant changes in water quality, such as increases in water temperature, electrical conductivity, dissolved organic carbon (DOC), and dissolved inorganic nitrogen (DIN).

## **6. Water policy in Brazil**

The first Brazilian experience in water resources management began in 1934 with the Water Code, the basis for the Brazilian legislation on water. This Code ensures the free use of any water stream for basic life necessities and permits everyone to use any public water, complying to administrative regulations. In 1988, the Brazilian Constitution defined federally controlled public waters as bodies of water or rivers which flow through, or border, on several States or a foreign country. As state controlled public waters, those water bodies and rivers which rise and end within the territory of a single State. After 1988, the water use in the sugarcane industry decreased rapidly under environmental legislation and also due to the imminent deployment of the system of charging for the use of water resources (ANA, 2009). In 1997, the Federal Law 9.433 established the National Water Resources Policy and created the National Water Resources Management System. It states that: (1) water is a public good and a limited natural resource with an economic value; (2) in situations of scarcity, the priority use for water is for human and animal consumption; (3) water resources management should always assure the multiple use of waters; (4) the river basin is the territorial unit for water management; and (5) the management of water resources should be decentralized and participatory. The law promotes an efficient water use based upon the “user-payer” and “pollutant-payer” principle. The user and polluter payment depend on the amount and quality of the water collected and released. This applies to irrigation and industrial water use (Smeets et al., 2008). For water use permits, the River Basin Committees define the water price for a four year period according to the requirements of bearing the cost of the approved plans and projects. These committees are established to manage the water resources in the river basins and include representatives of the State government, municipalities and civil society (entrepreneurs, workers, universities and NGOs for environment protection).

## **7. Final remarks**

The Brazilian sugarcane sector is involved in activities aimed to improve the environmental management in the sugarcane production. The process water demand has been reduced, indicating that the sugarcane industry effectively minimizes water use, both through rationalization and as the implementation of lower water demand technologies. The salvage irrigation carried out with vinasse, which in turn consists mostly of water coming from the harvested cane, is a clear example.

Technical improvements in agricultural practice, which represents around 70% of the total ethanol costs, are being carried out, aiming to perform a sustainable model of sugarcane planting and harvesting that reduces costs and conserves soil and water with a better utilization of sugarcane straw. Thereby, precision agriculture, no-till farming and low traffic reduction are currently some aspects of research.

The sugarcane sector presents great opportunities to diversify their products and increase the availability of energy, moving toward biorefineries, production complexes capable of providing various bioenergy and biomaterials, reinforcing the base of genetic resources, including level studies of the photosynthetic process.

The existence of countries with good conditions for sustainable ethanol production and the world's demand for renewable and environmentally sound biofuels gives interesting perspectives for this biofuel as a global product.

## References

- **Agência Nacional de Águas (ANA, 2009).** Manual de conservação e reuso de água na agroindústria sucroenergética. Available at: <http://www.ana.gov.br>
- **National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2013).** Biofuel. Available at: <http://www.anp.gov.br>
- **Asad, M.; Azevedo, L.G.; Kemper, K.E.; Simpson, L.D.** Management of water resources. World Bank Technical Paper, n.4, 1999.
- **Brazilian Development Bank (BNDES).** Sugarcane-based bioethanol: Energy for sustainable development. Rio de Janeiro: BNDES, 304p. 2008.
- **Borsoi Z.M.F., Torres S.D.A.** A política de recursos hídricos no Brasil. Rio de Janeiro: Revista do BNDES, 4(8):143-166, 1997.
- **Companhia Nacional de Abastecimento (CONAB).** Acompanhamento de safra brasileira: cana-de-açúcar, segundo levantamento, Agosto/2012. Companhia Nacional de Abastecimento, Brasília, Brazil, 2012.
- **Corrêa S.T.R., Scarpate F.V, Dourado-Neto D.** Agricultura irrigada: produtividade potencial de cana-de-açúcar sem limitações hídricas, Item; Irrigação e Tecnologia Moderna, 95-96:76-71, 2013.
- **CTBE, Brazilian Bioethanol Science and Technology Laboratory, 2013.** Cellulosic Ethanol. Available at: <http://www.bioetanol.org.br/english/>.
- **Dias M.O.S., Cunha M.P., Jesus C.D.F., Rocha G.J.M., Pradella J.G.C., Rossell C.E.V., Maciel Filho R., Bonomi A.** Second generation ethanol in Brazil: Can it compete with electricity production? Bioresource Technology. 102:8964-8974, 2011.
- **Dias M.O.S., Junqueira T.L., Cavalett O., Cunha M.P., Jesus C.D.F., Rossell C.E.V., Maciel Filho R., Bonomi A.** Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash. Bioresource Technology. 103:152-161, 2012.
- **Donzelli J.L., 2005.** The use of fertilizers in Brazil's sugarcane production in Macedo, I. d. C. et al., 2005. Sugar cane's energy. Twelve studies on Brazilian sugarcane agribusiness and its sustainability, UNICA.
- **Elia Neto A., 1995.** Tratamento de efluentes na agroindústria sucroalcooleira, FEBRAL/95 – Brazil – Germany Fair, São Paulo, SP, 1995
- **Elia Neto A., Zotelli L.C., Donzelli J.L.,** Cenários de demanda de água industrial para o setor sucroenergético nas bacias hidrográficas do Estado de São Paulo. II Congresso Estadual de Comitê de Bacias, São Pedro, 2010.
- **Food and Agriculture Organization of the United Nations (FAO), Aquastat, 2013.** Available at: [http://www.fao.org/nr/water/aquastat/countries\\_regions/brazil/index.stm](http://www.fao.org/nr/water/aquastat/countries_regions/brazil/index.stm)
- **Fiorio P. R., Demattê J. A. M., Sparovek G.,** Cronologia e impacto ambiental do uso da terra na Microbacia Hidrográfica do Ceveiro, em Piracicaba, SP Pesquisa Agropecuária Brasileira 35:671–679, 2000.
- **Gopinathan M.C., Sudhakaran R.,** Biofuels: Opportunities and challenges in India. In vitro Cell. Dev. Biol. – Plant 45:350-371, 2009.
- **Goldemberg J., Coelho S.T., Guardabassi P.,** The sustainability of ethanol production from sugarcane. Energy Policy 36:2086–2097, 2008.

- **Gunkel G., Kosmol J., Sobral M., Rohn, H., Montenegro S., Aureliano J.**, Sugar cane industry as a source of water pollution—case study on the situation in Ipojuca River, Pernambuco, Brazil. *Water, Air, and Soil Pollution* 180:261–269, 2007.
- **Hernandes, T.A.D.; Scarpore, F.V.; Guarenghi, M.M.; Pereira, T.P.; Galdos, M.V.** A case study of ethanol water demand during industrial phase in Brazil. In: American Geophysical Union, 2012, San Francisco, 2012.
- **Instituto Brasileiro de Geografia e Estatística (IBGE)**. Censo Agropecuário 2006.
- **Instituto de Economia Aplicada (IPEADATA)**, 2013, <http://www.ipeadata.gov.br/>
- **Leal M.R.L.V.**, The potential of sugarcane as an energy source, Proceedings of the XXVI International Society of Sugar Cane Technologists (ISSCT) Congress, July 2007, Durban, South Africa, pp 23-34.
- **Leal M.R.L.V., Galdos M.V., Scarpore F.V., Seabra J.E., Walter A., Oliveira C.**, Sugarcane straw availability, quality, recovery and energy use: A literature review. *Biomass and Bioenergy* , 53:11-19, 2013.
- **Macedo I.C.**, A energia da cana-de-açúcar - doze estudos sobre a agroindústria da cana-de-açúcar no Brasil e sua sustentabilidade. Editora Berlendis & Vertecchia, São Paulo, 2005, 245.
- **Martinelli L.A., Filoso S.**, Expansion of sugarcane ethanol production in Brazil: environmental and social challenges. *Ecological Applications*, 18(4):885–898, 2008.
- **Meyer J.H.; Rein P., Turner P., Mathias K.**, Good management practices manual for the cane sugar industry. World Bank Group. 696 p. 2011.
- **Moreira J.R.**, 2007. Water use and impacts due ethanol production in Brazil. International Conference on Linkages in Energy and Water Use in Agriculture in Developing Countries, Organized by IWMI and FAO, ICRISAT, India, January 2007. [http://www.iwmi.cgiar.org/EWMA/files/papers/Jose\\_Moreira.pdf](http://www.iwmi.cgiar.org/EWMA/files/papers/Jose_Moreira.pdf) .
- **Nass L.L., Pereira P.A.A., Ellis D.**, Biofuels in Brazil: An overview. *Crop science*, 47:2228-2237, 2007.
- **Oliveira M.E.D., Vaughan B.E., Rykiel Jr.E.J.** Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint. *Bioscience*, 55(7):593-602, 2005.
- **Ometto J., Martinelli L.A., Ballester M.V., Gessner A., Krusche A., Victoria R. L, and Williams M.**, Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba River Basin, Southeast Brazil. *Freshwater Biology* 44:327–337, 2000.
- **Pinto R., Afféri A., Díaz P., Elias A., Trento E.**, 2012. Resultados preliminares da pesquisa sobre a cana irrigada no Brasil. Available at: <http://canapedeagua.com.br/index.php>
- **Rudorff B. F. T., Aguiar D. A., Silva W. F., Sugawara L. M., Adami M., Moreira M. A.**, Studies on the Rapid Expansion of Sugarcane for Ethanol Production in São Paulo State (Brazil) Using Landsat Data. *Remote Sensing*. 2(4):1057-1076, 2010.
- **Scarpore F.V.** Simulação do crescimento da cana-de-açúcar pelo modelo agrohidrológico SWAP/WOFOST. PhD Dissertation. Piracicaba: Universidade de São Paulo, 2011.
- **Scarpore F.V., Galdos M.V., Kolln O.T., Gava G.J.C., Franco H.J.F., Trivelin P.C.O.** Increased sugarcane water productivity in Brazil avoids land use change and related environmental impacts. In: American Geophysical Union, 2012, San Francisco, 2012.
- **Shrivastava, A.K.; Srivastava, A.K.; Solomon, S.** Sustaining sugarcane productivity under depleting water resources, *Current Science*, 101(6):748-754, 2011.
- **Smeets E., Junginger M., Faaij A., Walter A., Dolzan P., Turkenburg W.**, The sustainability of Brazilian ethanol: an assessment of the possibilities of certified production. *Biomass and Bioenergy*, 32:781-813, 2008.

- **Socol C.R., Vandenberghe L.P.S., Medeiros A.B.P., Karp S.G., Buckeridge M., Ramos L.P., Pitarelo A.P., Ferreira-Leitão V., Gottschalk L.M.F., Ferrara M.A. et al.** Bioethanol from lignocelluloses: status and perspectives in Brazil. *Bioresource Technology*, 101(13):4820-4825, 2010.
- **Sparovek G., Schnug E.**, Temporal erosion-induced soil degradation and yield loss. *Soil Science Society of America Journal*, 65:1479–1486, 2001.
- **UNICADATA**, 2013. Statistics of sugarcane sector season 2011/2012. <http://www.unicadata.com.br/>.
- **Van den Berg, M.; Burrough, P.A.; Driessen, P.M.**, Uncertainties in the appraisal of water availability and consequences for simulated sugarcane yield potentials in São Paulo State, Brazil. *Agriculture, Ecosystems and Environment*, 81:43-55, 2000.
- **Walter A., Galdos M.V., Scarpere F.V., Seabra J.E., Leal M.R.L.V., Cunha M.P, Oliveira C.**, Brazilian sugarcane ethanol: Developments so far and challenges for the future. *WIREs Energy Environ.* 2013. doi: 10.1002/wene.87.

## Abbreviations

ANA	National Water Agency
ANP	National Agency of Petroleum, Natural Gas and Biofuels
BNDES	Brazilian Development Bank
BOD	Biochemical oxygen demand
CONAB	National Supply Company
CTBE	Brazilian Bioethanol Science and Technology Laboratory
DIN	Dissolved Inorganic Nitrogen
DOC	Dissolved Organic Carbon
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FFV	Flex-Fuel Vehicles
GRACE	Gravity Recovery and Climate Experiment
IBGE	Brazilian Institute of Geography and Statistics
PNPB	National Program of Biodiesel Production and Use
WP	Water Productivity



# **Hydrological consequences of cultivating Jatropha crop in degradable waste lands of India and ecosystem trade-offs at watershed scale**

**Suhas P. Wani, Kaushal K. Garg and Mukund D. Patil**

**Resilient Dryland Systems  
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)  
Patancheru 502 324, India**

## **Abstract**

Biofuel production from feedstocks grown on wastelands is considered as a means to address concerns about climate change and improve energy security while at the same time provide an additional source of income for improving livelihood. The establishment of biomass plantations on wastelands is likely to affect local livelihoods and surrounding ecosystems by influencing hydrologic flows and processes such as erosion. We analyzed the technical feasibility for cultivating Jatropha on degraded waste lands in India using a water balance approach. More specifically, an assessment was made for a wasteland located in the Velchal watershed, Andhra Pradesh, India, which recently was converted to a biofuel plantation with Jatropha. The previous land-use, in this case grazing, could continue in the Jatropha plantations. Several desirable effects occurred as a result of the land-use conversion: non-productive soil evaporation was reduced as a larger share of the precipitation was channeled to productive plant transpiration and groundwater recharge, and at the same time a more stable (less erosive) runoff resulted in reduced soil erosion and improved downstream water conditions. A win-win situation between improved land productivity and soil carbon content was observed for the Jatropha plantations. Results did not show a negative impact on the blue water generation after introducing Jatropha on waste lands. Using parameterized and validated hydrological model “Soil and Water Assessment Tool” we assumed the impact of Jatropha cultivation on 13.4 million ha of wastelands (15% of the total wasteland area) in seven states of India. The analysis shows that 22 million tons of Jatropha seed could be produced from Jatropha cultivable waste lands in India. In addition, Jatropha plantations on waste lands would not create negative impact on downstream water availability and ecosystem services.

## **1. Introduction**

### **1.1 Biofuels in India**

In India, rapid urbanization, coupled with industrialization and economic growth, drives the increasing energy demand and the substantial import of crude petroleum (TERI, 2002). Since the beginning of the 1990s, India’s oil import has increased more than five-folds and has considerable influence on the country’s foreign exchange expenditures. The Indian economy is expected to continue to grow, with resulting further increase in energy demand and rising oil imports, projected to reach 166 and 622 million tons by 2019 and 2047, respectively (TERI,

2002). A large increase compared to the 111 million tons of crude oil that was imported in 2006-2007 (GOI, 2006).

As in many other countries, in India biofuels are considered an option for addressing the energy security concerns (GOI, 2009; Achten et al., 2010b). Moreover, they respond to the challenges of climate change mitigation (Phalan, 2009). A Petrol blending program mandated a 5% ethanol blending of petrol, initially for selected states and union territories. In 2006, the program was extended to the whole country (Ministry of Petroleum and Natural Gas 2009). Programs for stimulating complementary use of biodiesel to displace petroleum-based diesel primarily focused on biodiesel production based on non-edible oil seeds from marginal or degraded lands. In 2009, the Government of India approved the National Policy on Biofuels targeting a 20% blend of biofuels with gasoline and diesel by 2017 (Achten et al, 2010a).

## **1.2. Wastelands in India**

Wastelands are characterized by sparse vegetation cover, exposing soils to both rainfall and solar radiation. Large soil losses occur during instances of intensive rainfall, and the non-productive soil evaporation can be very large due to the lack of vegetative cover. The results show that under favorable soil management and with a good water supply, the water uptake of *Jatropha* is similar to that of many water demanding cereal crops. However, on wastelands where crop management is quite difficult, *Jatropha* plantations might be a better option for enhancing productive water flows and at the same time protect these areas from further degradation (Achten et al, 2010a). Based on National Bureau of Soil Science and Land Use Planning (NBSS&LUP), Nagpur, India classification, nearly 120 Million ha of land in India is defined as degraded land, with nearly 13 million ha of land suitable to grow biodiesel crops like *Jatropha* (GOI, 2003, 2006, 2010). There are several criteria available to classify a soil into wasteland, such as excessive erosion, pH, salinity, alkalinity, water logging and land slope. Rajasthan, Madhya Pradesh, Utter Pradesh and Andhra Pradesh cover the largest land area with degraded or waste land, together 48% of entire waste land in India (GOI, 2003, 2010). Soil degradation processes have severely reduced the soil productivity. It has been estimated that, on average, wastelands have a biomass productivity less than 20% of the original potential (Ramachandra and Kumar 2003).

A substantial wasteland area consists of degraded lands that are deteriorating due to the lack of appropriate soil and water management, or due to natural causes. These soils can be brought into more productive use. The establishment of biofuel plantations is considered an option for rehabilitating wastelands, enhancing energy security, and providing employment opportunities and better livelihoods in rural areas (Wani and Sreedevi, 2005; Wani et al., 2006; Sreedevi et al., 2009; Wani et al., 2009; Phalan, 2009; Achten, 2010b). Considering that about 35% of India's inhabitants live below the poverty line and more than 70% of the poor are small or marginal farmers or landless labourers (Srivastava, 2005), it is essential that wasteland development provides socioeconomic benefits for poor people.

## **1.3. *Jatropha***

*Jatropha* (*Jatropha curcas L.*), commonly known as “purging nut” or “physic nut”, is a tropical, perennial deciduous, C<sub>3</sub> plant belonging to the family Euphorbiaceae (Tatikonda et al., 2009; Divakara et al., 2010). It adapted to perform best under conditions of warm temperatures and, as

with many members of the family Euphorbiaceae, contains compounds that are highly toxic. *Jatropha* has its native distributional range in Mexico, Central America and part of South America, but has today a pan tropical distribution (Trabucco et al., 2010). The productivity of *Jatropha* depends on precipitation rates, soil moisture availability, soil characteristics including fertility (Francis et al., 2005; Kumar and Sharma, 2008; Da Schio, 2010; Jingura et al., 2011), genetics (Kaushik et al., 2007; Sunil et al., 2008; Divakara et al., 2010), plant age (Carels, 2009) and various management factors, like pruning, fertilization and disease control (Kaushik et al. 2007; Achten et al., 2008; Behera et al., 2010; Ghosh et al., 2011; Jingura, 2011). Annual yield levels at 2-3 tons dry seeds are proposed as achievable in semi-arid areas and on wastelands, while 5 tons ha<sup>-1</sup> can be obtained with good management on good soils receiving 900-1200 mm average annual rainfall (Foidl et al. 1996; Francis, et al. 2005; Carels, 2009).

*Jatropha* is considered to be drought tolerant and possible to cultivate on degraded, sandy and saline soils with low nutrient contents (Da Schio, 2010). Nitrogen and phosphorous inputs may be required for high yields (Daey Ouwens et al., 2007; Jongschaap et al., 2007; Henning, 2009), but nutrient recirculates through the leaf fall reduces the need for fertilizer input (Wani et al., 2009). It is estimated that three-year old *Jatropha* plants return about 21 kg N ha<sup>-1</sup> back to the soil, although the quantity and nutrient content of the fallen leaves from the *Jatropha* plant vary with the plant age and the fertilizer application (Wani et al., 2009, 2012). *Jatropha* is found to be accumulated and added to soil significant amounts of C (305 kg ha<sup>-1</sup> year<sup>-1</sup>) from the year one itself. Three to five year old plantation added per year around 4000 kg plant biomass equivalent to 1450 kg C ha<sup>-1</sup> (Wani et al., 2012). *Jatropha* can be grown in a broad spectrum of rainfall regimes, from 300 to 3000 mm, either in the fields as a commercial crop or as hedges along the field boundaries to protect other plants from grazing animals and to prevent erosion (Achten et al., 2008; Kumar and Sharma, 2009).

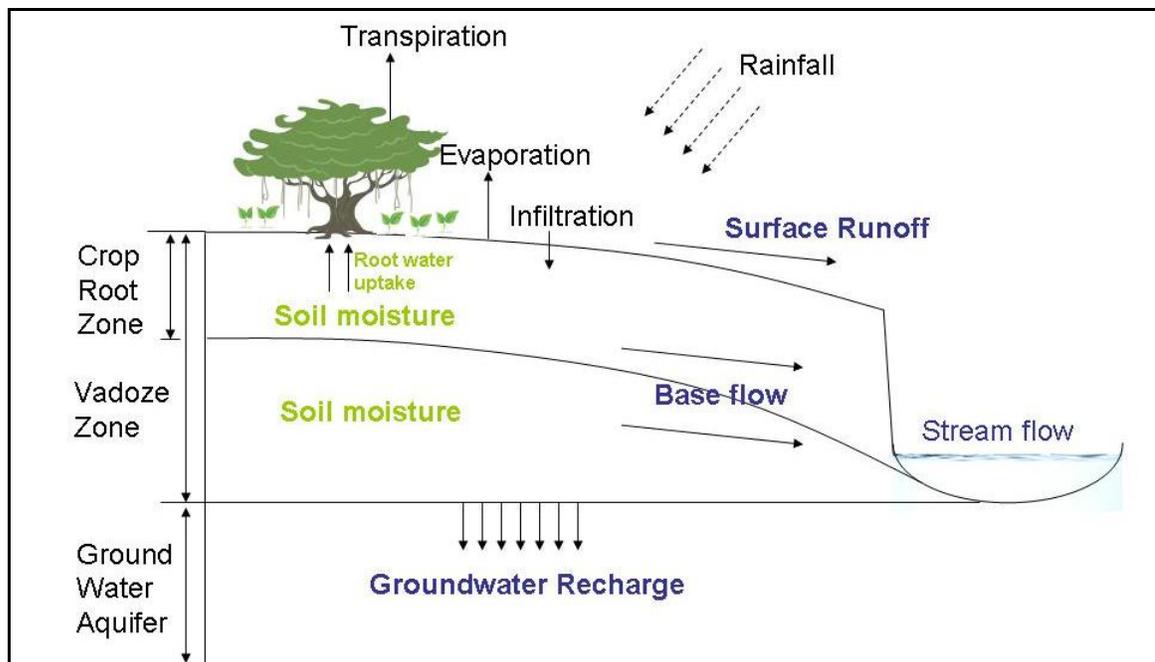
Policy support and demand for biodiesel are however building up; there is limited data and knowledge available on water requirements of *Jatropha*. Gerbens-Leenes et al., 2009a estimated water footprint of bioenergy generated from agricultural crops and also from *Jatropha* crop. For producing bio-diesel from *Jatropha*, water footprint was estimated relatively high (600 m<sup>3</sup>/GJ) compared to rapeseed and Soybean (400 m<sup>3</sup>/GJ). In contrary, recent studies on plant–water relations of *Jatropha* suggests relatively low water footprint (Maes et al., 2009). According to Maes et al., 2009 *Jatropha* strongly controls its stomatal conductance resulting in high transpiration efficiency and high water productivity. Data on *Jatropha* crop is limited available for different ecological regions resulted in to large uncertainty in estimating water foot prints (Hoekstra et al., 2009; Maes et al., 2009; Gerbens-Leenes et al., 2009a, b). There is an urgent need to carry out research efforts to address such issues (Raju, 2006). In the present study, the technical feasibility of cultivating *Jatropha* on degradable waste land is analyzed. The specific objectives of the current study are: i) to analyse the impacts of two different land-use scenarios (wasteland state vs. biofuel cropping with *Jatropha*) on a watershed scale hydrology and ecosystem trade-offs; ii) to analyze field water balances of *Jatropha* in different ecological regions of India and iii) to analyze crop yield potentials of degradable and waste lands in India.

## **2. Methodology and study area**

In 2005, the National Oilseeds and Vegetable Oils Development (NOVOD), together with the ICRIAT consortium, planted *Jatropha* on 160 ha common property land belonging to the

Velchal village, classified as wasteland. *Jatropha* seedlings, approximately 60 cm high, were planted at 2 m x 2 m spacing at the Velchal watershed. The plants were grown under rainfed conditions and without irrigation. Soil and water conservation practices (e.g., bunding and trenches) were implemented to harvest more rainfall. Fertilization (30 kg N ha<sup>-1</sup> and 12 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) was applied during the *Jatropha* planting. Further fertilization (50 kg N ha<sup>-1</sup> and 57 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) was applied in 2007. The growth parameters and seed yields of *Jatropha* were recorded. The plantations were mainly located in the hillock area, although some plantations are also found in the valley. Soil, hydrology and crop yield data collected from the Velchal watershed is used to parameterize the hydrological model SWAT (Soil and Water Assessment Tool). A detailed description of the SWAT modeling and parameterization processes is given by Garg et al., 2011.

Figure 1 shows a conceptual representation of the hydrological cycle at the watershed scale. Rainfall is partitioned into various hydrological components as defined by a mass balance equation: Rainfall = Out flow from the watershed boundary (Surface runoff + base flow) + Groundwater recharge + Evapotranspiration (Evaporation + Transpiration) + Change in soil moisture storages. Where fraction of rainfall stored into Vadoze zone is known as green water; and water available into groundwater aquifer and amount of water reached at river stream is known as blue water (Falkenmark, 1995).



**Figure 1: Conceptual representation of the hydrological cycle and different hydrological components at a field and watershed scale.**

The results are analyzed for dry, normal and wet years, according to the following classification (Indian Meteorological Department, Pune):

- Rainfall less than 20% of the long term average (< 725 mm\*) = dry;
- Rainfall between -20% to +20% of the long term average (> 725 mm and <1100 mm)= normal;
- Rainfall greater than 20% of long term average (>1100 mm) = wet.

(\*Note: Values in parenthesis describes rainfall of Velchal watershed, Andhra Pradesh, India)

From 2001 to 2010, the annual average rainfall in the study area was 910 mm. We included two land use scenarios:

- The “Wasteland” scenario, representing the situation where the soil is in a degraded stage. Soils are highly eroded and poor in organic matter and have poor water holding capacity. Bushes and seasonal grasses dominate the land, which is used for grazing.
- The “Jatropha land” scenario, representing the situation where Jatropha is cultivated and some soil and water conservation measures (*in-situ* interventions) are implemented. Leaf fall, stem and other bush and tree biomass is added to the soil, mainly at dormancy period. The local community harvests the Jatropha seeds.

In addition, we collected data on crop characteristics to estimate crop water uptake at the ICRISAT experimental site, a micro-watershed located at the ICRISAT campus in Hyderabad (17.53°N latitude and 78.27°E longitude) where in 2004 Jatropha seedlings (3m x 2m spacing) were planted on 4 ha of land. Since then, the Jatropha has been cultivated under good management practices, including fertilization (90 kg N and 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> year<sup>-1</sup>) and various agronomic measurements. Seed yield and oil content has been monitored. Soil moisture of different layers were monitored and used to estimate crop coefficients using a water balance approach.

The Jatropha crop coefficient estimated from the ICRISAT data base, a modeling study, is conducted to assess the technical feasibility to grow Jatropha on waste land in India. Nine states (Andhra Pradesh, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Orissa, Rajasthan and Utter Pradesh) that cover nearly 75% of the total waste lands of India are selected. We collected soil properties of different locations in these states from the NBSS&LUP database (Mandal et al., 1999). The water retention properties of the wasteland vary between 110 to 150 mm per m. The model was run for a 10 year period (2001-2010) with the two land use conditions as mentioned above.

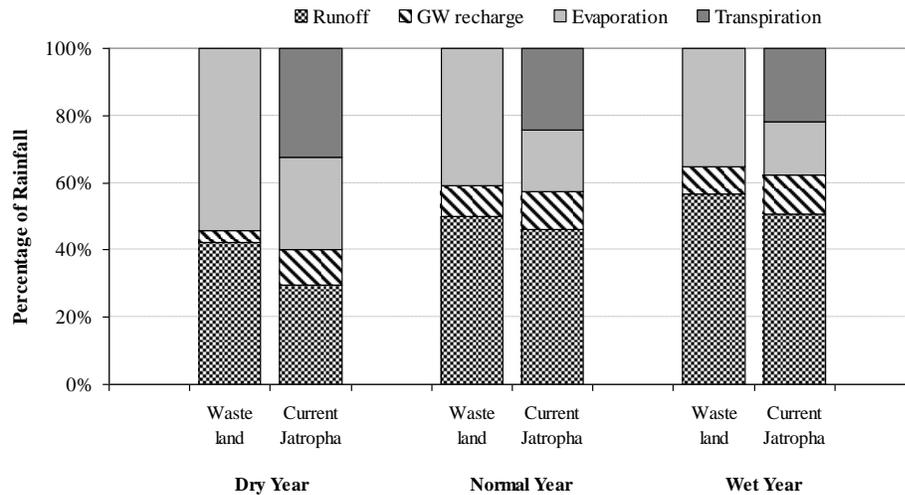
### 3. Results

#### 3.1 Impact of Jatropha plantation on the water balance in Velchal

Figure 2 shows that the water balance differs substantially for the two conditions and depends on the land use and the amount of annual rainfall. In general, there is a larger share of the total rainfall that forms runoff during wetter years when compared to drier years. For the Wasteland scenario, the runoff constituted 40-60% of the total rainfall, while for the Jatropha scenario, the corresponding fraction is 20-40%. Between 4 and 17% of the total rainfall was going to groundwater recharge, while the remainder was transferred to the atmosphere through evaporation or evapotranspiration.

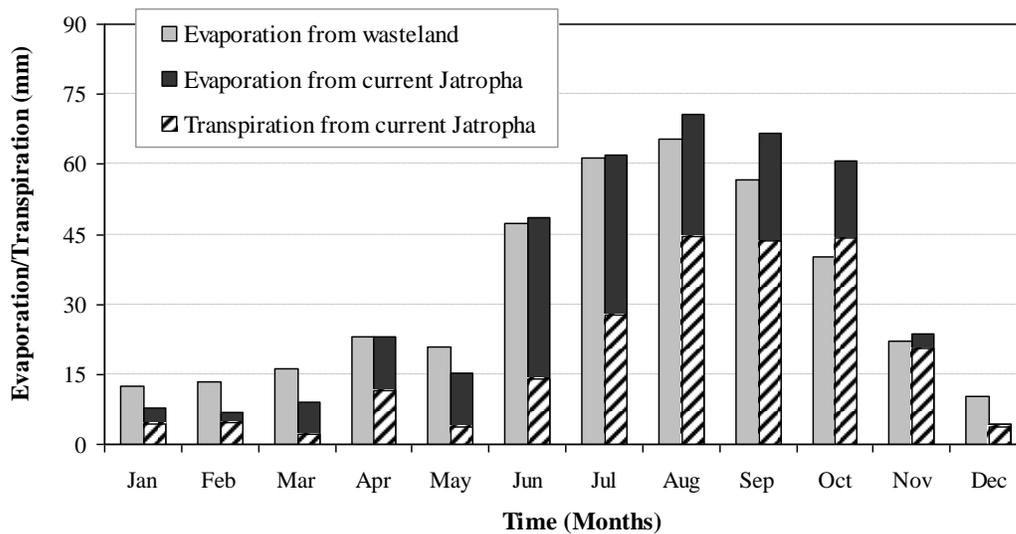
A comparison of the different land management scenarios shows that more than 50% of the non-productive soil evaporation in the Wasteland scenario is shifted into productive transpiration in the Jatropha plantation scenarios (Figure 2), while the total amount of evapotranspiration (ET) is relatively similar in all both scenarios, except during dry seasons when ET is higher in the Jatropha scenarios, and even higher under improved soil conditions. Groundwater recharges doubles in the Jatropha scenario, compared with the Wasteland scenario (Figure 2). As a result of higher ET and groundwater formation, runoff formation decreases in the Jatropha scenarios, in

particular during dry years. In the Wasteland scenario, runoff constitutes around 40% of the total rainfall during dry years while the corresponding figure for the Jatropa scenario is around 30%.



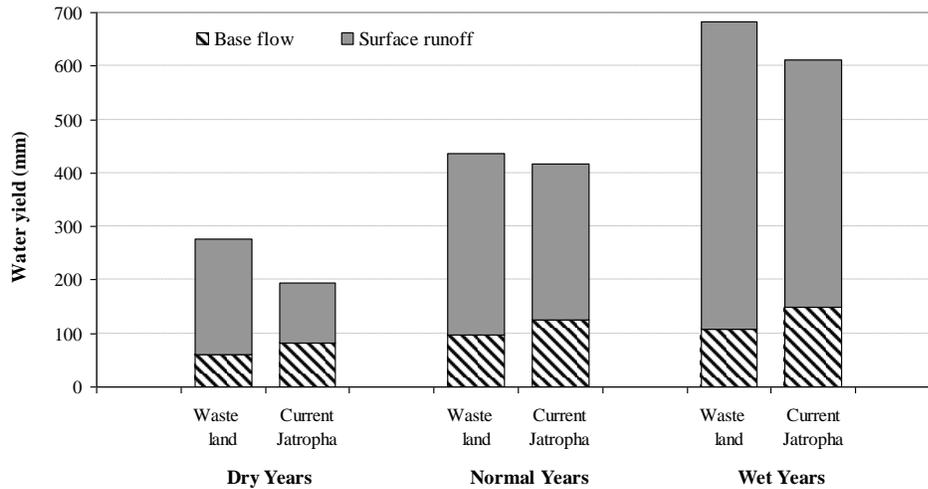
**Figure 2: Water balance components of different land management scenarios during dry, normal and wet years (data from 2001 to 2010).**

Figure 3 shows that the distribution of the water balance components over the year also varies with land use (Figure 3). While the total ET is lower for the two Jatropa plantation scenarios during the dry season (December-March), it becomes higher during the wetter parts of the year. This means that the annual fluctuations in runoff and groundwater generation are smaller in the Jatropa plantation scenarios compared with the wasteland scenario.



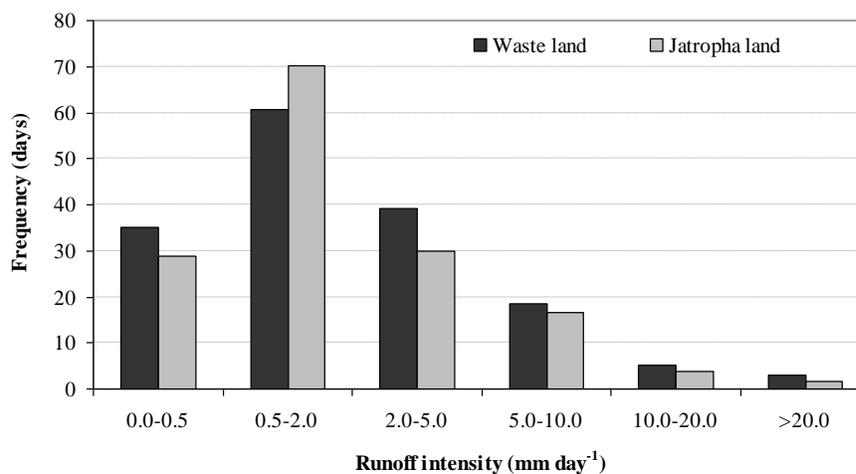
**Figure 3: Monthly soil evaporation and transpiration for three different land management scenarios in Velchal watershed.**

Runoff generated from the watershed consists of two components: i) surface runoff and ii) base flow generation. Figure 4 shows that even though the total runoff was slightly lower with Jatropha plantations compared with the waste-land condition, the base flow was in fact higher with Jatropha plantations. On average, the total amount of base flow generation in the Wasteland scenario was only 70% of the base flow in the Jatropha scenarios.



**Figure 4: Total runoff generation from the watershed, divided up into base flow and surface runoff, for three different land management scenarios during dry, normal and wet years (data from 2001 to 2010).**

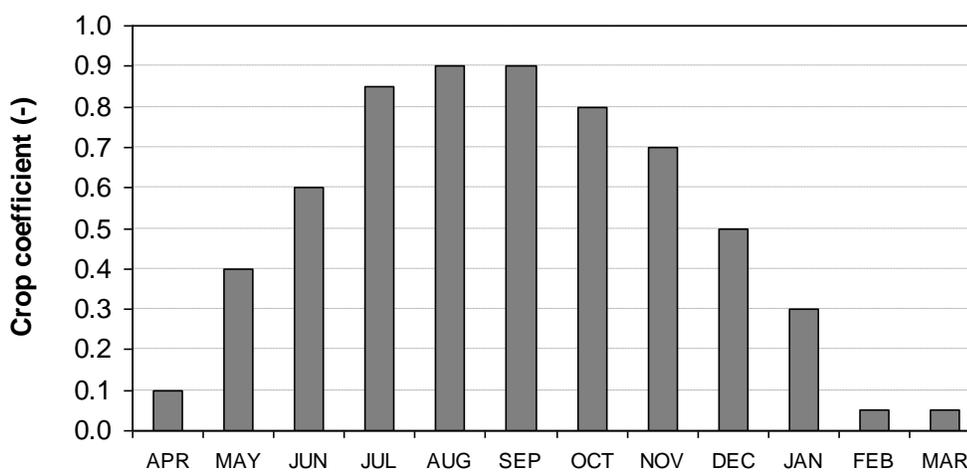
Land management also affects the runoff intensity. In general, higher runoff intensities were predicted for the wasteland state, compared with the Jatropha plantations (Figure 5). The results show that the average daily run-off intensity decreased by 12 % for the Jatropha plantation, compared with the wasteland condition.



**Figure 5: Frequency of daily runoff intensity, for three different land management scenarios (data from 2001 to 2010).**

### 3.2 Crop coefficients of Jatropha crop

The crop coefficient of Jatropha estimated from the ICRISAT experimental site lies between 0.05-0.90 (Garg et al, forthcoming). Figure 6 shows the variation of the crop coefficient on a monthly scale. The Figure shows the largest  $K_c$  in July and August and the smallest between January and March. New leaf flushes and biomass growth start by the beginning of April; flowering is initiated by May/June; and pod formation and harvesting stage start between September and December (Rao et al., 2012). These differences have consequences for water requirements.



**Figure 6: Monthly crop coefficients of Jatropha estimated at ICRISAT experimental site.**

### 3.3 Water requirement of Jatropha crop

Table 1 shows that based on the  $ET_0-K_c$  approach, the annual water requirement of Jatropha lies between 720 to 975 mm (Rao et al., 2012; Garg et al., forthcoming). The water requirement of Jatropha is largest for Rajasthan and smallest for Orissa. Jatropha is a perennial crop and requires significant amounts of water, especially from May to August. Especially May and June are critical for Jatropha, because the water requirements during this period are large, but moisture availability is relatively poor due to the depleted soil moisture status.

### 3.4 Yield potential of Jatropha in waste lands

Table 1 summarizes the water balance components for all the nine meteorological stations. The data show that rainfall in different states vary from 400 mm to 1500 mm. Out of that, 35-80 % of the rain is partitioned into ET and 30-60 % is exported as surface runoff and percolated down into groundwater recharge and develop base flow.

The level of water stress caused lower crop yields during dry years than in normal and wet years. At a location where rainfall was less than 500 mm, the crop experienced water stress half of the crop growth period. Jatropha cultivated in medium and high rainfall regions also experienced

water stress during 20-40% of the crop growth period. Several studies in India and elsewhere showed that production potential of Jatropha is 3-5 ton/ha under non limiting input conditions. Water stress estimated for Jatropha is transformed into seed yields. We considered 3 ton/ha seed yield from five to six year old tree under the optimal conditions, and then computed the actual yield under stresses inferred by water deficiency. Potential average crop yields for different states are found in range between 0.8 to 2.6 ton/ha (Table 1).

15% of the waste lands (14 Million ha) is considered for cultivating Jatropha crop out of 88 Million ha of waste lands in nine states. Our analysis suggested that 14 Million ha of degraded waste lands have the potential to produce nearly 22 Million ton of Jatropha seed every year on an average (Table 1).

### **3.5 Soil and water related impacts**

The results from this study confirm the hypothesis that Jatropha plantations on waste lands can have several positive effects in relation to soil and water:

- Reduced soil losses are expected as because soils are better protected by vegetation and roots. Besides the on-site benefits this also has the benefit that sedimentation loads on rivers and other water bodies are reduced;
- Increased soil carbon content (Wani et al., 2012), which changes the soil physical characteristics so that both water infiltrability and soil water holding capacity increase. The soil carbon increases also enhances the climate change mitigation benefit by withdrawing CO<sub>2</sub> from the atmosphere;
- Redirection of non-productive soil evaporation into productive transpiration, which improves the field level water productivity;
- Increased groundwater recharge.

In this study, the total runoff amount was 5-10% larger for the wasteland condition, but despite of this, base flows were higher when Jatropha was grown and runoff intensities were at the same time lower, which is generally positive, since it reduces the risks of flooding of cultivated areas. Higher deep percolation and base flow result in lower differences between high and low flows in rivers, which again is beneficial from a flood risk perspective. Most likely this is also positive for the riverine ecosystems, since rivers in this region are perennial and thus require a certain amount of base flow to sustain the key processes and functions. Jatropha plantations on waste lands in India is an attractive option. A larger share of the precipitation was channeled to productive transpiration and groundwater recharge, and a more stable (less erosive) runoff improved the downstream water conditions. The study clearly indicates that Jatropha plantation on waste lands would not create negative impact on downstream water availability and ecosystem services.

## References

- **Achten W.M.J., Almeida J., Fobelets V., Bolle E., Mathijs E., Singh V.P., Tewari D.N., Verchot L.V. and Muys B.**, Life cycle assessment of Jatropha biodiesel as transportation fuel in rural India, *Applied Energy*, 87, 3652–3660 (2010a)
- **Achten W.M.J., Maes W.H., Aerts R., Verchot L., Trabucco A., Mathijs E., Singh V.P. and Muys B.**, Jatropha: From global hype to local opportunity. *Journal of Arid Environments*, 74, 164–165 (2010b).
- **Achten W.M.J., Verchot L., Franken Y.J., Mathijs E., Singh V.P. and Aerts R.**, Review: Jatropha bio-diesel production and use, *Biomass Bioenergy*, 32, 1063–84 (2008).
- **Behera S.K., Srivastava P., Tripathi R., Singh J.P. and Singh N.**, Evaluation of plant performance of *Jatropha curcas* L. under different agro-practices for optimizing biomass- A case study, *Biomass and Bioenergy*, 34, 30-41 (2010).
- **Carels N.**, Chapter 2 *Jatropha Curcas: A review*, *Advances in Botanical Research*, 50, 39-86, (2009).
- **Da Schio B.**, *Jatropha curcas* L., a potential bioenergy crop. On field research in Belize. M.Sc. dissertation, Padua University, Italy and Wageningen University and Research centre, Plant Research International, the Netherlands (2010).
- **Daey Ouwens K., Francis G., Franken Y.J., Rijssenbek W., Riedacker A., Foidl N., Jongschaap R.E.E. and Bindraban P.S.**, "Position Paper on *Jatropha curcas*. State of the Art, Small and Large Scale Project Development", Expert seminar on *Jatropha curcas* L. Agronomy and genetics, FACT Foundation, Wageningen, the Netherlands, 26-28 March (2007)
- **Divakara B.N., Upadhyaya H.D., Wani S.P. and Laxmipathi G.**, Biology and genetic improvement of *Jatropha curcas* L.: A review, *Applied Energy*, 87, 732-742 (2010).
- **Falkenmark M.**, Coping with water scarcity under rapid population growth. Conference of SADC Ministers, Pretoria, 23-24 November (1995).
- **Foidl N., Foidl G., Sanchez M., Mittelbach M. and Hackel S.**, *Jatropha curcas* L. as a source for the production of biofuel in Nicaragua, *Bioresource Technology*, 58, 77-82 (1996).
- **Francis G., Edinger R. and Becker K.**, A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of *Jatropha* plantations, *Natural Resources Forum*, 29, 12-24 (2005).
- **Garg K.K., Karlberg L, Wani S.P., Berndes G.**, *Jatropha* production on wastelands in India: opportunities and trade-offs for soil and water management at the watershed scale. *Biofuels, Bioprod. Bioref.* 5:410–430 (2011).
- **Garg K.K., Wani S.P., Rao A.V.R.K.**, Crop coefficients of *Jatropha (Jatropha curcas)* and *Pongamia (Pongamia pinnata)* using water balance approach, *Willy Interdisciplinary Reviews: Energy and Environment* (Forthcoming).
- **Gerbens-Leenes W., Hoekstra A.Y., Van der Meer T.H.**, The water footprint of bioenergy. *Proceedings of the National Academy of Science (PNAS)* 106: 10219–10223 (2009a).
- **Gerbens-Leenes W., Hoekstra A.Y, Van der Meer T.H.**, Reply to Maes et al.: A global estimate of the water footprint of *Jatropha curcas* under limited data availability. *Proceedings of the National Academy of Science (PNAS)* (106) 40, E113 (2009b).
- **Ghosh A., Chikara J. and Chaudhary D.R.**, Diminution of economic yield as affected by pruning and chemical manipulation of *Jatropha curcas* L. *Biomass and Bioenergy*, 35, 1021-1029 (2011).

- **Government of India**, Ministry of Petroleum and Natural Gas, Annual report 2006-07, URL: [http://petroleum.nic.in/jsp/annual\\_report.jsp](http://petroleum.nic.in/jsp/annual_report.jsp) (2006).
- **Government of India**, National Policy on Biofuels. Ministry of New & Renewable Energy, New Delhi (2009).
- **Government of India**, Wasteland atlas of India, Government of India (GOI), Ministry of Rural Development, Department of Land Resources, New Delhi, India. URL: [www.dolr.nic.in/wasteland\\_atlas.htm](http://www.dolr.nic.in/wasteland_atlas.htm) (2010).
- **Government of India**, Report of the Committee on the Development of Biofuel. edited by Planning Commission. New Delhi (2003).
- **Henning R.**, The Jatropha Book, The Jatropha System, an integrated approach of rural development, <http://www.jatropha.de/>, Weissenberg, Germany (June 2009).
- **Hoekstra A.Y, Gerbens-Leenes W., Van der Meer T.H.**, Reply to Jongschaap et al.: The water footprint of *Jatropha curcas* under poor growing conditions. Proceedings of the National Academy of Science (PNAS) (106) 42, E119 (2009).
- **Jingura R.M., Matengaifa R., Musadamba D. and Musiyiwa K.**, Characterisation of land types and agro-ecological conditions for production of Jatropha as a feedstock for biofuels in Zimbabwe, Biomass and Bioenergy, 35, 2080-2086 (2011).
- **Jongschaap R.E.E., Corre W.J., Bindraban P.S. and Brandenburg W.A.**, Claims and facts on Jatropha curcas L. Plant Research International B.V., Wageningen, The Netherlands (2007).
- **Kaushik N., Kumar K., Kumar S., Kaushik N. and Roy S.**, Genetic variability and divergence studies in seed traits and oil content of Jatropha (*Jatropha curcas* L.) accessions, Biomass & Bioenergy, 31, 497-502 (2007).
- **Kumar A. and Sharma S.**, An evaluation of multipurpose oil seed crop for industrial uses (*Jatropha curcas* L.): A review, Industrial crops and products, 28, 1-10 (2008).
- **Maes W.H., Achten W.M.J., Muys B.**, Use of inadequate data and methodological errors lead to an overestimation of the water footprint of *Jatropha curcas*. Proceedings of the National Academy of Science (PNAS) 106:E91 (2009).
- **Mandal C., Mandal D.K., Srinivas C.V., Sehgal J., Velayutham M.**, Soil-climatic database for crop planning in India. National Bureau of Soil Science and Land Use Planning, NBSS Publication No 53 (1999).
- **Phalan B.**, The social and environmental impacts of biofuels in Asia: An overview, Applied Energy, 86, S21–S29 (2009).
- **Ramachandra T.V. and Kumar R.**, Wastelands: rehabilitation and management approaches. Low external input sustainable agriculture, 5 (4), 10-12 (2003).
- **Raju, K.V.**, Biofuels in South Asia: An overview, editorial introduction. Asian Biotechnology and development review 8(2): 1-9 (2006).
- **Rao A.V.R.K., Wani S.P., Singh P., Srinivas K., Rao C.S.** Water requirement and use by *Jatropha curcas* in a semi-arid tropical location. Biomass & Bioenergy 39: 175-181 (2012).
- **Sreedevi T.K., Wani S.P., Srinivasa Rao C.H., Chaliganti R., Reddy R.L.**, Jatropha and Pongamia rainfed plantations on wastelands in India for improved livelihoods and protecting environment, 6<sup>th</sup> international biofuels conference, March 4-5, Winrock International, New Delhi. Pp. 102-122 (2009).
- **Srivastava P.**, Poverty targeting in India, in Poverty targeting in Asia, ed by Weiss J, Cheltenham, Edward Elgar Publishing Limited, pp 34-78 (2005).
- **Sunil N., Varaprasad K.S., Sivaraj N., Kumar T.S., Abraham B. and Prasad R.B.N.**, Assessing *Jatropha curcas* L. germplasm in situ – A case study, Biomass and Bioenergy, 32, 198–202 (2008).

- **Tatikonda L., Wani S.P., Kannan S., Beerelli N., Sreedevi T.K., Hoisington D.A., Devi P. and Varshney R.K.**, AFLP-based molecular characterization of an elite germplasm collection of *Jatropha curcas* L., a biofuel plant, *Plant Science*, 176 (4), 505-513 (2009).
- **TERI**, Directions, innovations and strategies for harnessing action for sustainable development, New Delhi, The energy and resources institute (2002).
- **Trabucco A., Achten W.M.J., Bowe C., Aerts R., Orshoven J.V., Norgrove L. and Muys B.**, Global mapping of *Jatropha curcas* yield based on response of fitness to present and future climate, *GCB Bioenergy*, 2, 139–151 (2010).
- **Wani S.P., Osman M., D’Silva E. and Sreedevi T.K.**, Improved livelihoods and environmental protection through biodiesel plantations in Asia, *Asian Biotechnology and Development Review*, 8(2), 11-29 (2006).
- **Wani S.P. and Sreedevi T.K.**, Pongamia’s Journey from forest to Micro-enterprise for improving livelihood, International Crop Research Institute for the Semi-Arid Tropics, Research Report, Global Theme of Agroecosystems (2005).
- **Wani S.P., Sreedevi T.K., Marimuthu S., Kesava Rao A.V.R. and Vineela C.**, Harnessing the potential of *Jatropha* and *Pongamia* plantations for improving livelihoods and rehabilitating degraded lands. 6<sup>th</sup> International Biofuels Conference, March 4-5 Winrock International, New Delhi. Pp. 256-272 (2009).
- **Wani S.P., Chander G., Sahrawat K.L., Rao C.S., Raghvendra G., Susanna P., Pavani M.**, Carbon sequestration and land rehabilitation through *Jatropha curcas* (L.) plantation in degraded lands. *Agriculture, Ecosystems & Environment* 161: 112-120 (2012).

## **Abbreviations**

SWAT: Soil and Water Assessment Tool

TERI: The Energy and Resources Institute

GOI: Government of India

NBSS&LUP: National Bureau of Soil Science and Land Use Planning

NOVOD: National Oilseeds and Vegetable Oils Development

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

ET: Evapotranspiration

Kc: Crop coefficient

**Table 1: Degraded waste land area, water balance components of Jatropha crop and yield potential in different nine Indian States**

State	Metrological data used	AWC (mm)	Total waste land area (Mha)	Proposed waste land for Jatropha cultivation (Mha)	Water balance components (mm)					Crop water requirement under no stress condition	Water Stress (-)	Yield potential (ton/ha)	Total Seed production (Million tons)
					Rain fall	Blue water		ET	Change in SMC				
						Runoff	Deep percolation						
Andhra Pradesh	ICRISAT	100	9.19	1.38	957	164 (17)*	191 (20)	577 (60)	23 (2)	867	0.33	2.0	2.76
Chhattisgarh	Raipur	80	4.78	0.72	1211	185 (15)	474 (39)	534 (44)	18 (1)	831	0.36	1.9	1.36
Gujarat	Anand	125	3.13	0.47	764	149 (20)	210 (27)	415 (54)	-10 (1)	753	0.45	1.7	0.80
Karnataka	Bengalore	80	8.09	1.21	905	156 (17)	116 (13)	639 (71)	-7 (1)	865	0.26	2.2	2.67
Madhya Pradesh	Jabalpur	70	14.10	2.12	1324	194 (15)	642 (48)	443 (33)	44 (3)	693	0.36	1.9	4.02
Maharashtra	Sholapur	80	9.73	1.46	814	139 (17)	145 (18)	539 (66)	-9 (1)	779	0.31	2.1	3.06
Orissa	Bhubneshwer	75	3.72	0.56	1514	241 (16)	613 (40)	637 (42)	23 (2)	720	0.12	2.6	1.45
Rajasthan	Jodhpur	80	20.42	3.06	342	64 (19)	32 (9)	277 (81)	-31 (9)	975	0.72	0.8	2.45
Uttar Pradesh	Jhansi	90	14.41	2.16	820	91 (11)	280 (34)	465 (57)	-16 (2)	869	0.46	1.6	3.46

Note: \* Values given in parenthesis shows percentage of rainfall received

**Table 2: Water balance components of current land use (waste land)  
in different nine Indian states**

State	Data Meteorological Station used current analysis	Available water capacity (mm)	Total waste land area (Million ha)	Water balance components (mm)				
				Rain fall	Blue water		ET	Change SMC
					Runoff	Deep percolation		
Andhra Pradesh	ICRISAT	100	9.19	957	213 (22)*	145 (15)	589 (62)	10 (1)
Chhattisgarh	Raipur	80	4.78	1211	229 (19)	414 (34)	571 (47)	-2 (0)
Gujarat	Anand	125	3.13	764	182 (24)	157 (21)	428 (56)	-3 (0)
Karnataka	Bengalore	80	8.09	905	210 (23)	77 (9)	631 (70)	-13 (1)
Madhya Pradesh	Jabalpur	70	14.10	1324	244 (18)	574 (43)	495 (37)	11 (1)
Maharashtra	Sholapur	80	9.73	814	178 (22)	106 (13)	537 (66)	-7 (1)
Orissa	Bhubneshwer	75	3.72	1514	300 (20)	527 (35)	697 (46)	-10 (1)
Rajasthan	Jodhpur	80	20.42	342	83 (24)	25 (7)	264 (77)	-30 (9)
Uttar Pradesh	Jhansi	90	14.41	820	123 (15)	239 (29)	480 (59)	-22 (3)

Note: \* Values given in parenthesis shows percentage of rainfall

# **Water Impact of French biofuels development at the 2030 horizon**

**J.F.Bonnet (\*), D.Lorne (\*\*)**

**(\*) Université de Bordeaux - I2M, Esplanade des Arts et Métiers, F-33405 Talence,  
France**

**(\*\*) IFP Energies nouvelles, 1-4 Avenue de Bois Préau, 92852 Rueil-Malmaison Cedex,  
France**

## **Abstract**

This paper presents results of a Bioenergy–Water nexus study in France, focusing on potential impacts on water resources. In this prospective study (CLIP paper, 2009) four bioenergy production scenarios which could be developed at the 2030 horizon have been defined. Crops grown in these scenarios are used for biofuel production as ethanol, biodiesel or biomethane, but other uses of crops such as heat or fiber production could also be considered. The potential impacts of bioenergy development on water resources have been studied at large-basin scale using a typical crops method. This typical crops method allows to calculate the water balances of typical crops (seasonal profiles, annual values). Two Large Water Basins were investigated, Adour Garonne in the South and Seine Normandie in the North. Potential impacts were assessed in terms of quantity (summer water deficit, irrigation withdrawals) and quality (nitrogen loss, nitrate concentration under root). Pesticide pressure, not presented here, was also investigated in the CLIP paper. As results of the study, main indicators were calculated at large basin scale, showing very distinct potential impacts depending on the scenario. The existence of water resources protection criteria appeared, according to these results, to have more influence on the environmental pressure than the quantity of bioenergy produced.

## **1. Introduction**

### **1.1 Scope and objectives**

Bioenergy has long been seen as an important option for the supply of renewable energy. Among the advantages of bioenergy sources, we can mention: the biomass production potential, seen on a global scale; the ability of plants and crops to convert and store energy in solid or liquid forms and the cost of biomass production... Among the disadvantages, are frequently stated: the cost-benefit ratio of land use, the food-fuel dilemma and the water energy nexus (e.g. Berndes; Gerbens-Leenes and Hoekstra, 2012). In this paper, our work is specifically focusing on the bioenergy and water nexus.

The objective of this paper is to address the water–bioenergy issue in the specific case-study of biofuels production in France in a prospective view of year 2030. The first goal is to give an outlook of the potential impacts on water resources of the development of bioenergy, depending on the volume of the expected production as well as the technology and agriculture options. This study, addressing biofuels such as ethanol, biodiesel and biomethane, focuses on crop production impacts; hence other uses of non-food crops for heat or fiber productions

could also be considered. The second goal is to present a comprehensive methodology (which could be helpful to address similar situations) for the assessment of biomass and bioenergy impacts on water resources,

The results presented in this paper are based on a study performed in the framework of the Club d'Ingénierie et Prospective (CLIP i.e. Club for Prospective in Engineering) (Lorne and Bonnet, 2009). CLIP acts at the scale of the French territory as a Club for Prospective Studies in Energy Technologies. In this study, the approach relies on two main steps:

- Definition of 4 bioenergy scenarios for 2030 in France and implementation of the 4 scenarios at the scale of two large Water Basins, namely Adour Garonne and Seine Normandie,
- Definition of a methodology to assess the environmental pressure on water resources due to land use change (crop acreage) between 2006 and 2030, and implementation on the Adour Garonne and Seine Normandie Basins of the 4 scenarios.

The present paper focuses on the potential impact assessment on water resources at the level of a large Basin. Results are given, as indicators, in terms of environmental pressure on water quantity and water quality (nitrate).

The four scenarios studied focus on biomass production. They are meant to give four different possible visions of bioenergy production in France in 2030. The potential impacts on water resources are studied with specific assessment methods, concerning water quantity and water quality: potential nitrate pollution and potential pesticide contamination. This paper describes the main hypotheses of the study, the methodology briefs, the four scenarios definition and the different indicators used. The results are then presented for the quality and quantity (nitrate) aspects of the potential impact on water resources. The discussion and concluding remarks focus on the main findings, recommendations for biofuel development options and on methodological issues in the field of water related impact assessment.

## **1.2 The Water Basins studied**

### **a) Seine Normandie Basin**

The Seine Normandie Basin covers about 100 000 km<sup>2</sup>. The population is 17 Million inhabitants, 80% of them living in urban area (8 Million inhabitants in the 2000 km<sup>2</sup> metropole of Paris). Most rural territories are in the East and South of Basin (Champagne, Beauce) and in the North-East Normandie region. Mean precipitation on the Basin is about 750 mm/yr, mean local values ranging from 600 mm/yr (Beauce) to 900-1000 mm/yr in the South-East high part of Basin (Viennot et al, 2009).

### **b) Adour Garonne Basin**

The Adour Garonne Basin covers about one fifth (116.000 km<sup>2</sup>) of the French metropolitan territory. The mountains of the Pyrénées (south) and the Massif Central (eastern part of the Basin) are natural altitude reservoirs. The main rivers are Garonne, Dordogne, Adour and Charente. About 7 Million inhabitants live in the Basin, where agriculture and forest take an important place (30% of the population is rural). The two main cities are Bordeaux and Toulouse, with about 0.7 Million inhabitants in each city. The climate is mostly oceanic with warm summer. Precipitations are rather high on the coastline (800 to 1000 mm/yr), higher on the mountains (> 1400 mm/yr) and lower in the central part of Basin (600 – 700 mm/yr).

## **Basins basics**

It is important to keep in mind the differences in northern France and southern France climatic situations. In the northern part of the country, there is less difference between precipitations and evapotranspiration: water deficit of crops is hence smaller in the north, and water drainage from crop soils to groundwater resources is higher. In the southern part of the country, potential evapotranspiration (PET) is higher in Adour Garonne than in Seine Normandie, thus causing a longer water deficit period in the summer. This leads either to high irrigation needs, associated with high biomass yields if they are fulfilled, or to poor biomass yields for summer crops when no irrigation water is supplied. Resulting from these situations, statistical data in the years 2000 denote relatively low irrigation levels in Seine Normandie, with about 50-250 Mm<sup>3</sup>/yr. A few highly irrigated summer crops, such as sugar beet, require an important part of this total withdrawal. For the same year in Adour Garonne, irrigated agriculture is highly developed, withdrawing about 1000 Mm<sup>3</sup>/yr for different crops (maize, fruit crops, vegetables...).

## **2. Bioenergy scenarios for 2030**

### **2.1 Main assumptions in scenarios building**

The scenarios have been defined, from a prospective point of view, to describe different possible future biofuel levels and ways of production. They are not intended to give predictions or to draw projective trends from the present. Although all scenarios are meant to be realistic and consistent, the roadmaps between 2006 and 2030 are not studied in detail. The focus is made on 2030 schemes, designed to show contrasted situations that can be further studied and compared in terms of potential impacts on water resources.

The main assumptions in scenarios building are the following. First, scenarios are “biomass production scenarios”, i.e. defined in consideration of biomass potential production, rather than in terms of economic demand. Importation flows of biomass or biofuels, considered as having no influence on local water resources, are not considered. Secondly, overall Utilised Agricultural Area (UAA) is considered unchanged between 2006 and 2030. Third, forested areas are not taken into account as potential lands and energy crops are grown only on agricultural lands. Hence, biomass resources of forest lands and organic waste from industrial or municipal origin are not considered in this study. A more detailed description of the scenarios assumptions, as well as more complete bibliographic references, are given in the CLIP paper (Lorne and Bonnet, 2009).

### **2.2 Steps in scenario building**

The scenarios definition was undertaken following two main steps:

#### **Definition of the general characteristics of the scenarios**

- National biofuels 2030 production. In this step, was considered a base level of production (10% of national fuel use, corresponding to policy goals as stated at the time of the study) and a higher level of production (30 to 40% of national fuel use, corresponding to the biomass energy production goals in future scenarios with high biomass production).
- Technology and production options involved in the scenarios. For crop production options, a productive option and a water resource protection option are considered.
- Crop production required (crops selected in the scenario and corresponding crop acreage).

## **Transcription of biomass production scenarios at the basin scale**

- Choice of plant species,
- Definition of land use (crop acreage) change from 2006 to 2030.

### **2.3 The 2030 scenarios**

Aggregated field crop production of the two water Basins accounts for as much as one half of total French field crop production. Seine Normandie shows a good representation of mean climatic conditions on field croplands in the northern part of France, while Adour Garonne gives a sound vision of climatic conditions on croplands of the southern part of France.

In the 2030 perspective, different technology options can be considered as fully available. Moreover, from a prospective point of view, the 2030 situation can be conceived without following the 2006 trends. On the contrary it leaves space for very distinct options for biofuels development. Biofuels market and demand are not specifically analysed in the present study, because the intention is not to explain how biomass scenarios can develop, but to assess the potential impact of different biomass production levels on water resources. The goals of the scenarios are not to forecast, but to understand the water consequences of different long-term options.

The four scenarios are detailed in Table 1 and Table 2 (a) and (b):

- Scenario S1A: producing 5 Mtoe/yr (about 10% of liquid fuel consumption), it relies on “first generation” biofuel technologies, involving the energy conversion of usual food crops: cereal crops, sugar crops (sugar beet) for ethanol, and oil crops (rapeseed, sunflower) for biodiesel.
- Scenario S1B: as a more environment-friendly option of scenario S1A, it produces the same energy flow using less cropland area. Along with ethanol and biodiesel as in scenario 1A, a part of energy production is biomethane production from crop residues (maize stems, etc.) and from pasture crops. Biomethane could be produced either with existing technologies (anaerobic fermentation) or with gasification technologies, not currently developed.
- Scenario S2: meant to produce as much energy as possible using 25% of agricultural lands, it relies on lignocellulosic biofuels technologies to produce 20 Mtoe/yr from the processing of non-food energy crops: special crops (miscanthus, switchgrass), whole cereal crops and fiber crops (triticale, fiber maize, fiber sorghum), pasture crops (fescue, alfalfa, etc.) short rotation tree crops (poplar, eucalyptus, acacia).
- Scenario S3: defined as a water resources protection scenario, it involves the same agricultural land area than scenario S2, to grow the same kind of non-food energy crops as in scenario S2. However, crop management practices aim at a lower impact on water resources (low irrigation or no irrigation, lower fertilization or improved recycling, lower pesticide use). In each scenario, the set of crops is defined following these main characteristics.

## **3. Methodology for Water Impact Assessment at Large Basin Scale**

### **3.1 Assessment goals and global approach**

The method for Water Impact Assessment at Large Basin Scale (Wia-LBS) is defined to assess trends and compare very distinctive scenarios on large territories and for a long time span. Therefore, this method produces annual and seasonal mean indicators.

### **a) Pressure assessment on water basins**

The potential impact assessment on water resources is conducted in terms of pressure evaluation. Transfer in hydrosystems and specific impacts on water resources, important and difficult issues in the evaluation, are not studied in the present paper. The pressure evaluation on water resources is conducted at the scale of the two Water Basins.

### **b) Assessment of changes between 2006 and 2030**

In this paper, the attention is focused on the changes from 2006 to 2030 of the main indicators. The reference year 2006 is an average climatic year, with agricultural yields close to long-time average. For this reference year, biofuels production is not much developed. The year 2030 is chosen to describe the future situation, although this future situation could be reached earlier or later depending on the scenarios and the technologies involved.

### **c) Using typical crops to produce water impact assessment**

On both Basins studied, the assessment relies on the typical systems method in order to define typical crops used for the evaluation. The typical crops are defined with:

- Plant species,
- Average soil water reserve,
- Average climatic year,
- Set of crop management options adapted to the scenario studied.

The main interest of the typical crops method is to produce large-scale average models and to address a wide variety of crops – even those not well known in precise crop growth simulation – with a single method.

### **d) Using a water balance method for the typical crops**

The method calculates the water balance of the crop soil water reserve. The different terms of the water balance can be calculated from climatic data and crops parameters such as crop evapotranspiration, total soil evapotranspiration, irrigation requirements, drainage... These terms are related to crop yields through crop mean water use efficiency (Amigues et al., 2006). Plant water needs are caused by leaf transpiration, which requires high flows of water taken in the soil through the root system. Water vapour is lost by the leaf through the stoma used by the plant to let the CO<sub>2</sub> reach the photosynthetic system in the leaf. Crop transpiration and soil evaporation are aggregated into evapotranspiration. In terms of seasonal average value, the relation between evapotranspiration and plant biomass production can be considered as linear and is given by the mean water use efficiency of crop WUE (Lemaire, INRA Lusignan, personal communication, January 2007). Although more detailed crop models can make an explicit distinction between crop transpiration and soil evaporation, the use of a simpler model is justified by its cost efficiency and its ability to produce robust indicators.

### **e) Producing large basin scale average indicators, based on an average climatic year**

The indicators used in this paper are evaluated using a water balance methodology on an average growing season. Various indicators can be calculated, such as Summer Water Deficit (SWD), drainage, irrigation requirements, irrigation supply, irrigation withdrawal...The

indicators are defined and described in the next part of this paper. They are averaged in time and space in order to be as representative as possible of the actual basin situation:

- Time averaged values: impact assessment values are calculated from average values of climate data (precipitation, evapotranspiration). The inter-annual variability is not taken into account but this could be the case in further developments. The seasonal aspects are considered, in terms of an average season, in order to calculate specific variables and indicators
- Spatial mean values: model crops parameters are calculated or chosen to be as representative as possible at large Basin scale.

### **3.2 Design of typical crops**

The goal is to design a typical crop suitable for representation at basin-scale. For each scenario, a set of typical crops is defined in 2006 and 2030, according to the scenario options (technology pathways, feedstock requirement...). The estimation of average crop values is an important step of the process. These average values are obtained using existing data and studies (e.g. Amigues et al., 2006; JRC and IES, 2006; Ruelle et al., 2003; Straebler et le Gall, 1998) and specific calculations often based on cartographic data and statistical data.

#### **a) Crop species - crop coefficient**

The choice of the crop species comes from the biomass scenarios. The crop average yield is taken from the statistical data. The crop coefficient seasonal curve is defined according to crop yields, growing season and crop management practices. The crop coefficient method is based on the method described in FAO technical papers (Allen et al., 1998; Smith, 1993; Doorenbos and Pruitt, 1977). Each typical crop is adapted to the region where it is grown (northern or southern part of France).

#### **b) Maximum soil water reserve**

The maximum soil water reserve depends on the soil parameters: depth, composition, organic matter content... Three soil categories are defined with the specification of a maximum water reserve value: shallow, intermediate or deep soils are considered. Values are taken from soil statistical or cartographic data.

#### **c) Crop management practices**

Crop management practices are defined according to the scenario options: no irrigation, adapted irrigation, highly productive irrigation; irrigation system average efficiency; maximum or intermediate crop yield; treatment of weeds using herbicides or mechanical treatment... Some crop data, coming from statistical studies, are not explicitly considered in the typical crop but are used to check the coherence of the hypotheses and the calculated values. This can be considered as a strong advantage of this methodology, since a coherent vision of very distinct crops and systems can be targeted.

### 3.3 Variables and indicators for typical crops

The water balance of crop soil allows the calculation of a set of water variables. The consistency of the quantitative evaluation is given by the closure of the water balance.

#### a) Water balance variables

For each typical crop, the input data are the average weather data at a 10-day time step (reference evapotranspiration, effective precipitation). The main water variables are calculated at a 10-day time step, giving the seasonal profile of a typical crop:

- Typical crop evapotranspiration,
- Water deficit, defined as the difference between evapotranspiration and precipitation,
- Water content of soil, expressed as a percentage of maximum soil water reserve,
- Drainage, defined as water flowing downwards from crop soil to groundwater resources (drainage occurs in excess water supply when the soil water reserve is full),
- Irrigation requirement for a maximum average production.

From these 10-day calculations are calculated seasonal and annual variables, as a sum of 10-day values during the growing season or during the whole year:

- Growing season evapotranspiration,
- Annual evapotranspiration,
- Summer water deficit, defined as the difference between evapotranspiration and precipitation in the summer period,
- Annual water withdrawal, defined as the quantity of water abstracted from water resources in order to bring irrigation water to the crop parcels (this variable takes into account the water use efficiency of the irrigation systems),
- Summer irrigation withdrawals (In average years their values do not differ much from annual withdrawals, for most of the studied crops),
- Annual drainage,
- Winter drainage (as for summer withdrawals, it does not differ much from annual drainage in average years),

Drainage is not detailed here among water quantity variables, but it helps evaluating nitrate loss in the water quality study. Other parameters of interest for water resources management have been studied but are not presented in this paper. These water variables are complemented by other crop variables:

- Crop yield, in metric tons of dry matter per hectare (t d.m./ha)
- Crop biomass production, possibly including stems, leaves, etc. Crop yield and crop biomass production are linked by a harvest index (HI), widely used in crop science. Crop biomass production is linked to evapotranspiration by crop water use efficiency (WUE).

#### b) Nitrogen balance variables

Two basic Nitrogen variables have been studied for each typical crop:

- Nitrogen Loss (NL), in tons of Nitrogen per hectare (tN/ha),
- Nitrate Concentration (NC) in drainage water [ $\text{NO}_3$ ], in mg/l.

These two variables are linked by the drainage variable:  $\text{NL} = \text{drainage} \times \text{NC}$ .

Nitrogen Loss, as a conservative flow, can be assessed by Nitrogen balance calculations (e.g. Comifer, 2002; Eulenstein et al., 2008; Van Beek et al., 2003). However, Nitrogen balance is more difficult to assess than water balance, since Nitrogen is present within different ions or

molecules (nitrate, nitrite, organic molecules...), and since Nitrogen remaining from the previous crop affects the balance. Hence, Nitrogen loss can show important inter-annual variations and depends on climate and crop management (crop rotations especially). Bibliographical study and numerical simulation results shown that, on a yearly basis, Nitrogen loss is more strongly depending on water drainage than on nitrate concentration in drainage. Although nitrate concentration in under root drainage may also vary as a function of other parameters, some typical values can be observed and considered as reliable on a long-time period (Sebilo et al., 2000). For annual crops, nitrate concentration in drainage under root can reach 300 mg/l NO<sub>3</sub><sup>-</sup> for leguminous field crops (peas...), 100 to 150 mg/l for some field crops such as maize or rapeseed. For other field crops (wheat...) it does not exceed 30 to 50 mg/l depending on the previous crop. For most perennial crops, nitrate concentration under root does not exceed 3 to 5 mg/l and even for leguminous perennial crops such as alfalfa it is under 10 mg/l. Provided no excess fertilization is applied, perennial crops will lead to low nitrates losses. Forests and short rotation crops show the lowest values among vegetation covered soils, about 0-2 mg/l without fertilisation.

For each typical crop, nitrate leaching is assessed, on a yearly basis, using the estimation of drainage under root (m<sup>3</sup>/yr) given by water balance assessment, along with mean nitrate concentration in drainage (gNO<sub>3</sub>/m<sup>3</sup>), given by bibliography, simulations, or expert estimations (e.g. Justes et al., 1999; Salameh et al., 1997; Sebilo et al., 2000; Stout et al., 1999; Han Lee and Jose, 2004; Arregui and Quemada, 2006). This method has the advantages of giving coherent estimations for all typical crops studied and allowing to estimate values for poorly documented crops. For instance, at the time of the study, complete nitrogen balance data were not yet available for many “new” energy crops (miscanthus, switchgrass...).

### **c) Pesticide pressure variables**

Pesticide pressure was also investigated in this study, using two main variables specific to the French context: Treatment Frequency Index (TFI) and contamination potential score, called SIRIS score. Conducting such an assessment at basin scale requires large sets of data on pesticide use for all typical crops in the scenarios. Results, given in the Lorne-Bonnet CLIP study, are not presented in the present paper which focuses on balance methods. An aggregated conservative indicator, such as grey water footprint could also be used (e.g. Champagain and Hoekstra, 2011; Gerbens-Leenes and Hoekstra, 2012). Water contamination can be expressed as the volume of water corresponding to acceptable contaminants concentration.

### **3.4 Using typical crops to assess changes at large basin scale**

Typical crops variables were used in large basin scale assessment through the definition of cropland change matrices. These matrices were defined, for each scenario and for each large Basin, from the scenarios specifications, giving the 2006 cropland area of each 2006 typical crop, and the 2030 area of 2030 typical crops. Applying any conservative flow variable (e.g. evapotranspiration in m<sup>3</sup>/ha, drainage in m<sup>3</sup>/ha, NL in t/ha ...) to a cropland change matrix gives a conservative flow change matrix. The global approach is summarized in Figure 3.

#### 4. Assessment of potential impacts on water quantity

Water quantity pressure assessment has been conducted for Adour Garonne and Seine Normandie Basins. During the study, 7 main water quantity variables were estimated, from the typical crops variables, at the Basin scale:

- Crop evapotranspiration and total annual evapotranspiration,
- Summer Water Deficit (SWD),
- Annual withdrawal, and summer withdrawal,
- Annual drainage, and winter drainage.

All these water variables were calculated by aggregation of values for each typical crop defined in the scenario. As already explained, the difference between 2006 and 2030 is then calculated for all water variables, taking into account the area change for each crop as defined in the scenarios.

Among these 7 water variables, two proved to be the most useful to build scenarios indicators in this study:

- Summer Water Deficit (SWD). SWD is calculated from the soil water balance, as (crop evapotranspiration – efficient precipitation) during the “low water” summer period, here considered as lasting from June to September. An increase in SWD value denotes a potential increase of crop water needs in the low water period.
- Annual Irrigation Withdrawal (AIW). AIW is calculated from crops water requirement, and takes into account the irrigation rules of the scenario and the water efficiency of irrigation systems. Irrigation rules are for instance “production maximisation” in S2 or “no irrigation” in S3. An increase in irrigation withdrawal leads to lower water resource flow. Withdrawals during the low water period, also calculated, are not presented since they were not significantly different from annual withdrawal for most of the studied crops.

In this paper are presented 4 indicators for each variable, based on:

- Absolute change from 2006 to 2030 ( $\text{Mm}^3/\text{yr}$ ) (this indicator calculated for biofuel dedicated cropland area is also valid for whole basin change),
- Water intensity of energy ( $\text{m}^3/\text{GJ}$ ), defined here as absolute change from 2006 to 2030 (indicator 1,  $\text{Mm}^3/\text{yr}$ ) / biofuel energy production in 2030 ( $\text{GJ}/\text{yr}$ )
- Relative change of the variable at Basin-scale, defined as absolute change from 2006 to 2030 (indicator 1,  $\text{Mm}^3/\text{yr}$ ) / 2006 basin-scale variable ( $\text{Mm}^3/\text{yr}$ ). The basin-scale variable is calculated by aggregation for the whole cropland area in the Basin. This indicator is used to appreciate if the scenario significantly affects water resources at the whole basin scale,
- Absolute value of the variable in 2030. This indicator is used to compare the effective pressure on water resources in 2030.

##### 4.1 Summer Water Deficit (SWD)

###### a) SWD change 2006 to 2030 (SWD1)

A very noticeable change in SWD appears (Figure 4) for scenario S2, on Seine Normandie and on Adour Garonne. For this scenario, the implantation of highly productive crops, the growth of which takes place throughout the year, instead of winter or spring crops, leads to increase the SWD significantly at the Basin scale. SWD increase in scenario S1A, although lower than in S2 due to a lesser part of croplands concerned by energy end-use, is also significant. Both S1B and S3 show very low changes in SWD; in S1B on Seine Normandie the SWD is decreasing, due to a lesser part of summer growing crops in the 2030 scenario.

## **b) SWD water intensity of energy (SWD2)**

The indicator SWD2, already defined as SWD1/2030 energy production ( $\text{m}^3/\text{GJ}$ ), shows higher values for scenario S1A (Figure 5), due to the lower energy production of first generation biofuels. For scenario S2, the value of the water intensity indicator SWD2 is comparable to the value of S1, due to higher energy production of lignocellulosic biofuels in S2, and even better in Seine Normandie where the energy produced is greater.

## **c) Relative change in Basin SWD (SWD3)**

The indicator SWD3, already defined as SWD1/whole basin croplands SWD in 2006 (%), is given in Table 3 and Table 4. SWD3 shows a significant relative variation for S2 in Adour Garonne (+36%) and Seine Normandie (+21%), and also for S1A (+12% for both Basins). The relative variation is low or negative for S1B and S3. Data used for 2006 SWD value are approximations, since the order of magnitude of relative changes are primarily considered in this indicator. It must be kept in mind that the calculated variation would be much lower if whole Basin SWD took into account all vegetation lands (crops, pasture, forests).

## **d) SWD absolute values (SWD4)**

SWD4 indicates the absolute value of SWD in 2030 for dedicated biofuel croplands. The differences between scenarios S1A and S1B can be explained by the difference in biofuel total area in each scenario. The difference between scenarios S2 and S3 is more significant: since S2 and S3 involve the same productive biofuel total area in 2030, this difference can be attributed to the choices made in plant species and in crop management. This gives an indication of the influence of crops choice in water needs at basin scale.

## **4.2. Annual irrigation withdrawal**

### **a) AIW change 2006 to 2030 (AIW1)**

The greatest change in annual irrigation withdrawal (AIW1, Figure 6) is for scenario S2, due to the implantation of irrigated crops on a large area. Although the value is greater in Adour Garonne ( $>1200 \text{ Mm}^3/\text{yr}$ ), where irrigation requirements are usually high, than in Seine Normandie ( $800 \text{ Mm}^3/\text{yr}$ ), both values denote a very significant increase compared to other scenarios, especially the water resource protecting scenarios S1B and S3. Almost no change can be seen for scenario S1A in Seine Normandie, because in this case the irrigated crop area (e.g. sugar beet) does not change much.

### **b) AIW water intensity of energy (AIW2)**

The water intensity of energy indicator AIW2 (Figure 7) shows that, in Adour Garonne, the water use in scenario S2 is slightly more efficient than in scenario S1A, due to the higher energy production value in scenario S2. A different pattern is observed in Seine Normandie, because crops in scenario S1A, most of which being harvested in July, require few irrigation.

### **c) Relative change in Basin AIW (AIW3)**

Values for AIW3 are given in Table 3 and Table 4. The highest values of AIW3 are found for S2 in Adour Garonne (>+100%) and in Seine Normandie (>+250%), where the 2006 situation requires less irrigation. In S1A, the relative change, almost +30%, is also quite significant. Scenario S1B also shows in Adour Garonne an even higher relative change (>+40%), because of the place of irrigated crops in this scenario. This relative increase cannot be reached without significant changes in Basin water management.

### **d) AIW absolute values (AIW4)**

The indicator AIW4, given in Table 3 and Table 4, shows high absolute values in S2: >1700 Mm<sup>3</sup>/yr in Adour Garonne and 800 Mm<sup>3</sup>/yr in Seine Normandie. Such values appear difficult to reach, unless very important changes in water management and infrastructures are conducted (dams, irrigation infrastructures, ...).

### **4.3. Other variables**

Drainage, defined as water flow from crop soil towards groundwater resources, was another variable studied. At the scale of dedicated cropland area, the relative change in drainage was most often less than +10%, except for scenarios S1A and S1B on Adour Garonne (about +20%). At the whole Basin scale, the relative change in drainage was less than +3%. This variable appeared not as significant as SWD and AIW for the quantitative assessment in this study. However, being also useful for nitrate leaching assessment, it has to be mentioned here.

## **5. Assessment of potential impacts on water quality (nitrates)**

According to the European Nitrates Directive and to national legislation, nitrate concentration in drinkable water should not exceed 50 mg/l. Water resources showing higher nitrate concentration may need expensive water treatment to reach drinking water standards. Water quality pressure assessment has been conducted at large basin scale using typical crops variables for nitrate potential pollution. Nitrate leaching, described as nitrate flow leaving crop soils towards underground water resources, may cause non source pollution in agricultural areas. It can be expressed in terms of Nitrate NO<sub>3</sub> or Nitrogen N (1 kg NO<sub>3</sub> = 4,43 kg N). Due to the significant level of Nitrogen exported from croplands in harvested products, an often high Nitrogen supply is required annually for most crops (as fertilizers, organic Nitrogen, Nitrogen remaining in the soil from former crops). Two main variables are presented to describe nitrate leaching, at the scale of dedicated croplands and at the large basin scale:

- Nitrogen Loss (NL), which is the Nitrogen annual flow towards water resources, can be expressed in (tN/yr) at Basin scale or in kgN/ha,
- Nitrate Concentration (NC, mgNO<sub>3</sub>/l) in under root drainage.

Nitrate Loss and Nitrate Concentrations in drainage may be underestimated with the method presented. However, this should not affect the conclusions of the study, aiming more to assess changes from 2006 to 2030 rather than to calculate precise absolute values.

Four main indicators are presented here:

- Change in Nitrogen Loss (NL) from 2006 to 2030 (NL1, tN/yr) and Change in Nitrogen Loss (NL) from 2006 to 2030, divided by dedicated crops area (NL2, kgN.yr<sup>-1</sup>.ha<sup>-1</sup>),

- Relative change in Nitrogen Loss (NL) from 2006 to 2030, compared to Basin croplands 2006 Loss ( $NL3 = NL1/\text{Basin croplands NL}$ , %),
- Change in Nitrogen Loss (NL) from 2006 to 2030, divided by the energy production in 2030 ( $NL4$ , gN/GJ),
- Mean nitrate concentration in drainage under root in 2006 and 2030 (NC, mgNO<sub>3</sub>/l). The absolute value of mean NC is useful to compare to the reference threshold of 50 mgNO<sub>3</sub>/l, which is the limit concentration authorized in drinking water in the EU.

a) Nitrogen Loss  $NL1$  (tN/yr),  $NL2$  (gN.yr<sup>-1</sup>.ha<sup>-1</sup>) and  $NL3$  (%)

The indicators  $NL1$ ,  $NL2$  and  $NL3$  are shown in Table 5. According to  $NL1$  and  $NL3$  indicators, Nitrogen Loss is significantly reduced for scenarios S2 and particularly for S3, mostly due to the better Nitrogen balance of perennial crops. The absolute value of NL reduction in S2 and S3 is quantitatively comparable to the NL increase in S1B and S1A. In terms of relative change, NL change is significant when compared to Basin crops 2006 NL in indicator  $NL3$  (also shown in Figure 10): +20% in scenario S1A, -20% in S3-AG and -34% in S3-SN. This shows that implantation of energy croplands can affect positively or negatively the nitrogen impact at large Basin scale, depending on the crops involved. Scenario S2 leads to a smaller reduction of NL relative change (-6% and -14%), while in S1B the Nitrogen balance is not reduced, but just less increased than in S1A. The  $NL2$  indicator expresses NL change in terms of kgN/ha, a useful unit in crop science.

b) Change in Nitrogen Loss (NL) from 2006 to 2030, divided by the energy production in 2030 ( $NL4$ , gN/GJ)

The indicator  $NL4$  is shown in Table 5 and in Figure 11. Due to the lesser energy produced,  $NL4$  is much higher, compared to other indicators, in S1A-AG. For scenarios S2-SN and S3-SN, the difference between values of NL indicators is smaller with  $NL4$  than with  $NL1$ ,  $NL2$ , and  $NL3$  because S3 produces less energy than S2.

c) Mean nitrate concentration in drainage under root in 2006 and 2030 (NC, mgNO<sub>3</sub>/l)

The  $NC1$  indicator (Table 5 and Figure 12), calculated in mean value for dedicated crops, shows important variations: an increase in S1A and S1B, a decrease in S2 and S3. The value of  $NC1$  in 2030 exceeds the 50 mg/l threshold for S1A-AG, S1A-SN and S1B-SN. Both S2 and S3 in Seine Normandie lead to an important decrease of  $NC1$ : this suggests that implantation of bioenergy perennial crops in specific areas where nitrate content in groundwater resources is high could help improve the local environmental impact of agriculture, along with other crop management practices such as Nitrogen balance precision management or intermediate crops for instance (e.g. Justes et al., 1999). The NC reduction can be expected at large Basin scale, as shown with the  $NC2$  indicator (Table 5): it is noticeable that  $NC2$  is reduced by 4 to 7 mg/l in scenarios S2 and S3.

## 6. Discussion and concluding remarks

### 6.1 Water impact assessment of scenarios

Water quantity and water quality indicators show clear trends in the 8 scenarios studied.

- In scenario S1A, irrigation pressure and Nitrogen pressure are increased from 2006 to 2030 in both Basins (+29% in Adour Garonne, cf Table 3; +28% in Seine Normandie, cf Table 4), particularly when compared to the energy production (Figure 7).

- In scenario S1B, where cropland area is reduced thanks to residue valorisation, the quantity pressure (+4% in Adour Garonne) and the nitrate pressure (+6% in Adour Garonne and +17%

in Seine Normandie, cf Table 5) show most often a smaller increase from 2006 to 2030 than in scenario S1A, but no significant improvement in long terms indicators.

- In scenario S2, the energy production goal is very high: it induces high irrigation requirements (>+100% in Adour Garonne, >+250% in Seine Normandie), difficult to achieve without very significant changes in Basin water management. On the contrary, water quality nitrate indicators are improved (-6% in Adour Garonne, -14% in Seine Normandie), thanks to the perennial energy crops ability to capture nitrate in the soil. This improvement is significant at the whole basin scale, reminding the ability of perennial crops to improve nitrate concentration in water basins.

- In scenario S3, high water resources protection criteria are considered. From 2006 to 2030, water quantity indicators (-8% in Adour Garonne, -25% in Seine Normandie) and water quality indicators (-20% in Adour Garonne, -34% in Seine Normandie) are significantly improved, this improvement being also significant at the whole Basin scale.

The findings of this study can be summarized as follow:

- The water impacts of scenarios depend on the choices in cropland use and in crop management practices. When large cropland areas are involved, the scenarios can lead to significant changes in the water indicators, positive or negative depending on the scenarios.

- A significant potential improvement of water indicators can be achieved, especially when water resources protection criteria are applied.

- The potential benefits of water indicators improvement can be greater if specific zones are targeted for cropland change, especially in zones where nitrate pressure or quantity impacts are high.

- The water indicators improvement has an energy cost, since the water protection scenario produces less energy. The balance of the water and energy costs and benefits is one of the key issues of this paper. Depending on the value of water quality and quantity improvement, the energy cost can be considered as affordable.

## 6.2 Methodological issues

The assessment method, relying on typical crop evaluation, is suitable for long-term and large scale assessment. Trends can be considered to be correctly shown with typical crops results associated with cropland use change matrices. The basic advantages are:

- Coherence of the evaluations, among a wide variety of crop species and situations
- Reliability of the results from balance methods, based on average values, as long as relations between variables are linear
- Ability to deal with a large set of situations
- Cost effectiveness of the method.

Some drawbacks of the methodology can be mentioned:

- Based on average climatic year data, the method is suitable to long-term trends study, but does not presently take into account climatic annual or interannual variability.
- Based on large-scale spatial averaging of data and parameters, the method can deal with heterogeneous data but does not explicitly calculate the effects of heterogeneity.

In the present work, variability and heterogeneity have been considered and discussed from a qualitative point of view. However, adaptations of the method can be considered to deal with the issues of variability and heterogeneity:

- Using a set of different climatic years (at least average, dry, wet) is possible, to show influence of inter-annual variability. However, in dry years, the crop relations can no longer be considered as linear and more precise crop models must be used to run simulations.
- Using smaller spatial scales data is possible without important changes in the method. These adaptations have been tested successfully. The question of availability and representativeness of data at smaller scales can be crucial.

### **6.3 Potential impacts on water resources at sub Basin scale**

The extension of the method at the scale of sub basins has been considered on a set of 7 sub-basins in Adour Garonne Basin. This allows to take into account more homogeneous zones, in terms of climate, soil properties, cropland use and crop management. The water resources of each sub-basin can also be studied: groundwater, streams with surface storage, river and alluvial groundwater, ... Potential impacts on sub-basins can vary according to the climatic pattern and the storage capacity of resources. The transcription of a scenario should take water resource characteristics, at sub-basin scale, to better control potential impacts on water resources.

### **6.4 Concluding remarks**

The results of the prospective work show the wide variety of potential impacts, depending on the quantity of energy produced of course, but more strongly on crop choices and management practice. Water resource protection criteria can be considered as an opportunity to produce energy from land while reducing pressure on water resources. The typical crops method has proved to be robust and efficient at large time and space scales. Possible adaptations and improvements of the method lie in intermediate scale (sub-basin) assessment to better deal with spatial heterogeneity and in calculations based on a wider set of climate data to deal with climate variability. This method can be adapted to multiple water uses prospective study at large basin scale. The methodological options are also a very interesting base for water and energy indicators improvement.

### **Acknowledgements**

The authors wish to thank M.Colombier (IDDRI) for his implication in the study, all Steering Committee Members, INRA crop scientists and other contributors, all of them being mentioned in the CLIP paper (Lorne and Bonnet, 2009).

### **References**

- **Allen R., Pereira LA., Raes D., Smith M.**, 1998, Crop evapotranspiration, FAO Irrigation and Drainage Paper No. 56. FAO, Rome.
- **Amigues J.P., Debaeke P., Itier B., Lemaire G., Seguin B., Tardieu F., Thomas A.** (éditeurs), 2006, Sécheresse et agriculture. Réduire la vulnérabilité de l'agriculture à un risque accru de manque d'eau, Expertise scientifique collective, Rapport, INRA (France), 72 pp.
- **Arregui L. M., Quemada M.**, 2006, Drainage and nitrate leaching in a crop rotation under different N-fertilizer strategies: application of capacitance probes, *Plant Soil* (2006) 288:57–69
- **Champagain A.K., Hoekstra A.Y.**, 2011, The blue, green and grey water footprint of rice from production and consumption perspectives, *Ecological Economics*, 70, 749-58

- **Comifer**, 2002, Lessivage des nitrates en systèmes de cultures annuelles. Diagnostic du risque et propositions de gestion de l'interculture. Note du Comifer, groupe Azote, 2002, 41 p.
- **Eulenstein F., Werner A., Willms M., Juszczak R., Schlindwein S.L., Chojnicki, B.H., Olejnik J.**, Model based scenario studies to optimize the regional nitrogen balance and reduce leaching of nitrate and sulphate of an agriculturally used water catchment, *Nutr Cycl Agroecosyst* (2008) 82:33–49
- **Gomez E., Ledoux E., Mary B.**, Modélisation de la contamination nitrique des masses d'eau souterraine par les nitrates d'origine agricole, Rapport PIREN Seine, 2002, 37 p.
- **Han Lee K., Jose S.**, 2004, Nitrate leaching in cottonwood and loblolly pine biomass plantations along a nitrogen fertilization gradient, *Agriculture, Ecosystems and Environment* 105 (2005) 615–623, 23/08/2004
- **Hydratec, BIPE, GERPA**, 2007, Elaboration de scénarii d'évolution des besoins en eau à comparer à la disponibilité de la ressource en eaux superficielles dans le bassin Seine-Normandie. Horizon 2015 et 2025. Rapport final 2007 commandité par l'Agence de l'Eau Seine-Normandie. <http://www.eau-seine-normandie.fr/index.php?id=5308>
- **Joint Research Centre (JRC)**, European Commission, 2006, Sustainable Bioenergy Cropping Systems for the Mediterranean, JRC/EEA/CENER/CIEMAT Workshop, Madrid, EUR 22326.
- **Justes E., Mary B., Nicolardot B.**, Comparing the effectiveness of radish cover crop, oilseed rape volunteers and oilseed rape residues incorporation for reducing nitrate leaching, *Nutrient Cycling in Agroecosystems* 55: 207–220, 1999.
- **Lorne D., Bonnet J.F.**, 2009, Water and biofuels in 2030, Water impacts of French biofuel development at the 2030 time horizon, CLIP Papers, Issue 19, 98 pp., [www.iddri.org](http://www.iddri.org).
- **Viennot P., Ducharne A., Habets F., Lamy F., Ledoux E.**, 2009, Hydrogéologie du Bassin de la Seine, Agence de l'Eau Seine Normandie, 55 pp., France.
- **Ruelle P., Mailhol J.C., Quinones H., Granier J.**, 2003, Using NIWASAVE to simulate impacts of irrigation heterogeneity on yield and nitrate leaching when using a travelling rain gun system in a shallow soil context in Charente (France), *Agricultural Water Management* 63 (2003) 15-35
- **Salameh Al-Jamal M., Sammis T.W., Jones T.**, 1997, Nitrogen and chloride concentration in deep soil cores related to fertilization, *Water Management* 34 (1997) I–16.
- **Sebilo M., Billen G., Grably M., Bleuse N., Bardoux G., Mariotti A.**, 2000, Caractérisation et quantification du processus de dénitrification riparienne à l'échelle d'un bassin versant: Cas du Grand Morin, Rapport pour le PIREN Seine, 13pp.
- **Stout W.L., Fale S.L., Muller L.D., Schnabel R.R., Weaver S.R.**, 1999, Water quality implications of nitrate leaching from intensively grazed pastures wards in the northeast US., *Agriculture, Ecosystems and Environment* 77 (2000) 203–210
- **Straëbler M., Le Gall A.**, 1998, Luzerne sorgho et betterave. Trois cultures fourragères sécurisantes en conditions sèches ou froides, *Fourrages*, 156: 573-587
- **Van Beek C.L., Brouwer L. Oenema O.**, 2003, The use of farmgate balances and soil surface balances as estimator for nitrogen leaching to surface water, *Nutrient Cycling in Agroecosystems* 67: 233-244.



**Figure 1: The six main Water Basins (France, Adour Garonne in the Southwest, Seine Normandie in the North.**

	<b>Biofuel production</b>	<b>Biofuel Technologies</b>	<b>Dedicated areas</b>	<b>Agricultural productivity scheme</b>
<b>Scenario 1A</b>	5 Mtoe* 210 10 <sup>6</sup> GJ	VOME Bioethanol G1	2,6 Mha	As usual
<b>Scenario 1B</b>	5 Mtoe 210 10 <sup>6</sup> GJ	VOME Bioethanol G1 Biomethane	1,67 Mha	As usual
<b>Scenario 2</b>	20 Mtoe 840 10 <sup>6</sup> GJ	BtL Bioethanol G2	6,9 Mha (¼ UAA)	Productive (high input level)
<b>Scenario 3</b>	~14 Mtoe ~590 10 <sup>6</sup> GJ	BtL Bioethanol G2	6,9 Mha (¼ UAA)	Environmental priority

**Table 1: Summary of the four bioenergy development scenarios (CLIP Paper, Lorne and Bonnet, 2009) (Nota: Utilised Agricultural Area, UAA)**

S1A-SN				S1B-SN			
species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr	species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr
Rapeseed	4	519	0.76	Rapeseed	4	428	0.63
Wheat	10	215	0.47	Wheat	10	112	0.25
Beet	80	126	0.50	Beet	80	34	0.14
				Alfalfa	12	61	0.18
				Wheat straw			0.27
<b>TOTAL</b>		<b>859</b>	<b>1.73</b>			<b>635</b>	<b>1.47</b>
S2-SN				S3-SN			
species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr	species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr
Whole triticale	13	471	0.98	Alfalfa	12	268	0.51
Alfalfa	15	281	0.67	Fescue	6	98	0.16
Fescue	15	229	0.55	Fescue-clover	15	461	1.1
Miscanthus	25	335	1.34	Miscanthus	15	493	1.18
VSRC Poplar	15	172	0.41	SRC Acacia	8	143	0.18
<b>TOTAL</b>		<b>1488</b>	<b>3.95</b>			<b>1434</b>	<b>3.13</b>

**Table 2 (a): Crops and production in the four scenarios, as implemented in Seine Normandie (adapted from CLIP Paper, Lorne and Bonnet, 2009)**

S1A-AG				S1B-AG			
species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr	species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr
Rapeseed	3.5	174	0.19	Rapeseed	3.5	133	0.17
Sunflower	2.8			Sunflower	2.8	138	0.14
Wheat	8	116	0.20	Maize	10	29	0.07
Maize	10	152	0.33	Straw			1.14
<b>TOTAL</b>		<b>442</b>	<b>0.72</b>			<b>300</b>	<b>1.52</b>
S2-AG				S3-AG			
species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr	species	Harvest yield t/ha	dedicated land 1000 ha	Fuel production Mtoe/yr
Biomass Maize	25	287	1.15	Fiber Sorghum	13	253	0.52
Fiber Sorghum	25			Fescue	6	69	0.06
Switchgrass	20	404	1.3	Fescue-clover	14	262	0.59
Provence Cane	25	149	0.59	Miscanthus	13	265	0.55
VSRC Eucalyptus	15	185	0.44	Switchgrass	12	132	0.25
				SRC Eucalyptus	12	102	0.19
<b>TOTAL</b>		<b>1164</b>	<b>4.03</b>			<b>1084</b>	<b>2.16</b>

**Table 2 (b): Crops and production in the four scenarios, as implemented in Adour Garonne (adapted from CLIP Paper, Lorne and Bonnet, 2009)**

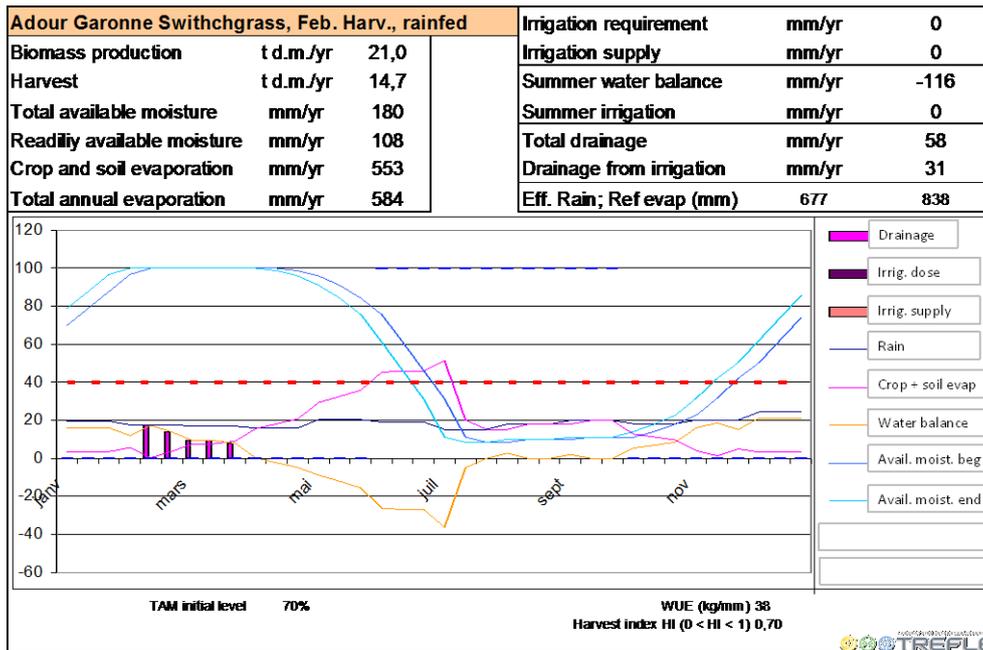


Figure 2: Example of crop soil water balance profile (Rainfed Switchgrass with deep soil, February harvest, in Adour Garonne).

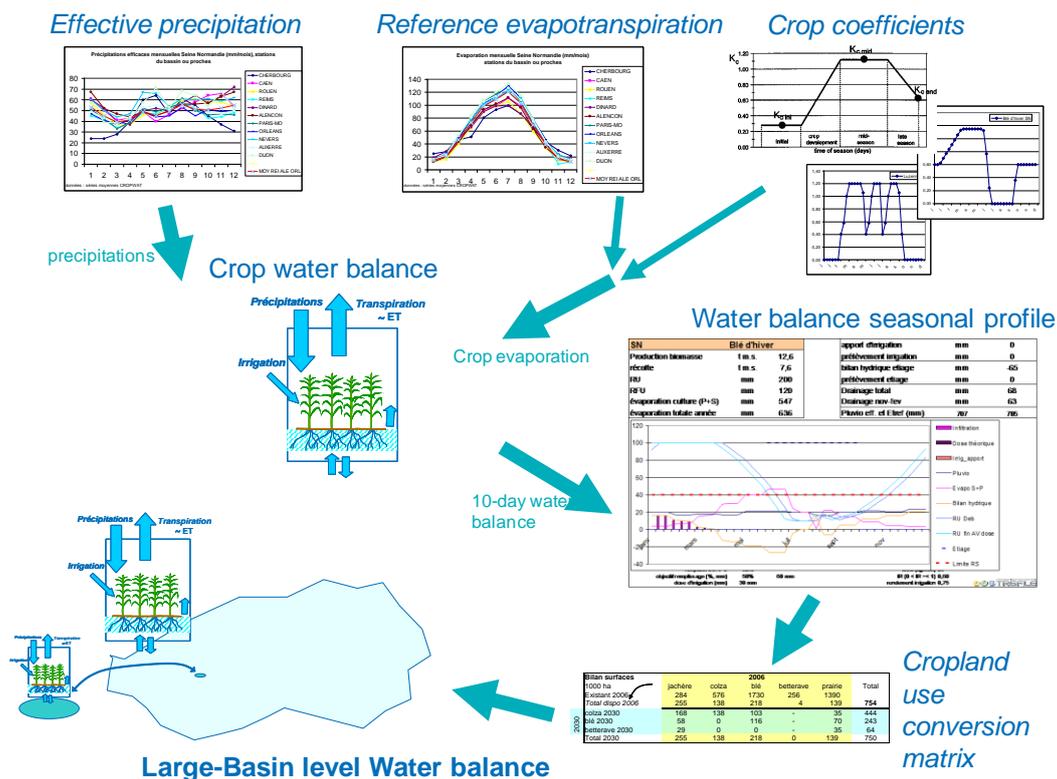
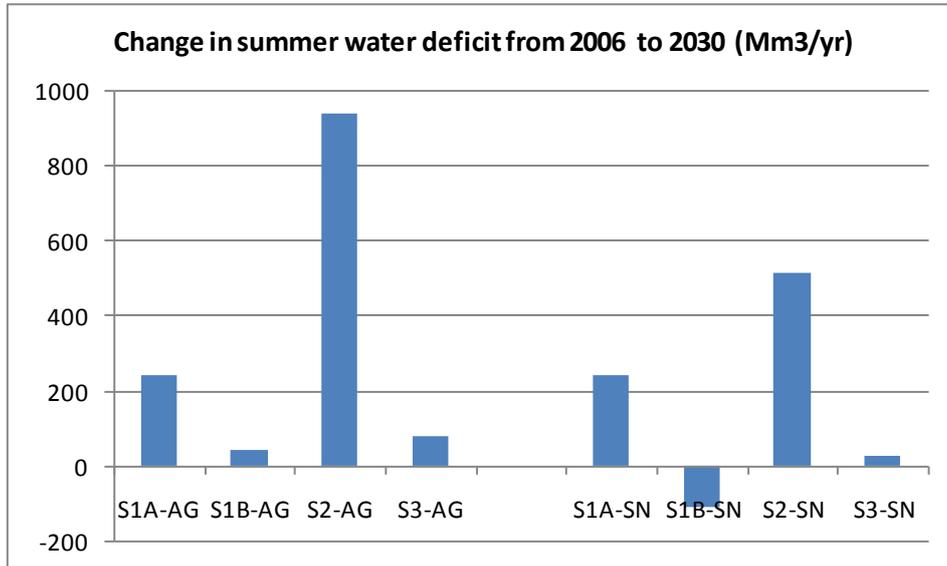
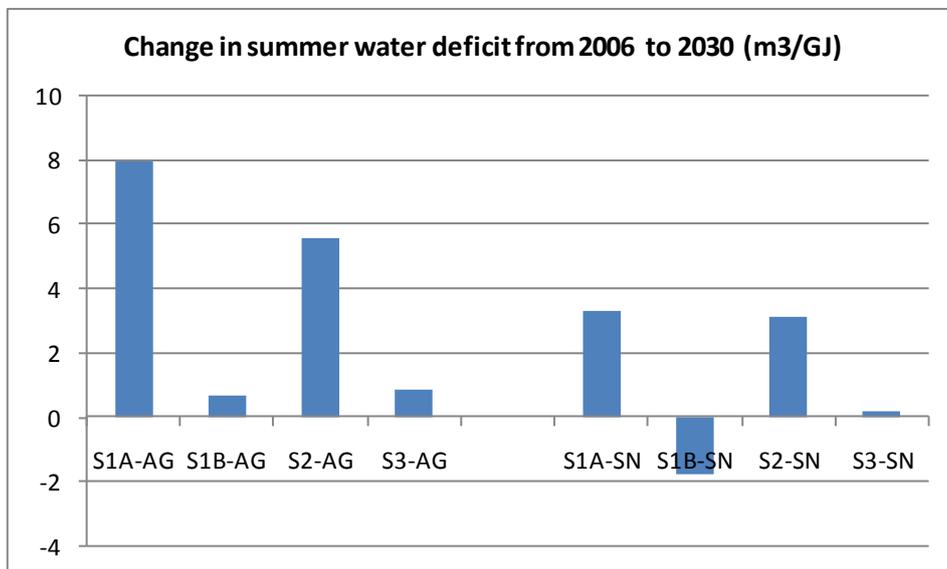


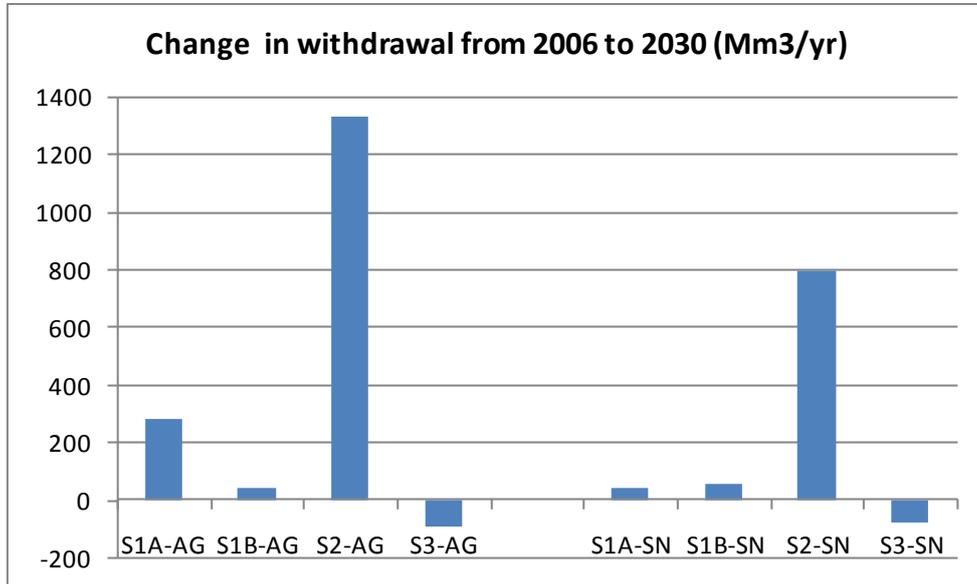
Figure 3: Methodology of assessment at basin level, based on the typical crops system evaluation. Typical crops systems are defined to be as representative as possible of the mean value at large basin level.



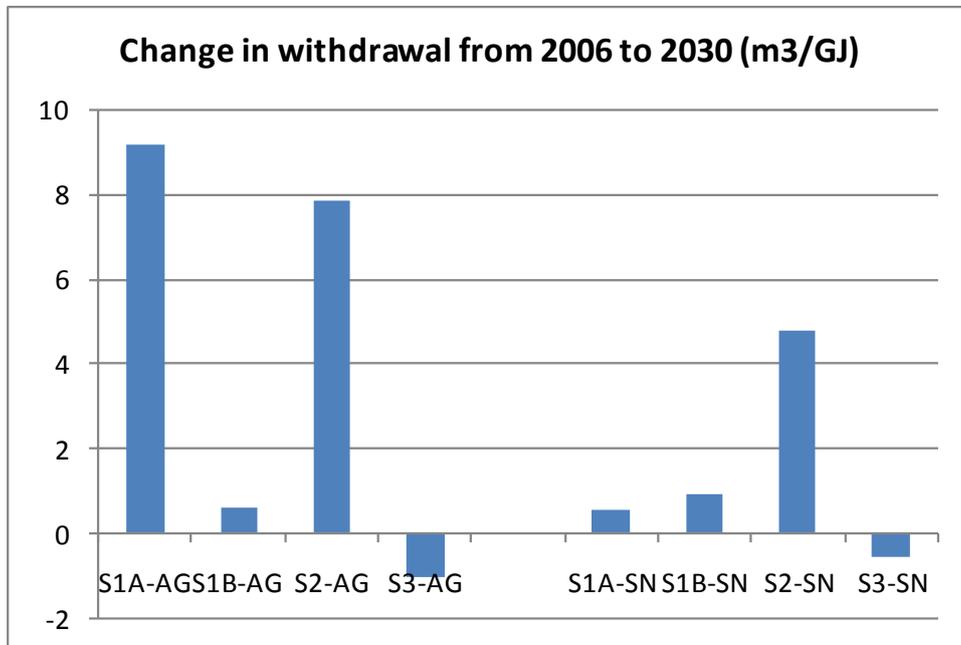
**Figure 4: Change in Summer Water Deficit (SWD) from 2006 to 2030 (Mm<sup>3</sup>/yr)**



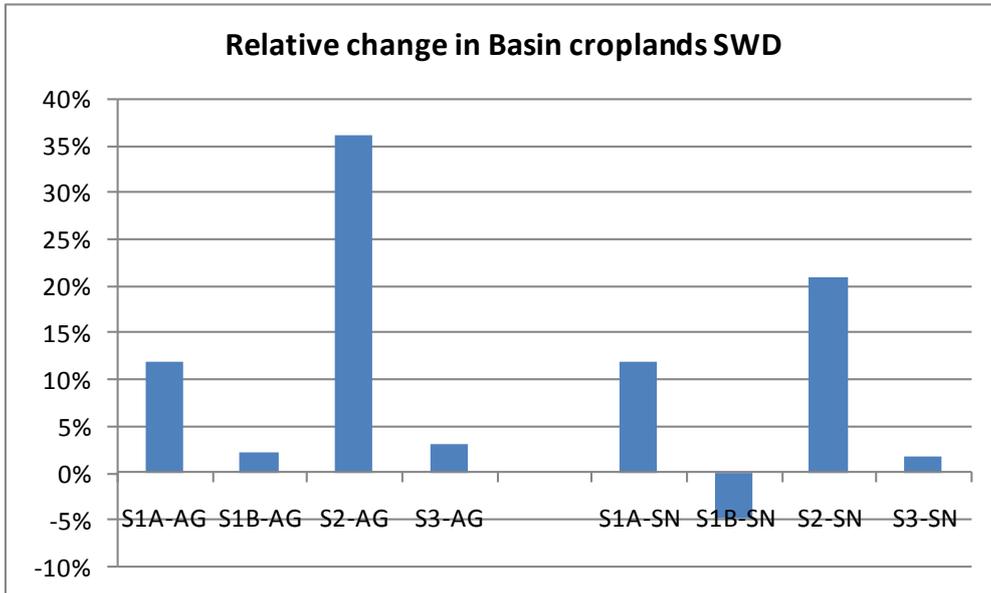
**Figure 5: Change in Summer Water Deficit (SWD) from 2006 to 2030, related to the energy produced in different scenarios (m<sup>3</sup>/GJ)**



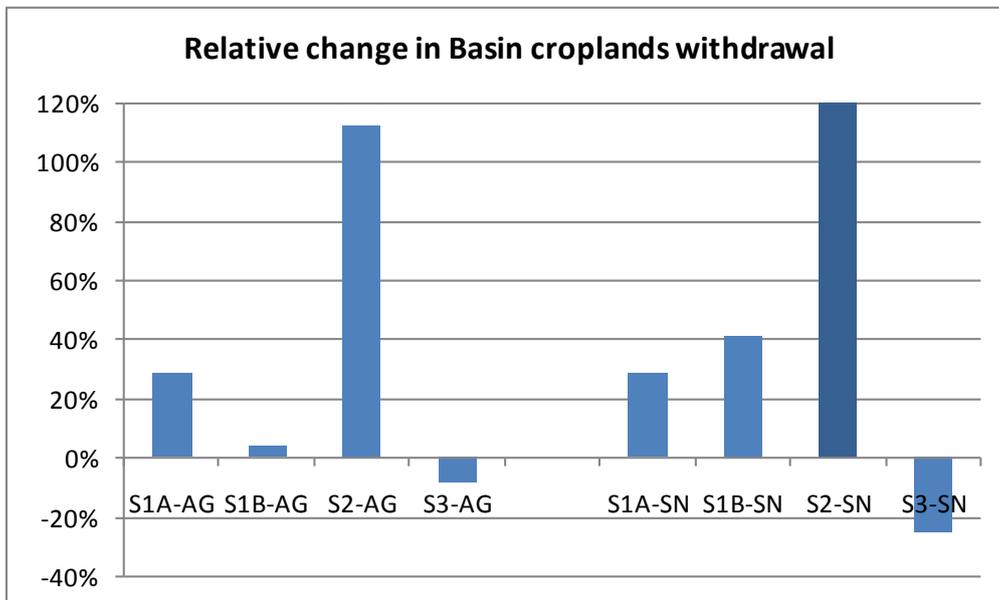
**Figure 6: Change in water withdrawal from 2006 to 2030 (Mm<sup>3</sup>/yr)**



**Figure 7: Change in water withdrawal from 2006 to 2030, related to energy produced in the scenario (m<sup>3</sup>/yr)**



**Figure 8: Relative change in Basin croplands Summer Water Deficit (SWD, % of change from 2006 to 2030)**



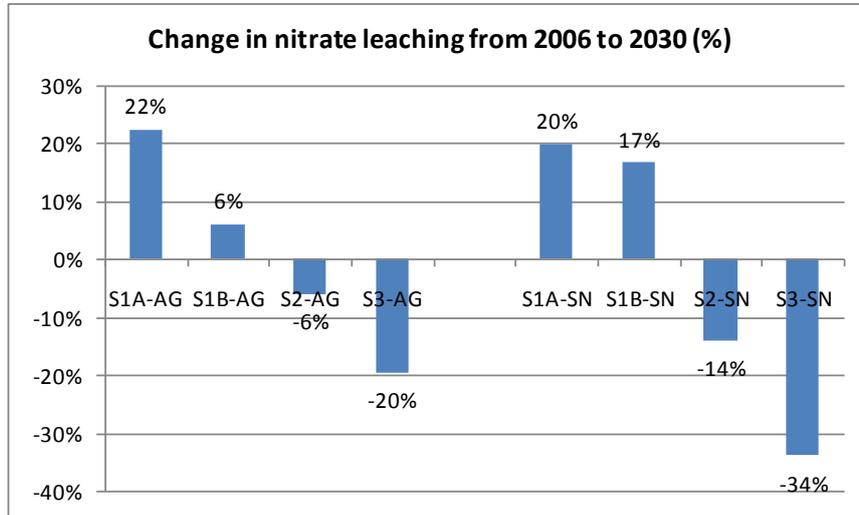
**Figure 9: Relative change in Basin croplands withdrawal (% of change from 2006 to 2030)**

		Adour Garonne			
		S1A-AG	S1B-AG	S2-AG	S3-AG
<b>Summer water deficit (SWD)</b>					
SWD 2030 converted croplands	Mm3/yr	387	209	2000	591
Change in SWD 2006 to 2030	Mm3/yr	241	43	944	77
Relative change in Basin croplands SWD	%	12%	2%	36%	3%
Change in SWD 2006 to 2030	m3/GJ	8,0	0,7	5,6	0,9
<b>Withdrawal</b>					
Withdrawal 2030 converted croplands	Mm3/yr	278	51	1782	0
Change in withdrawal 2006 to 2030	Mm3/yr	277	37	1326	-95
Relative change in Basin croplands withdrawal	%	29%	4%	112%	-8%
Change in withdrawal 2006 to 2030	m3/GJ	9,2	0,6	7,8	-1,0

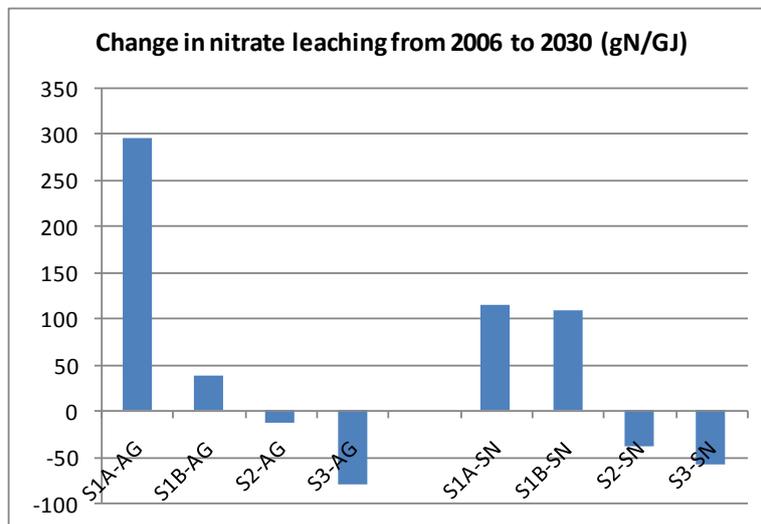
**Table 3: Basic water quantity indicators on Adour Garonne Basin for the four scenarios. Relative change is calculated with reference to Basin main croplands and pasture land total area**

		Seine Normandie			
		S1A-SN	S1B-SN	S2-SN	S3-SN
<b>Summer water deficit (SWD)</b>					
SWD 2030 converted croplands	Mm3/yr	387	267	1340	774
Change in SWD 2006 to 2030	Mm3/yr	241	-111	516	25
Relative change in Basin croplands SWD	%	12%	-5%	21%	2%
Change in SWD 2006 to 2030	m3/GJ	3,3	-1,8	3,1	0,2
<b>Withdrawal</b>					
Withdrawal 2030 converted croplands	Mm3/yr	80	64	793	0
Change in withdrawal 2006 to 2030	Mm3/yr	39	56	793	-78
Relative change in Basin croplands withdrawal	%	28%	41%	254%	-25%
Change in withdrawal 2006 to 2030	m3/GJ	0,5	0,9	4,8	-0,6

**Table 4: Basic water quantity indicators on Seine Normandie Basin for the four scenarios. Relative change is calculated with reference to Basin main croplands and pasture land total area**



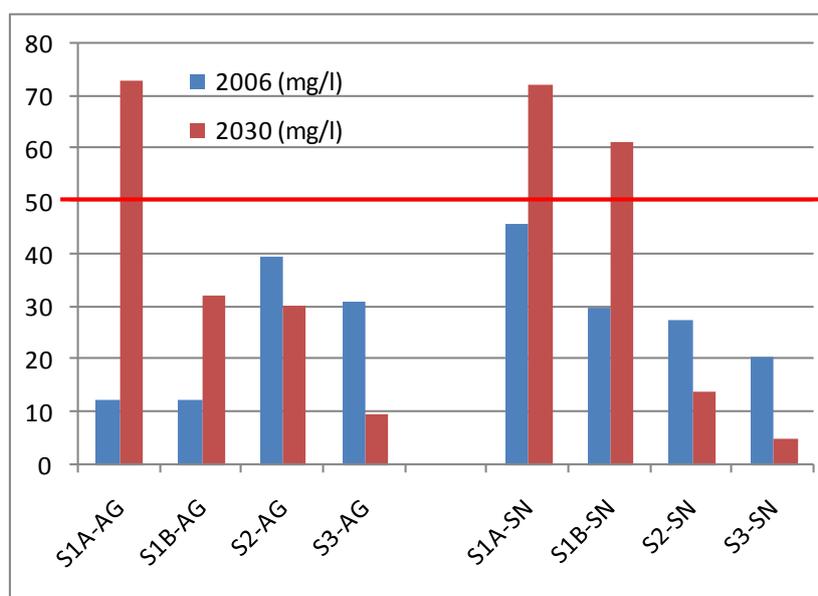
**Figure 10: Relative change in Nitrogen loss from 2006 to 2030 related to Basin croplands (gN/GJ)**



**Figure 11: Change in Nitrogen loss from 2006 to 2030 divided by the energy produced in various scenarios (gN/GJ)**

		Adour Garonne				Seine Normandie			
		S1A-AG	S1B-AG	S2-AG	S3-AG	S1A-SN	S1B-SN	S2-SN	S3-SN
NL1 Nitrogen Loss change	(tN/yr)	8944	2392	-2220	-7197	8329	6762	-6291	-7727
NL2 Nitrogen Loss change	kgN/(ha.yr)	20,3	8,0	-1,5	-4,9	9,7	10,6	-5,4	-7,2
NL3 Relative change in Basin croplands NL	(%)	22%	6%	-6%	-20%	20%	17%	-14%	-34%
NL4 NL content of energy	gN/GJ	295,8	37,5	-13,1	-79,3	114,6	109,5	-37,9	-58,8
NC1 NC in dedicated crops drainage 2006	mgNO <sub>3</sub> /l	13	12	39	31	46	30	28	21
NC1 NC in dedicated crops drainage 2030	mgNO <sub>3</sub> /l	73	32	30	10	72	61	14	5
NC2 NC in Basin croplands drainage 2006	mgNO <sub>3</sub> /l	47	68	42	41	37	32	30	23
NC2 NC in Basin croplands drainage 2030	mgNO <sub>3</sub> /l	56	70	38	35	43	37	25	15

**Table 5: Basic water quality indicators for nitrogen loss (NL) and nitrate concentration (NC) for the four scenarios.**



**Figure 12: Nitrate concentration in under root drainage (mgNO<sub>3</sub>/l) for crop areas converted from 2006 to 2030. The red line shows, as an indicative threshold, the maximum authorized value in drinking water**

## Abbreviations

AIW	Annual Irrigation Withdrawal
CLIP	Club d'Ingénierie Prospective Énergie et Environnement
GJ	Giga Joule ( $10^9$ )
HI	Harvesting Index
IDDDRI	Institute for Sustainable Development and International Relations
IFPEN	Institut Français du Pétrole Energies Nouvelles
INRA	Institut National de la Recherche Agronomique
Mm <sup>3</sup>	Million Cubic meters
NC	Nitrogen Concentration
NL	Nitrogen Loss
PET	Potential Evapotranspiration
SWD	Summer Water Deficit
TFI	Treatment Frequency Index
UAA	Utilised Agricultural Area
Wia LBS	Water Impact Assessment at Large Basin Scale
WUE	Water Use Efficiency



# Water and bioenergy in Australia

**B.H. George**

**University of New England & New South Wales**

**Department of Primary Industries, Australia**

## **Abstract**

Bioenergy is an important part of the small but growing renewable energy mix in Australia currently contributing approximately 67% of the renewable portion of energy consumed. Wood and bagasse are the dominant biomass feedstocks in bioenergy and are most commonly used for electricity and heat generation.

Whilst the utilisation of biomass for energy in Australia is significant there is a large, unrealised potential. In developing bioenergy opportunities there are significant technical, economic and social challenges including the competition for scarce natural resources such as water.

Australia is a dry continent with water scarcity a regular problem for agricultural production, human consumption and environmental systems; drought is common. The impact and implications of water availability and utilisation change with time and scale of the biomass production and energy transformation systems (the larger the biomass production the greater the potential impact). Not only does the Australian continent receive relatively little rain, the climate is highly variable. Agriculture is a significant consumer of available water (approximately 70%) and competing demands for water, in production, social and environmental spheres is increasing the pressure on water and other natural resources (Tilman et al., 2002; Pink, 2012). There are significant national, state and local initiatives and policy instruments deployed to address the impacts and implications of water scarcity. The National Water Initiative (NWI), established to underpin intergovernmental agreement and action in 2004, has significant ramifications for certain land uses including forestry, and potentially will impact on the development of large-scale bioenergy feedstock production.

The production systems are varied, examples in Australia include sugar cane and bagasse, wheat and stubble, residues from native and plantation forests and dedicated energy crops. The impact on the hydrological cycle from the production of biomass for energy can be significant. And depending on the management of the respective systems biomass production can affect local scale hydrology including the infiltration of water into the soil and the soil water holding capacity, to regional-scale impacts on stream flow and water quality. Associated with the hydrological impacts are other concerns from changed management practices such as the increased use of fertiliser (potentially leading to pollution problems such as eutrophication and release of N<sub>2</sub>O). The harvesting of biomass can impact on the nutrient balance in the soil and pH leading to a decline in soil health (e.g., soil carbon).

Water significantly influences the soil health of bioenergy production systems. Our focus here is in relation to water quantity and quality but consideration of other physicochemical and biological aspects of soil health are important in bioenergy feedstock production systems, especially with expected increases in scale and intensity to meet demand. Many impacts from

production are interrelated and can lead to significant long-term changes to the site-specific and catchment<sup>1</sup> hydrology. It is important that the potential changes are understood, and actual changes managed; to ensure positive outcomes through maximising benefits (e.g., ameliorating soil salinity) and minimising impacts (e.g., competition for water).

Government policies at the national (e.g., Renewable Energy Target) and state levels (e.g., New South Wales Biofuels Act) facilitate the development of renewable energy options, including bioenergy. These instruments and the supporting programmes will increase the scale of bioenergy activities and supply chains leading to reduced costs and security of energy supply. Scale will significantly influence the impact of renewable energy systems and the required management to optimise the outcomes (*viz.*, reduce costs and ensure sustainable production systems are employed).

This paper, through reviewing the current literature and reporting some of our existing findings, aims to discuss the hydrological implications of developing bioenergy systems in Australia, a water-limited environment.

## **1. Status of bioenergy**

The consumption of energy is increasing within Australia as it is internationally. In Australia the growth in energy production averaged of 3.5% a year from 1997-98 to 2007-08 (ABARE, 2010). Renewable energy currently supplies  $\approx 5\%$  of energy consumed within Australia (ABARE, 2010). The proportion of energy supplied from renewable sources is increasing with bioenergy contributing approximately 67% of renewable energy (Penney et al., 2012). Biomass is also utilised for transport fuels with production capacity of approximately 440 ML for ethanol and 270 ML biodiesel during 2011 (Penney et al., 2012). Most ethanol production is from waste and low-value cereal grain and biodiesel from tallow and used cooking oil. There is little dedicated biomass grown for biofuel production.

The supply of energy from biomass sources is still, generally, more costly than existing fossil fuel based energy sources (Duer and Christensen, 2010; Bureau of Resources and Energy Economics, 2012). Due to the so-called ‘market failure’ linked to climate change (Stern, 2007), other social and environmental drivers are considered by government in arguing and facilitating development of renewable energy (O’Connell et al., 2009; Verbruggen et al., 2010).

## **2. Targets & relevant legislation**

### **2.1 Energy**

Whilst the existing fossil fuel resources are still significant, supplies are finite (International Energy Agency, 2009; Aleklett et al., 2010; BP, 2010). The different forms of energy carrier (e.g., coal, gas, oil) and different needs (e.g., heat, power and transport) lead to different values for energy (Dale, 2007). Concepts such as ‘energy security’ have different meanings and implications for different regions. In response, a multitude of policy options meeting local, national and global objectives are required. And when the policy is developed to meet multiple outcomes, for example linking energy security with climate change mitigation (e.g., through the use of biofuels displacing fossil fuels), then the choice of appropriate industry development and supply systems to meet these objectives is challenging.

<sup>1</sup> In Australia ‘catchment’, synonymous with ‘watershed’, is the most commonly used term.

Reasons often nominated in Australia to support the increase in the development of policy for renewable energy include:

- Energy security<sup>2</sup> ;
- Environmental benefits including mitigation for Climate Change;
- Rural and regional development;
- Human health.

Australia is continuing the development of various initiatives and policies to reduce carbon emissions via various instruments at the state and national level. The current policy and market mechanisms addressing energy security and cost, competition for food, carbon emissions and climate change are dynamic and subject to significant debate. Australia, through the introduction of the Clean Energy Act 2011 and related legislation, has established a carbon pricing mechanism and related programs to support the development of a market-based response to the need to reduce greenhouse gas emissions driving climate change<sup>3</sup>. Bioenergy, whilst identified in the Energy White Paper and identified as ‘mostly underdeveloped’ (Australian Government, 2012), is not considered as a significant contributor to long-term electricity supply (e.g., Energy White Paper Figures 3.7 and 3.8 on page 33). However, there are expectations that aviation fuels will be significantly supplied from biomass feedstocks (Energy White Paper pp.35 & 127).

Within Australia different states (provinces) have also legislated to address energy and climate concerns that impact on the production and use of bioenergy. For example, in New South Wales (NSW) a biofuel mandate currently exists, supported via the Biofuels Act 2007. The mandate includes consumption of ethanol and biodiesel. Other states have targets to increase the use of biofuels, but these are not supported by legislation. Nationally, the Australian Centre for Renewable Energy (ARENA) supports the production of biofuel through various programmes and initiatives<sup>4</sup>.

## 2.2 Water

Low rainfall, a variable climate of extremes and overutilization of existing water resources dictates the need for significant care and concern in land use, production and environmental requirements. Australia has long recognised the need to develop robust and resilient production systems and improve the management of environmental parameters. In a hydrological sense determining and delivering ‘environmental flows’ in rivers and addressing land-based issues such as soil health including salinity are priorities. There are significant and still-debated initiatives underway aiming to balance social, environmental and production implications from water capture, extraction and use.

Much of the framework for the respective legislation related to water in Australia is established through the Water Act (2007) and subsequent Water Amendment Act (2008). The National Water Initiative (NWI) is an intergovernmental agreement initiated in 2004 between the Territory, State and Federal governments aiming to “improve the management of the

<sup>2</sup> Energy security is a broad term with different interpretations. The term generally includes the concepts of access to reliable, secure and competitively priced energy (ideally this should be environmentally sound).

<sup>3</sup> See <http://www.cleanenergyfuture.gov.au/clean-energy-future/an-overview-of-the-clean-energy-legislative-package/> for details; accessed September 2012.

<sup>4</sup> See <http://www.arena.gov.au/> for details; accessed September 2012.

nation's water resources and provide greater certainty for future investment”<sup>5</sup>. Complicating the development of outcomes for industry, society and the environment is the interaction between different jurisdictions. For example, through the NWI “governments across Australia have agreed on actions to achieve a more cohesive national approach to the way Australia manages, measures, plans for, prices, and trades water”. But the interplay between the jurisdictions and their respective legislated roles demands extensive negotiations to achieve agreed outcomes.

Initiatives, such as the NWI, have implications for biomass production systems such as plantation forestry. For example, under the NWI there is a specific clause (#55) regarding land use change activities and water interception. Large-scale plantation forestry, identified as one activity of ‘concern’ could potentially supply significant biomass for energy – bioenergy. A balance between resource utilisation and outcomes is required and this complicates the policy environment with potentially competing initiatives.

### **2.3 Land**

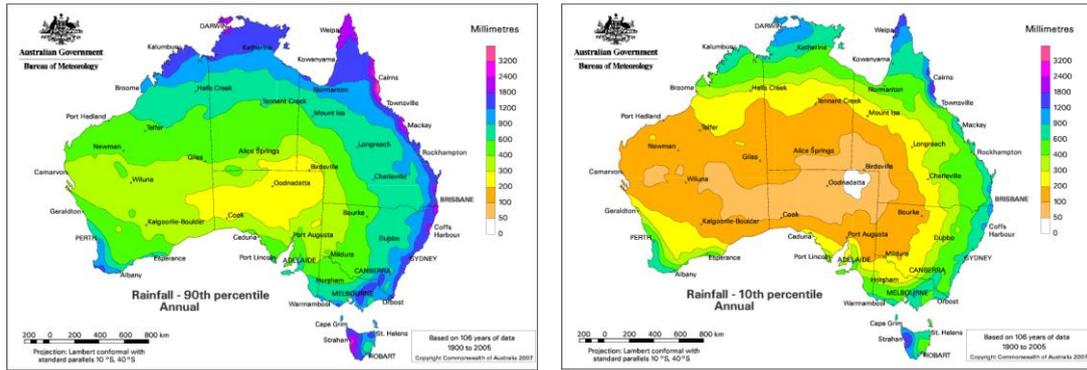
In Australia the legislation concerning land management is determined by tenure (i.e., who owns/controls land), the existing status (such as native vegetation/forest cover or cleared agricultural areas), the proposed land use and potential impacts. Many of the regulations are determined at a state level (e.g., the NSW Native Vegetation Act 2003).

For bioenergy production, some uses and even specific activities, are limited. For example, native forests may be harvested for wood but the residues are ineligible for the renewable energy target (electricity generation). In meeting the NSW state-based biofuels mandate the Roundtable for Sustainable Biofuels (RSB) principles and criteria apply throughout the supply chain, including the management of land and water resources. However, the same (feedstock) produce may go to a different market and not have to meet any particular environmental requirements/regulations. There is inconsistent treatment of biomass depending on the end market.

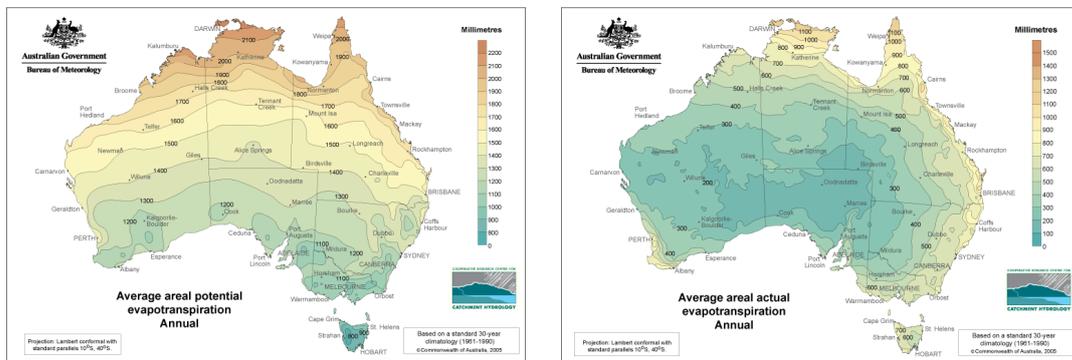
### **3. Climate**

Australia receives lower average rainfall than most other continents and some of the most variable climatic patterns complicate this (Figure 1). Not only is rainfall modest but evaporation is large (Figure 2). The climatic variability has very practical implications for human water consumption including increased need for water storage. For example, Melbourne has approximately 10 times per capita water storage compared to London (Prosser, 2011).

<sup>5</sup> [http://www.water.gov.au/introductiontoawr2005/TheNationalWaterInitiative/index.aspx?Menu=Level1\\_2\\_3](http://www.water.gov.au/introductiontoawr2005/TheNationalWaterInitiative/index.aspx?Menu=Level1_2_3); accessed September 2012.

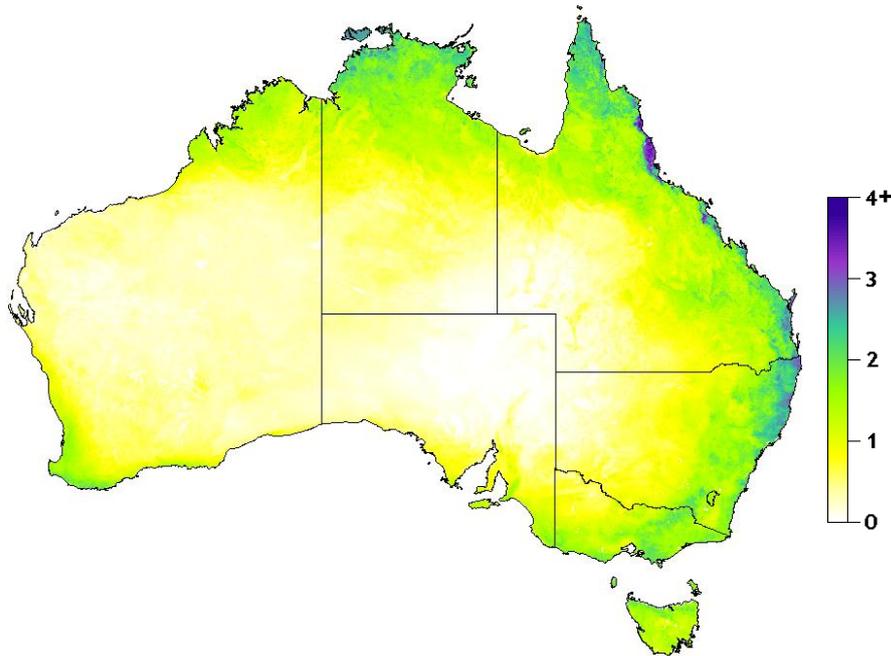


**Figure 1: The variation in rainfall across Australia showing ‘wet season’ (Left) and ‘dry seasons’ (Right) indicating the 90<sup>th</sup> and 10<sup>th</sup> percentile readings respectively (Source – Bureau of Meteorology).**



**Figure 2: Potential (LHS) and actual (RHS) evaporation across the Australian continent (Source – Bureau of Meteorology).**

Crop yields fluctuate significantly according to the climatic variability as well as location, soil type and management. Water use by vegetation also varies significantly across the landscape. And water use, not only driven by evaporation, but also transpiration is similarly variable across the nation (Figure 3). Whilst it is estimated that Australia has the capacity to meet the needs of more than 60 million people climatic variability and uneven distribution of water resources has led to the over-allocation of some resources where others have significant scope for future development (Prosser, 2011). The Murray-Darling basin in Eastern Australia, considered the ‘food-bowl’ for many agricultural commodities, is an example of the water stress on catchments and the complexity in negotiating government and community responses to the social, environmental and production needs (see the Case Study below).



**Figure 3: Estimated average transpiration ( $\text{mm day}^{-1}$ ) for Australia during 2011**  
(Source [www.eoc.csiro.au/awap/cgi/awap2.pl](http://www.eoc.csiro.au/awap/cgi/awap2.pl); accessed September 2012).

#### 4. Biomass production for bioenergy

Estimation of biomass production and water consumption varies significantly. High-level (global or national) estimations give indicative values such as those from Farine et al. (2012). Table 1 (taken from their Table 2; p152), list significant biomass production for bioenergy products including ethanol and electricity. Not considered in the Table are the existing or alternative uses for the biomass. For example, sugar is currently consumed in domestic markets and exported; pulplogs from hardwood plantations are mostly committed to existing domestic and international markets. For dedicated woody energy crops in southern Australia yields of  $>8 \text{ M t (dry) per annum}$  has been estimated (Bartle et al., 2007). There are regional estimations of available biomass (e.g., Kovac & Scott (2012) in NSW)<sup>6</sup>. Others have estimated biomass production from the ‘bottom-up’ where growth data is extrapolated via modelling (Bartle et al., 2007; Polglase et al., 2008). However, these estimations do not account for on-farm variability in production.

Spatial and temporal variability make the prediction of production rates difficult. For example, Peck et al. (2012) found large spatial and temporal variability in eucalyptus mallee plantings on agricultural land with yield differences of 50% or more over short distances (i.e., in tens of meters). Inter and intra-seasonal climatic variation has a significant impact on biomass production across Australia (Prosser, 2011; Herr et al., 2012) further confounding modelled estimates of available biomass for bioenergy.

Water availability, whilst critical in many locations is not the only limiting factor. For example, most Australian soils have low nutrient hold capacity and the balance of retaining

<sup>6</sup> For Victoria see <http://www.rdv.vic.gov.au/business-and-industry-programs/biofuels-and-bioenergy>; accessed December 2012.

nutrients on site and utilisation for current production is critical to sustain biomass energy systems (George and Cowie, 2011).

<b>Biomass class » energy carrier/form</b>	<b>Area ('000 ha)</b>	<b>Estimated annual production (dry kt)</b>	<b>Potentially available annual biomass (dry kt)</b>
<i>Starch » ethanol</i>			
Grains	16 632	31 492	31 492
<i>Sucrose » ethanol</i>			
Sugar cane and molasses	418	6 547	5 653
<i>Oil » biodiesel</i>			
Canola	1 060	1 382	1 382
Animal tallow and waste oil		689	689
<i>Lignocellulose » electricity or ethanol</i>			
Bagasse	418	6 377	5 505
Annual crop stubble	19 498	63 077	33 213
Native forest residue	9 408	5 445	1 634
Native forest sawmill residue		1 320	1 320
Plantation forest hardwood residue	991	871	199
Plantation forest hardwood pulplog	991	2 037	2 037
Plantation hardwood sawmill residue		106	106
Plantation forest softwood residue	1 020	2 676	614
Plantation softwood sawmill residue		2 808	2 808
Urban wood waste		1 064	1 064

**Table 1: The estimated biomass feedstock production and harvest for various energy carriers for all of Australia (Summarised from Farine et al., 2012).**

Note the potentially available annual biomass harvest is significantly lower than the estimated annual production to account harvesting limitations, environmental constraints (See Farine et al. 2012 for details).

## 5. The hydrological cycle and bioenergy

All vegetation will transpire water during growth and evaporation is relentless where water is freely available. Evapotranspiration (Figures 2 & 3) accounts for ≈89% of rainfall in Australia with the remaining water either running off the soil surface (9%) or percolating into the soil below the root zone of plants as groundwater recharge (2%) (Prosser, 2011). Agriculture, including rangelands, uses the majority of available water.

Water is one of the most significant limiting parameters in most Australian agricultural enterprises. This limitation will be a challenge for the utilisation of biomass for energy purposes as feedstock supply will be variable (especially due to the climate) and potentially compete for land and water resources for food production.

Competition for water will increase if woody species, with deep roots, are planted as they utilise more than annual crops (White et al., 2002). A general conclusion that ‘trees use more water than pasture and annual crops’ is widely accepted (e.g., Zhang et al., (2001)). The increased capacity to intercept water below the annual crop root zone is important to promote tree survival and increase biomass productivity and potentially enhance environmental benefits (Robinson et al., 2006). But this increased water use increases competition with other agricultural crops (Sudmeyer et al., 2012).

The impact of vegetation on local and catchment scale hydrology though fundamentally understood is difficult to accurately estimate and predict. In Australia there is a need for better understanding of soil water movement at the farm level and the implications for larger-scale catchment implications (Barrett-Lennard, 2002; Herron et al., 2003; Vertessy et al., 2003). Changes in cropping practice leading to increased or decreased water movement on a small scale (e.g., in a single paddock) can have consequences that only become evident years, decades or even centuries later; often at a considerable distance of kilometres or even hundreds of kilometres from the area of land use change.

Though hydrological impacts can be significant at local and larger scale catchments (Herron et al., 2003; Vertessy et al., 2003), recent studies in Western Australia indicate that a large proportion of catchments would need to be planted to mallees to significantly reduce salinity. Bennett et al. (2011) found at sites located in 450 mm rainfall zones that “a belt canopy area of 3–10 per cent of the landscape accounted for up to a 30 per cent net decrease in recharge to groundwater systems”. However, this had “no discernable effect on catchment-scale groundwater levels”. They concluded that two-row mallee systems would have a strong competitive effect with crops whilst not significantly ameliorating secondary salinity. That is, unless significant portions of the catchment are planted, the introduction of woody crops would not have a significant effect on the catchment hydrology.

Comprehensively developing and measuring spatially and temporally sensitive metrics capable of reporting the quantity of water utilised for production whilst accounting for environmental needs is a significant task.

In growing biomass and converting to a useable energy (carrier) we can differentiate between consumptive and non-consumptive use of water and the partitioning between ‘grey’, ‘blue’ and ‘green’ components as outlined by the Water Footprint Network (WFN). We can then estimate the quantities used for various production and environmental requirements. This is based on the concept developed earlier by Hoekstra and Hung (2002) and developed by others.

Whilst an onerous task, quantification of the amount of water, availability and use is but an initial step; the impact of water use for bioenergy production is required to allow value judgements about the appropriate use of this scarce resource. Several approaches try to quantify the impact of water use including: water footprints (Hoekstra and Chapagain, 2007); water stress indicators (and indices) (Rijsberman, 2006); and water scarcity (Pfister et al., 2011). A challenge for these indicators is to integrate temporal and spatial information that is timely and at a scale where analysis will match the capacity to adapt to or mitigate water-related issues.

We can readily agree with the logic described by Young & McColl (2009) where they suggest “that if entitlement and allocation regime are set up in ways that have hydrological integrity, the result should be a regime that can autonomously adjust to climatic shifts, changes in prices and changes in technology without compromising environmental objectives”. Critical to their logic is the interpretation of the ‘hydrological integrity’; this is often either poorly or partially considered, or overlooked<sup>7</sup>.

<sup>7</sup> There is significant information in the existing literature regarding hydrology and hydrological implications of vegetation across the landscape. This topic, whilst fundamental to this discussion, is not detailed in this paper. Instead we focus on the hydrological implications of bioenergy systems and interpretation of impacts.

### **Case Study - the Murray-Darling Basin**

The Murray-Darling Basin (MDB) in the south eastern Australian mainland is an area (1 060 000 km<sup>2</sup>) covering some 14% of Australia receiving on average 530 600 GL of water as rainfall with 94% of this transpiring or evaporating, 2% entering the groundwater and 4% becoming run-off (Pink, 2008). The MDB encompasses five jurisdictions including the States of Queensland, New South Wales, Victoria and South Australia; and the federal jurisdiction of the Australian Capital Territory.

Agriculture (66.7%) and native forestry (31.9%) are the dominant land-uses in the basin. Plantation forestry, covering an area of approximately 3 600 km<sup>2</sup>, represents approximately 0.3% of the basin (Pink, 2008). 'Production' forestry represents approximately 3.2% of land use. Clearing of native vegetation is limited under respective state legislation and new forest plantations are established on cleared agricultural land.

Water consumption in the basin, like the rest of the continent, is variable and dependent on the climate (rainfall and temperature). In 2008-09 ≈6 000 GL was consumed in the basin. In 2009-10 consumption decreased to ≈5 700 GL; equating to 42% of total water consumption in Australia (Pink, 2012). The agriculture industry consumed nearly 4 000 GL representing ≈70% of water use and more than 50% of water consumed for agriculture across the nation. In contrast household consumption during 2009-10 was 185 GL. The process of distributing the water is inefficient with losses of an estimated 1 280 GL (28%) across the basin.

Production of biomass for bioenergy is not directly controlled by legislation (with the exception of an inability to utilise native forest residues). However, instruments such as the National Water Initiative, especially where planted forests may have to meet specific water-based regulations, will influence production amounts. Whilst this is occurring other initiatives aim to increase water use efficiency of the agricultural systems potentially leading to reduced water availability downstream (e.g., increased utilisation of perennial pastures).

Competition for land and water resources in the MDB is significant and likely to increase in response to demand (e.g., population and market opportunities) and expectations (e.g., changing living standards) whilst resource limits are tested (e.g., climate change impacts, increasing fossil fuel and fertiliser costs). Management of resources, including water, in the MDB are going to remain complex and controversial.

## **6. Measuring the impact of bioenergy on water resources**

### **6.1 Water quantity**

We can estimate the expected water use in production of biomass for native species in many locations across Australia. For example, for native woody species selected for biomass potential in lower rainfall (<600 mm) areas of Australia Bartle et al. (2007) estimated water use efficiency of 1.8 dry g of biomass per kg (L) of water transpired. Bartle et al. aimed to specifically investigate the amount of material (biomass) that was produced per unit water that was transpired to compare vegetation types in relation to productivity. In their study they concluded that 8 Mt of biomass would require >4 440 ML of water (assuming availability at the most appropriate times for plant survival and optimal growth).

The amount of water used across a catchment can then determine the 'water footprint' (WF) (Hoekstra and Chapagain, 2007). But the concept needs to be carefully applied to ensure that all components of the hydrological cycle are considered and adequately partitioned. This issue is particularly related to rain-based systems and utilisation of 'green' water diminishing the availability of 'blue' water. Recently the application of the WF by Gerbens-Leenes & Hoekstra (2012) reported an efficient use of water for sugar cane production compared to

other countries and especially the 'green' water consumption. But this does not account for the on-site spatial or temporal impacts of water use, a limitation of WF recently raised by Sausse (2011).

Earlier studies sometimes confused or neglected important hydrological components, especially the impacts of evapotranspiration. For example, Ridoutt & Pfister (2010) argued that water transpired in biomass production was "better considered in the context of the land use impact category". Whilst this may simplify analysis of freshwater (blue) in LCA studies it can lead to outcomes that focus on the minor part of the hydrological balance. If the majority of the water is consumed/utilised in the growing phase for feedstocks (as evapotranspiration) in the bioenergy value chain this needs to be considered in analysis and reporting.

Recognising the way water is partitioned, measured and accounted can impact the development of markets. Nordblom et al. (2012) estimate the economic impact of policy requiring the purchase of water rights, advocated under the NWI, in south eastern Australia. Yet this analysis is also limited in that some selected land uses (and water consumption) are included but not others. In this case water use in forested areas is considered. However, agricultural management options that increase in situ water use and reduce downstream availability (e.g., increasing water holding capacity of the soil, increasing proportion of perennial pastures) are not. There is scope to extend the economic analysis across the landscape and to all parts of the hydrological cycle.

Much of the current analysis is ad hoc, limited and rarely comprehensive (i.e., does not consider the full hydrological balance or account for space and time). Developing the methodology, especially in LCA applications (e.g., Jeswani & Azapagic (2011)), will improve confidence in reported impacts (for example May et al. (2012) consider the 'blue' and 'green' components of the forest production system).

## **6.2 Water quality**

All land uses have an impact on the environment. And bioenergy systems can have both positive and/or negative effects (Diaz-Chavez et al., 2011). Water quality impacts can arise from non-point source pollutants (especially during the planting, growing and harvesting of the feedstock where issues such as soil erosion may occur), or as a point-source pollutant during the transformation of the feedstock into an energy carrier (e.g., waste water discharge from an ethanol plant). Non-point source pollution is significant and is often regulated through land use and best practice management guides. However, different land tenures and land uses need to meet variable regulations. For example the impact of harvesting woody biomass is regulated via different legislation than utilisation of crop residues such as cereal stubble. Both are potential sources for lignocellulosic feedstocks for bioenergy production. And the impacts of different crops (e.g., sugarcane production in coastal northern Australia) vary according to management, soil type/location and time (Renouf et al., 2010). Other land uses (e.g., long rotation native forest operations) can improve water quality when compared to (annual) agricultural systems (Hunter and Walton, 2008) due to reduced disturbance and increased vegetation along stream banks and a reduction in chemical usage (Prosser, 2011). Sustainable use of residues from these forests may have a negligible to positive impact on water quality (Webb, 2012).

Soil erosion, by wind or water, is a clear example of the importance of management of feedstock systems. Frequent disturbance and removal of residues are likely to increase the risk of erosion (Blanco-Canqui, 2010; Delucchi, 2010). Displacement of the soil significantly impacts soil health through loss of nutrients and soil carbon contributing to reduced production (Pimentel, 2006; Gregg and Izaurralde, 2010). The eroded soil can increase turbidity of streams and rivers (Tilman et al., 2002), and thus, combined with eutrophication

from nutrient runoff and leaching, can reduce water quality (Brandão et al., 2011). This is of particular concern for energy crop production systems where frequent disturbance and removal of residues are likely to increase the risk of erosion (Blanco-Canqui, 2010; Delucchi, 2010).

Processing and transformation into bioenergy products at a specific site (e.g., power station or ethanol production plant) is regulated via planning and operations legislation that may be applied to specific enterprises. These regulations are generally determined at a state level unless a project is deemed to be of national significance. And point-source pollution is generally easier to regulate and monitor than non-point source pollution.

### **6.3 Bioenergy water footprint**

Many of the sustainability schemes developed and applied to bioenergy systems rely on robust reporting frameworks that rely on the development and application of robust criteria and indicators. These, in turn, are supported by the provision of data that reports activities, outcomes and impacts. For selected indicators Life Cycle Assessment (LCA) is employed, often with success.

In application to some impact categories (e.g., GHG) LCA is reasonably robust, in a global sense, as a unit of CO<sub>2</sub>-e is uniform wherever sequestered or released. However, the application of the LCA approach can be problematic when considering the impact of water use in bioenergy systems. Whilst water quality (e.g., eutrophication) is often addressed as an impact category in the LCA, the quantity of water utilised is more difficult to estimate.

There are two significant limitations to the application of LCA for bioenergy systems to date. Firstly, many water-LCA results focus on the 'blue' water associated with production of bioenergy (e.g., water use of an ethanol plant). Few analyses consider the potential and actual partitioning of the 'green' and 'blue' components of bioenergy systems; that is the water that is utilised during the feedstock production stage (i.e., evapotranspiration from the plants). This is particularly important in rain-based systems and their influence on water that can then be utilised for irrigation (therefore 'blue') or environmental values (e.g., ecosystem services). A second issue is the need to consider the importance of time and space on the value we place on a unit of water. For example, a megalitre (ML) of water that is utilised in production of a bioenergy feedstock crop will be of relatively different value depending on when and where it is consumed. Some catchments have greater 'water stress' than others due to overall availability and use for production, social and environmental reasons. And in time of drought the value of water increases compared to times when it is abundant; the relative water scarcity changes in space and time with competing human and ecological demands.

To determine the limitations and impacts of the developing bioenergy (and any biomass-based industry) improved understanding of the hydrological systems, impacts and linkages via instruments such as LCA and water footprint analysis are required, especially at the farm scale.

## **7. Implications for bioenergy**

Bioenergy utilises water in the growing of the feedstock, the processing and transformation to energy carriers and consumption. Understanding the overall hydrological cycle is fundamental to estimating and ameliorating the impacts of bioenergy systems during the various stages along the supply chain. The increasing utilisation of biomass resources for bioenergy will have significant impacts on water use in Australia. Where residues are used the evapotranspiration may not change significantly. Where new crops are introduced, and replace inefficient systems, (generally replacing shallow rooted annual crops with deep-rooted

perennial systems) there could be significant changes to the local hydrology. And this may have larger impacts across the catchment.

As outlined above there is significant competition for water resources in most Australian catchments. Estimating and modelling water use of plants and the impacts on local and large-scale catchments over time is a significant field within itself (Zhang et al., 2001; Vertessy et al., 2003). And the implications for bioenergy already recognised (Berndes, 2011; Yeh et al., 2011). However, at the local (small) scale there is little site-specific information and this inhibits the development of management options that balance the need to optimise water use for production and minimise negative environmental impacts whilst potentially maximising environmental benefits. Management of the bioenergy systems is critical in determining favourable production and sustainability outcomes (George and Cowie, 2011).

## 8. Summary conclusions

We expect that biomass production for energy purposes in Australia will be limited by the availability of water due to climate, natural variability and competition with other uses including food, feed, fibre and the environment. Addressing the respective demands will need to occur at a local (sub-catchment) scale with an understanding of national goals and expectations.

There are many positive aspects to the utilisation of biomass and the potential and scale of implications will be determined through appropriate land-use and crop selection, coupled with judicious management of water and other natural resources including soil health.

It will be important to further understand and explore the implications across the hydrological cycle (including green, blue and grey water) for all vegetation systems providing food, feed, fibre, energy and environmental services. To focus on a single use (e.g., energy) will miss the important aspects of how to best manage limited resources for multiple outcomes. If a particular vegetation type or land use increases the overall water used by plants then less water is likely to be available as 'blue' water due to lower access to groundwater tables and reduced run off leading to storages and rivers.

A systematic understanding of the hydrology, linking with methods to measure and define impacts (e.g., LCA), and the development of flexible and appropriate regulatory frameworks are significant remaining challenges in Australia.

## References

- **ABARE**, Australian Bureau of Agricultural and Resource Economics, 2010, Energy in Australia 2010, pp. 98, Canberra.
- **Aleklett K., Höök M., Jakobsson K., Lardelli M., Snowden S., Söderbergh B.**, 2010, The peak of the oil age - Analyzing the world oil production reference scenario in World Energy Outlook 2008. Energy Policy 38(3): 1398-1414.
- **Australian Government**, 2007, Water Act.
- **Australian Government**, 2008, Water Amendment Act.
- **Australian Government**, 2012, Energy White Paper 2012: Australia's energy transformation, pp. 257, Canberra.
- **Barrett-Lennard E. G.**, 2002, Restoration of saline land through revegetation. Agricultural Water Management 53(1-3): 213-226.
- **Bartle J., Olsen G., Cooper D., Hobbs T.**, 2007, Scale of biomass production from new woody crops for salinity control in dry land agriculture in Australia. International Journal of Global Energy Issues 27(2): 115-137.

- **Bennett D., Simons J., Speed R.**, 2011, Hydrological impacts of integrated oil mallee farming systems. Vol. 377, pp. 83. Perth, WA Department of Agriculture & Food, Australia.
- **Berndes G.**, 2011, Bioenergy and Water – Challenges and Opportunities. In *Towards 2020: Growing our sustainable future. The 12th Annual Bioenergy Australia Conference*, Sunshine Coast Australia, (Ed Schuck S.). Queensland, Bioenergy Australia.
- **Blanco-Canqui H.**, 2010, Energy crops and their implications on soil and environment, *Agronomy Journal* 102(2): 403-419.
- **BP**, 2010, BP Statistical Review of World Energy, pp.50.
- **Brandão M., Milà i Canals L., Clift R.**, 2011, Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass and Bioenergy* doi:10.1016/j.biombioe.2009.10.019(35): 2323-2336.
- **Bureau of Resources and Energy Economics**, 2012, Australian Energy Technology Assessment. pp. 122, Canberra.
- **Dale B. E.**, 2007, Thinking clearly about biofuels: ending the irrelevant ‘net energy’ debate and developing better performance metrics for alternative fuels, *Biofuels, Bioproducts & Biorefining* 1: 14–17.
- **Delucchi M. A.**, 2010, Impacts of biofuels on climate change, water use, and land use. *Annals of the New York Academy of Sciences* 1195: 28-45.
- **Diaz-Chavez R., Berndes G., Neary D., Elia Neto A., Fall M.**, 2011, Water quality assessment of bioenergy production. *Biofuels, Bioproducts and Biorefining* 5(4): 445-463.
- **Duer H., Christensen P. O.**, 2010, Socio-economic aspects of different biofuel development pathways, *Biomass and Bioenergy* 34(2): 237-243.
- **Farine D. R., O'Connell D. A., Raison R. J., May B. M., O'Connor M. H., Crawford D. F., Herr, A., Taylor J. A., Jovanovic T., Campbell P. K., Dunlop M. I. A., Rodriguez L. C., Poole M. L., Braid, A. L., Kriticos D.**, 2012, An assessment of biomass for bioelectricity and biofuel, and for greenhouse gas emission reduction in Australia. *GCB Bioenergy* 4(2): 148-175.
- **Fingerman K. R., Torn M. S., O'Hare M. H., Kammen D. M.**, 2010, Accounting for the water impacts of ethanol production. *Environmental Research Letters* 5(1): 8.
- **George B. H., Cowie A. L.**, 2011, Bioenergy systems, soil health and climate change. In *Soil Health and Climate Change*, pp. 369-397 (Eds Singh B., Cowie A. L., Chan K.Y.). Springer.
- **Gerbens-Leenes W., Hoekstra A. Y.**, 2012, The water footprint of sweeteners and bio-ethanol. *Environment International* 40: 202-211.
- **Gregg J. S., Izaurrealde R. C.**, 2010, Effect of crop residue harvest on long-term crop yield, soil erosion and nutrient balance: trade-offs for a sustainable bioenergy feedstock. *Biofuels* 1(1): 69-83.
- **Herr A., O'Connell D., Farine D., Dunlop M., Crimp S., Poole M.**, 2012, Watching grass grow in Australia: is there sufficient production potential for a biofuel industry ? *Biofuels, Bioproducts and Biorefining* 6(3): 257-268.
- **Herron N., Davis R., Dawes W., Evans R.**, 2003, Modelling the impacts of strategic tree plantings on salt loads and flows in the Macquarie River Catchment, NSW, Australia. *Journal of Environmental Management* 68(1): 37-50.
- **Hoekstra A., Chapagain A.**, 2007, Water footprints of nations: Water use by people as a function of their consumption pattern. *Water Resources Management* 21(1): 35-48.
- **Hoekstra A. Y., Hung P. Q.**, 2002, Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade. In *Value of Water Research Report Series*, Vol. 11, pp. 120. IHE Delft, The Netherlands.

- **Hunter H. M., Walton R. S.**, 2008, Land-use effects on fluxes of suspended sediment, nitrogen and phosphorus from a river catchment of the Great Barrier Reef, Australia. *Journal of Hydrology* 356(1–2): 131-146.
- **International Energy Agency (IEA)**, 2009, *Key World Energy Statistics*, pp.82, Paris.
- **Jeswani H. K., Azapagic A.**, 2011, Water footprint: methodologies and a case study for assessing the impacts of water use. *Journal of Cleaner Production* 19(12): 1288-1299.
- **Kovac M., Scott A.**, 2012, Organic material audit for North West New South Wales: An overview of resource availability, pp.59., NSW Department of Primary Industries. Sydney, Australia.
- **May B., England J. R., Raison R. J., Paul K. I.**, 2012, Cradle-to-gate inventory of wood production from Australian softwood plantations and native hardwood forests: Embodied energy, water use and other inputs. *Forest Ecology and Management* 264(0): 37-50.
- **Nordblom T. L., Finlayson J. D., Hume I. H.**, 2012, Upstream demand for water use by new tree plantations imposes externalities on downstream irrigated agriculture and wetlands, *Australian Journal of Agricultural and Resource Economics* 56(4): 455-474.
- **O’Connell D., Braid A., Raison J., Handberg K., Cowie A. L., Rodriguez L., George B. H.**, 2009, Sustainable Production of Bioenergy: A review of global bioenergy sustainability frameworks and assessment system, pp. 164, Rural Industries Research & Development Corporation, Canberra.
- **Peck A., Sudmeyer R., Huxtable D., Bartle J. R., Mendham D. S.**, 2012, Productivity of mallee agroforestry systems under various harvest and competition management regimes. pp.247. Canberra, Australia.
- **Penney K., Schultz A., Ball A., Hitchins N., Stark C., Martin K.**, 2012, *Energy in Australia 2012*, Canberra.
- **Pfister S., Bayer P., Koehler A., Hellweg S.**, 2011: Environmental impacts of water use in global crop production: hotspots and trade-offs with land use. *Environmental Science & Technology* 45(13): 5761-5768.
- **Pimentel D.**, 2006: Soil erosion: a food and environmental threat. *Environment, Development and Sustainability* 8(1): 119-137.
- **Pink B.**, 2008, Water and the Murray-Darling Basin - A statistical profile, pp. 162, Australian Bureau of Statistics, Canberra.
- **Pink B.**, 2012, Water account, pp. 100, Australian Bureau of Statistics, Canberra.
- **Polglase P., Paul K., Hawkins C., Siggins A., Turner J., Booth T., Crawford D.; Jovanovic T., Hobbs T., Opie K., Almeida A., Carter J.**, 2008, Regional opportunities for agroforestry systems in Australia, pp.111, Rural Industries Research & Development Corporation, RIRDC, Canberra.
- **Prosser I.**, 2011, *Water: science and solutions for Australia*, pp.193, Canberra.
- **Renouf M., Wegener M., Pagan R.**, 2010, Life cycle assessment of Australian sugarcane production with a focus on sugarcane growing. *The International Journal of Life Cycle Assessment* 15(9): 927-937.
- **Ridoutt, B. G.; Pfister, S.**, 2010, A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. *Global Environmental Change* 20(1): 113-120.
- **Rijsberman, F. R.**, 2006, Water scarcity: Fact or fiction? *Agricultural Water Management* 80(1–3): 5-22.
- **Robinson N., Harper R. J., Smettem K. R. J.**, 2006, Soil water depletion by Eucalyptus spp. integrated into dryland agricultural systems. *Plant and Soil* 286(1/2): 141-151.
- **Sausse, C.**, 2011, On the water footprint of energy from biomass: A comment. *Ecological Economics* 71: 1-3.

- **Stern, N. H.**, 2007, The economics of Climate Change: the Stern review, Cambridge, UK, Cambridge University Press.
- **Sudmeyer R. A., Daniels T., Jones H., Huxtable D.**, 2012, The extent and cost of mallee-crop competition in unharvested carbon sequestration and harvested mallee biomass agroforestry systems. *Crop and Pasture Science* 63(6): 555-569.
- **Tilman D., Cassman K. G., Matson P. A., Naylor R., Polasky S.**, 2002, Agricultural sustainability and intensive production practices. *Nature* 418(6898): 671-677.
- **Verbruggen A., Fischedick M., Moomaw W., Weir T., Nadai A., Nilsson L. J., Nyboer J., Sathaye J.**, 2010, Renewable energy costs, potentials, barriers: conceptual issues. *Energy Policy* 38(2): 850-861.
- **Vertessy R. A., Zhang L., Dawes W.**, 2003, Plantations, river flows and river salinity. *Australian Forestry* 66: 55-61.
- **Webb A.**, 2012, Can timber and water resources be sustainably co-developed in south-eastern New South Wales, Australia ? *Environment, Development and Sustainability* 14(2): 233-252.
- **Water Footprint Network**, (WFN), <http://www.waterfootprint.org/>
- **White D. A., Dunin F. X., Turner, N. C., Ward, B. H.; Galbraith, J. H.**, 2002, Water use by contour-planted belts of trees comprised of four Eucalyptus species. *Agricultural Water Management* 53(1-3): 133-152.
- **Yeh S., Berndes G., Mishra G. S., Wani S. P., Elia Neto A., Suh S., Karlberg L., Heinke J., Garg K. K.**, 2011, Evaluation of water use for bioenergy at different scales. *Biofuels, Bioproducts and Biorefining* 5(4): 361-374.
- **Young M. D., McColl J. C.**, 2009, Double trouble: the importance of accounting for and defining water entitlements consistent with hydrological realities. *Australian Journal of Agricultural and Resource Economics* 53(1): 19-35.
- **Zhang L., Dawes W. R., Walker G. R.**, 2001, Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37(3): 701-708.

## Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ARENA	Australian Renewable Energy Agency
BP	British Petroleum
GHG	Greenhouse Gases
GL	Giga litre
LCA	Life Cycle Analysis
MDB	Murray-Darling Basin
ML	Mega litre
Mt	Mega tonnes
NSW	New South Wales
NWI	National Water Initiative
RSB	Round Table for Sustainable Biofuels
WF	Water Footprint



# **Impact of land use change due to bioenergy on Midwestern US hydrology**

**Carl J. Bernacchi<sup>1</sup>, Andy VanLoocke<sup>2</sup>, Stephen W. Nesbitt<sup>2</sup>**

**<sup>1</sup>USDA-Agriculture Research Service, Global Change and Photosynthesis Research Unit  
and Department of Plant Biology, University of Illinois Urbana, IL USA**

**<sup>2</sup>Department of Atmospheric Sciences, University of Illinois Urbana, IL USA**

## **Abstract**

The objective of this paper is to analyze and discuss the impact of land use change due to bioenergy on Midwestern US hydrology. Together, soybean and maize form the largest single ecosystem type of the contiguous United States. This agro-ecosystem represents the largest single land-use in the Midwestern US and dominates regional ecosystem services such as food production, water quality, evaporation of water to the atmosphere, nutrient cycling, carbon sequestration, as well as other services. In addition to being two of the dominant food crops grown throughout the US and the world, these two crops represent the dominant feedstocks used for bioenergy production in the US with close to 40% of the total corn harvested in the US being used specifically for grain ethanol production. The recent increase in the percentage of harvested corn dedicated to ethanol production is coupled with an increase in total area of land planted in corn.

Biophysically-based land surface models provide an opportunity to investigate the consequences of land use change over longer time scales and over larger spatial scales. For example, one such model was used to evaluate changes in Midwest U.S. hydrology resulting from large-scale conversion from the existing land cover to one that contains miscanthus and one that contains switchgrass. The new algorithms for miscanthus and switchgrass were created through integration of an existing grass algorithm with crop management modules. These algorithms were calibrated by adjusting model parameters based on observations of miscanthus and switchgrass at the University of Illinois south farms and at a number of locations in Illinois. Regional simulations with the current land cover, miscanthus and switchgrass land cover scenarios were conducted to examine the impact of large-scale perennial grass production on the hydrologic cycle.

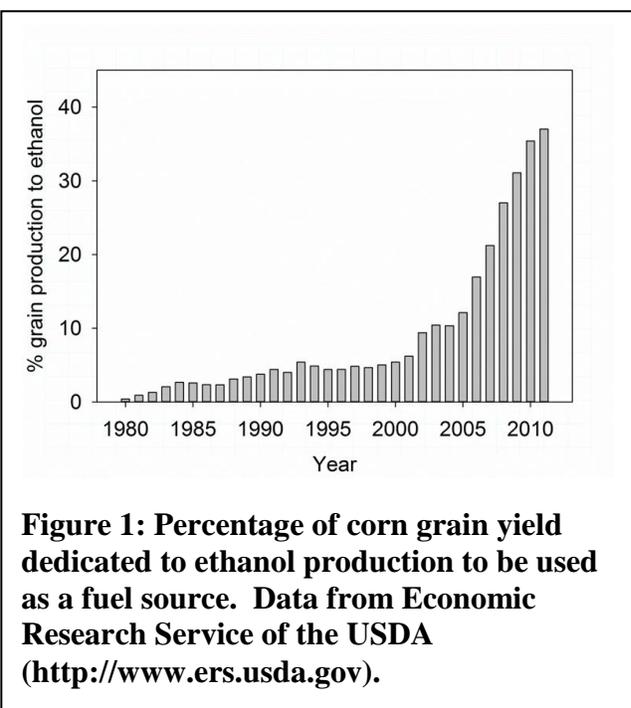
Land use change to accommodate production of miscanthus and switchgrass are likely to influence more than the quantity of water flowing through vegetation and other major components of the hydrologic cycle. Current agricultural practices result in large amounts of nitrogen fertilizer leaching out of maize/soybean fields through subsurface runoff (drainage) which reaches the Gulf of Mexico causing an area over 10000 km<sup>2</sup> of hypoxic conditions. Since perennial grasses require less fertilizer than maize, the potential exists for cellulosic feedstock production to decrease the leaching of nitrogen into the water improving water quality. Alternatively, if the hydrologic cycle is perturbed by an increase in rates of ET, less water flowing through streams and rivers could potentially be more concentrated in pollutants, thereby degrading water quality. In either case, large-scale changes in ET and nutrient application compared to existing land cover has the potential to alter the flux of nitrate through the Mississippi River Basin to the Gulf of Mexico

This paper addresses evapotranspiration, water use efficiency, surface hydrology and climate as well as future directions of related research.

## 1. Introduction

Together, soybean and maize form the largest single ecosystem type of the contiguous United States. This agro-ecosystem represents the largest single land-use in the Midwestern US and dominates regional ecosystem services such as food production, water quality, evaporation of water to the atmosphere, nutrient cycling, carbon sequestration, as well as other services. In addition to being two of the dominant food crops grown throughout the US and the world, these two crops represent the dominant feedstocks used for bioenergy production in the US with close to 40% of the total corn harvested in the US being used specifically for grain ethanol production (Figure 1). The recent increase in the percentage of harvested corn dedicated to ethanol production is coupled with an increase in total area of land planted in corn. Given the significant fraction of harvested corn grain dedicated to ethanol production, it is unlikely that corn grain ethanol will rise beyond current production levels.

The US 2007 Energy Independence and Security Act requires that production of ethanol from corn grain is capped near current production levels and that the majority of renewable fuels will be produced by cellulosic feedstocks by 2022 (Figure 1; Sissine, 2007). Cellulosic feedstocks is a general name given to plants in which the fibrous, woody and generally inedible portion of the plant (representing up to 75% total biomass) can be used as a fuel source. The use of cellulosic feedstocks for renewable energy is an advantage over current production methods which only convert the corn grain into liquid fuel. In addition to the liquid fuel mandates set in place by the US Government, cellulosic feedstocks are currently being used as energy sources for electricity production through direct combustion. Thus, future liquid fuel production will require dedicated bioenergy feedstocks to provide cellulosic-based liquid energy. The agriculturally rich areas of the Midwest have been proposed as a region capable of producing a significant portion of the biomass required for cellulosic ethanol refineries. The majority of the land area in the Midwestern “Corn Belt” was once host to tall grass prairies, thus the soils, climate, and topography are well suited for the production of tall perennial grass species. Highly productive perennial grasses such as *Miscanthus × giganteus* (miscanthus) and *Panicum virgatum* (switchgrass) have been proposed as ideal feedstocks for cellulosic ethanol production based on rapid growth and high biomass measured at number of experimental sites throughout Illinois. The benefit of incorporating cellulosic plant material into the energy sector is to decrease the demand for fossil fuels and the pollution they cause (Environmental Protection Agency Renewable Fuel Standard 2; EPA; RFS2). However, cellulosic feedstock production should not result in



unsustainable agronomic practices or have negative impacts on ecosystem services. Little is currently known about the perturbations to the environment that will occur if production of cellulosic feedstocks were to be executed on a large scale (Rowe et al., 2009), although recent research results are beginning to shed light on some of the key changes that potentially might alter the hydrology of the Midwestern US.

Two candidate species identified as ideal candidates for cellulosic feedstock production for this region are *Miscanthus × giganteus* (miscanthus) and *Panicum virgatum* (switchgrass; Heaton et al., 2008). Based on small-scale experiments, it is shown that miscanthus and switchgrass take up more carbon (Stampfl et al., 2007; Davis et al., 2010; Zeri et al., 2011) and require less nutrient application (Heaton et al., 2004, 2010). Productivity is an important criterion by which to evaluate the potential of these feedstocks, but it is crucial to also understand the environmental impacts of a large scale shift in land use before it is implemented. Water is a crucial component in agricultural production (Wallace et al., 2000; Chaves et al., 2003; Oliver et al., 2009), the demand for which is predicted to increase in the future (Steduto et al., 2007). There are many uncertainties associated with future water availability, many of which are driven by predicted climatic changes (e.g., Wuebbles and Hayhoe, 2004). But through impacts on the timing and rate of evapotranspiration of miscanthus and switchgrass compared to existing land cover, could changing the land use to accommodate perennial grasses have large-scale consequences on many components of the regional hydrologic cycle?

Large-scale land use change has occurred multiple times within the Midwestern US region. The potential for perennial grasses to once again establish in certain areas of the landscape that was once home to prairies dominated by perennial grasses suggests that the predicted land use change to accommodate cellulosic biofuels could be sustainable. However, significant changes in water resources from installation of drainage tiles, drainage ditches, and water routing, coupled with atmospheric and climatic conditions, have altered the landscape, thus the impact of perennial grass reestablishment on the hydrologic cycle needs to be directly studied. Due to the nascent nature of biofuels in the US, the two main objectives of this section of the report are to focus on the few studies that have specifically address issues related to (1) ecosystem water use (evapotranspiration) and (2) water use efficiency. These objectives will be addressed based on a limited number of in-field and modeling studies. A third objective is to discuss the secondary changes associated with altered water use through cellulosic biofuel establishment by discussing possible water quality and climate links.

## **2. Evapotranspiration**

The environmental impacts of changing vegetation cover over large areas of land are uncertain, although it is expected such changes will influence the hydrologic cycle, which in turn can have profound impacts on local and regional meteorology and climate (Sellers et al. 1997). Of the energy entering an ecosystem, the majority is partitioned into either sensible heat flux ( $H$ ) or into latent heat flux ( $\lambda$ ) which is the sum of evaporation and transpiration (evapotranspiration,  $ET$ ). While the balance between these two fluxes is physiologically controlled at the stomatal level (Sellers et al. 1997), environmental conditions may result in situations where physiological control is lacking (e.g., severe water stress). The transition from annual crop rotation to perennial biomass crops can influence the partitioning of energy into  $H$  vs.  $ET$ . Factors that are likely to play a key role in this interaction include length of growing season, rooting depth, leaf area index (LAI), residue cover, and leaf physiology. Perennial species often have substantially longer growing seasons which results in more opportunity for transpiration, deeper roots which may

allow for more access to water during dry periods, and higher LAI, which may result in more transpiring surfaces (Schenk and Jackson 2002). Relative to annual crops, perennial grasses will have differences in the ground cover during the fallow season; the amount and quality of plant litter impacts evaporation rates from the soil and is shown to lead to soil moisture differences (Potter, Torbert and Morrison 1995). Previous research shows clear links between climate and vegetation in areas where rates of *ET* and *H* vary over the landscape (Adegoke, Pielke and Carleton 2007). The influences of perennial vs. annual cropping systems can cause similar responses through alteration in hydrological cycle. Changes in the hydrologic cycle will likely be initiated by vegetation through altered rates of *ET*, and as a result there will be measureable differences among the vegetation types in soil moisture, run-off, and plant water status, and these differences will drive changes in nutrient cycling and microbial activity.

The establishment of perennial feedstocks for cellulosic biofuels in the Midwestern US will likely cause changes in various aspects of the hydrologic cycle; however, the magnitude and direction of change will be determined based on a variety of factors, including local climate, existing vegetation, soil properties, management practices. Given that the land area within the Midwestern US is currently dominated by annual row crops, the most likely scenario is that perennial grasses will replace at least some portion of this existing ecosystem. Therefore, it is critical to understand the major drivers between annual row crops and perennial grasses as it relates to water use. The root systems of perennials penetrate deep into the soil and generally have access to deeper soil moisture than annual crops (Neukirchen et al., 1999; Stephens et al., 2001; Hall, 2003). Leaf area index is higher for perennial grasses relative to corn (Dohleman & Long, 2009), providing greater area for photosynthesis and transpiration. These physiological differences between PRGs and maize are further accentuated by a much longer growing season, differences in canopy architecture, and increased residue accumulation in the PRGs (Heaton et al., 2004; Dohleman & Long, 2009). Thus, it is critical to assess changes in evapotranspiration (*ET*), the combination of both ecosystem evaporation and transpiration, to assess the impacts of bioenergy crop growth on local and regional hydrology.

Based on the key differences between perennial grasses and annual row, there is evidence that the water issues related to perennial grasses will lead to significant alterations in the hydrologic cycle. A combination of physiological and morphological factors, in addition to growing season length, could drive the observed differences among the species. Physiological differences among the species such as stomatal conductance, which is shown to be closely coupled to canopy water use (e.g., Bernacchi et al., 2007), could also drive the differences in water use. Potential morphological differences include higher mean root mass and greater distribution throughout the soil profile (Neukirchen et al., 1999), greater aboveground biomass (Heaton et al., 2008; Dohleman & Long 2009) for perennials relative to annuals. These factors are likely to lead to more access to water for longer periods driving a higher water use in the perennial ecosystems.

The impacts of changing vegetation over large areas of land are uncertain, but based on the inherent differences between annuals and perennials, evidence exists suggesting that large-scale changes to the vegetation within the Midwestern US will lead to changes in water use. These changes in turn can have profound impacts on local and regional meteorology and climate (Sellers et al. 1997). The first side-by-side comparison of miscanthus, switchgrass, and maize was conducted in Central Illinois, USA during the 2007 growing season and incorporated two separate metrics of water use—changes in soil volumetric water content (McIsaac et al., 2010) and micrometeorological measurements of the exchange of sensible and latent heat flux above the plant canopies (Hickman et al., 2010). Both of these measurement techniques are prone to errors resulting in poor ability to resolve absolute quantities of ecosystem water use, but both methods

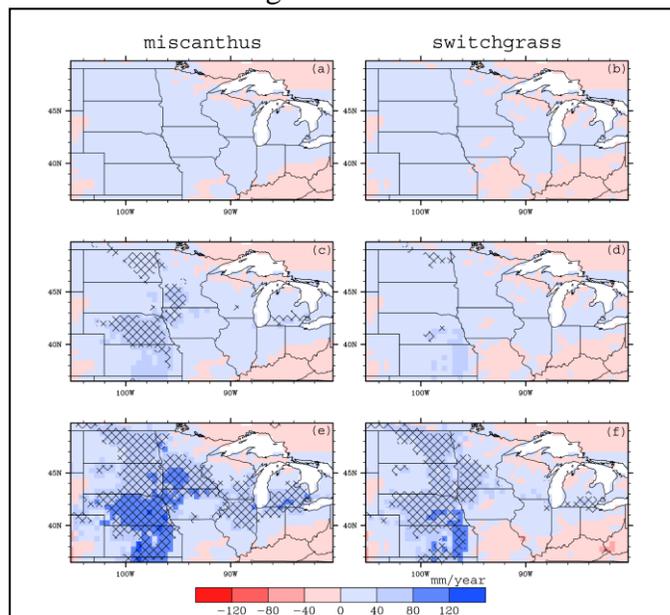
have a proven ability to assess relative differences between different treatments, such as plots with different species. Thus, while the absolute water use for miscanthus from both studies differed quite substantially, the relative differences between the maize and miscanthus plots were similar suggesting that the perennial grasses use more water than the existing vegetation.

The perennial nature of miscanthus and switchgrass results in a longer growing season and more opportunity to evapotranspire relative to maize. Mean ET was 25% higher for miscanthus compared with maize over the entire duration when both crops were transpiring (i.e. seasonal) and dropped to only about 18% higher than maize when considering the time period when both canopies were closed (Hickman et al., 2010). Based on these differences it is likely that higher water use in miscanthus is not only the effect of a longer growing season, but also physiological or morphological factors. Mean seasonal and ‘mature canopy’ water use was not statistically different from maize, for switchgrass however (Hickman et al., 2010). Given these small differences, the higher *ET* for switchgrass relative to maize is likely dominated by the longer growing season. These results suggest that growing season length drives the majority observed differences relative to maize for switchgrass and a portion of the differences for miscanthus.

Some evaporation in maize will occur during the times that the PRGs are evapotranspiring and maize/soybean is fallow. This component of water use was not considered in the studies addressing comparisons between the existing vegetation and the perennial grasses (Hickman et al., 2010; McIsaac et al., 2010). Because of the nascent cellulosic biofuel industry in the US there has been little research dedicated to understanding the influence of land use change to perennials on the complete annual timecourse or over larger spatial scales than has been reported in Hickman et al., (2010) or McIsaac et al., (2010). However, biophysically-based land surface models provide an excellent opportunity to investigate the consequences of land use change over longer time scales and over larger spatial scales. One such model, Agro-IBIS (Foley et al., 1996; Kucharik et al., 2000; Kucharik & Brye, 2003) was used to evaluate changes in Midwest U.S. hydrology resulting from large-scale conversion from the existing land cover to one that contains

miscanthus (VanLoocke et al., 2010) and one that contains switchgrass (VanLoocke et al., 2012). The new algorithms for miscanthus and switchgrass were created through integration of the existing Agro-IBIS grass algorithm with crop management modules. These algorithms were calibrated by adjusting model parameters based on observations of miscanthus and switchgrass at the University of Illinois south farms and at a number of locations in Illinois. Regional simulations with the current land cover, miscanthus and switchgrass land cover scenarios were conducted to examine the impact of large-scale perennial grass production on the hydrologic cycle.

Over the annual timecourse, the model predicts that perennial grasses will use more water than annual row crops (VanLoocke et al., 2010; 2012), however,



**Fig.2: The Agro-IBIS-simulated difference (miscanthus/switchgrass–current vegetation) in 30 year (1973-2002) mean evapotranspiration for varying densities a,b) 10% , c,d) 25%, d,e) 50% of crop production. The hatch marks indicate a statistically significant ( $P < 0.01$ ) difference according to the Student’s *t*-test.**

the difference in water use will be substantially less than what was observed during just the growing season (Hickman et al., 2010; McIsaac et al., 2010). The model also predicts that an evenly distributed change in land cover throughout the Midwestern US will likely have little to no impact on ecosystem water use (Figure 2). Large-scale changes in ecosystem water use are not observed until planting densities that surpass 25% for miscanthus and 50% for switchgrass.

The scenarios where the planting density surpasses 10% of the land surface (e.g., Figure 2) are not likely to occur within the Midwestern US and the analysis did not suggest that planting densities of 25% or 50% are feasible over the whole of the Midwestern US. However, the energetic and economic costs of producing energy from biomass would be minimized if high planting densities of biomass crops are established surrounding biorefineries in ‘hot spots’ and transported from within a certain radius (Khanna et al., 2008; Kim and Dale 2008, 2009; Lambert 2008). Often in the Midwest, corn-soy rotations in agriculturally intensive counties compose the majority of land cover. Therefore if the model for production of corn ethanol is replaced with miscanthus, it is likely that fraction covers of miscanthus could exceed 25% or even 50% and significant changes to the hydrologic cycle in those areas might occur (VanLooche et al., 2010).

### **3. Water Use Efficiency**

A trade-off often exists between agricultural productivity and water use (Jackson et al., 2005). The term water use efficiency (WUE) relates the amount of water used for a given amount of biomass produced or carbon gained. An increase in the WUE of an agro-ecosystem can be considered an ecosystem service. Therefore, consideration of the total water resources available to plants and the efficiency of biomass productivity relative to the use of water (i.e., water use efficiency) should be considered when determining the sustainability of introducing new species on landscapes (Wallace 2000; Somerville et al., 2010).

In the first estimation of WUE between miscanthus, switchgrass, and maize, it was apparent that miscanthus and maize had similar water use efficiencies during the growing season, both of which were higher than switchgrass (Hickman et al., 2010). The similarity in WUE between maize and miscanthus, however, could be somewhat misleading due to the smaller portion of above-ground biomass removed as harvested material from maize. The residues left after a typical maize harvest, which are considered by some to be waste products, are required as inputs into the soils to maintain sustainability of the agroecosystem (Blanco-Canqui & Lal, 2009; Mann et al., 2002; Andrews, 2006). Therefore, there exists a trade-off between maximizing biomass harvest in maize to increase WUE and agricultural sustainability of this ecosystem (VanLooche et al., 2012). Given the goal of bioenergy ecosystems in mitigating environmental impacts of fossil fuel consumption and maintaining sustainability, the agronomic practice of removing residue to achieve higher biomass and improved WUE, the WUE calculated from corn-grain is a more relevant comparator to perennial grasses. In the case of estimating WUE from corn grain alone, the WUE decreases by approximately a factor of two but is still higher than the WUE for switchgrass grown in Central Illinois (Hickman et al., 2010). However, the harvested biomass frequently used in agricultural studies to calculate WUE but this neglecting all other carbon pools.

The perennial grasses most likely to be established in the Midwestern US invest a greater amount of biomass below-ground than annual crops (Anderson-Teixeira et al., 2009; Dohleman et al., 2012; Khale et al., 2001; Neukirchen et al., 1999). The component of carbon that is retained belowground is an important ecosystem service that is neglected when calculating WUE using harvested material alone. Using net ecosystem productivity (NEP), the total sum of carbon from

the net exchange by an ecosystem not including carbon removed at harvest (Chapin et al., 2006), in calculating WUE allows for direct comparison of WUE based on carbon removal from the atmosphere in a given year. Most of the carbon entered the ecosystem from NEP is lost through respiration or removal during harvest leaving a small fraction of carbon in the soil generally considered to be sequestered. This carbon pool is termed net biome productivity (NBP); calculating WUE from NBP yields the water requirement needed to achieve a secondary (non-harvested) ecosystem service associated with agronomic practices (VanLoocke et al., 2012).

Because miscanthus and switchgrass are both perennial grasses they share many of the same physiological and phenological traits, including higher water use (Hickman et al., 2010) and harvestable yield (Dohleman & Long, 2009; Heaton et al., 2008) relative to the existing Midwest US crops. There are however significant challenges in predicting water use over larger spatial scales given measurements in the Midwestern US are limited to a few plots in Central IL. As with the challenges in extrapolating evapotranspiration from the single plot (e.g., Hickman et al., 2010; McIsaac et al., 2010) to the region (e.g., VanLoocke et al., 2010; 2012), care must be taken in extrapolating WUE across both time and space. Because carbon fluxes can represent different aspects of the ecosystem carbon cycle, there are numerous additional factors that drive variability in important carbon-related processes. Many of these carbon-related factors are also closely coupled to hydrology such as the influence of soil moisture levels on soil respiration. In-field measurements are limited over the timescales in which biofuel feedstocks have been planted in side-by-side experiments with current agronomic species. Therefore, the only means to assess WUE metrics for any aspect of the carbon cycle other than for harvested carbon is through the ecosystem models parameterized and evaluated for miscanthus and switchgrass.

VanLoocke et al. (2012) used three measures of productivity to describe the three WUE metrics based harvest (HWUE), ecosystem (EWUE) and biome (BWUE) water use efficiency for miscanthus, switchgrass and maize within the Midwestern US. The results showed that over the study domain, the perennial grasses consistently used more water than maize and compared with maize the total biomass harvested was similar for switchgrass and greater for miscanthus. The evidence for higher yield and increased water use for perennial grasses raised the key question whether the increase in water use was greater than the increase in biomass. Throughout the Midwestern US, the model output from the HWUE analysis shows that the high harvested biomass for miscanthus more than compensates for the higher water use compared with maize. Alternatively, comparable harvested biomass for switchgrass coincided with more water use than maize. Using NEP in calculating WUE includes belowground allocation of carbon into all ecosystem pools, therefore since perennial grasses partition a significant amount of resources below-ground (Anderson-Teixeira et al., 2009; Jackson et al., 1996) they should in theory have a higher EWUE. Comparisons of EWUE among the current annual crop maize and the future predicted crop miscanthus shows that a larger annual net flux of carbon into the perennial drives the EWUE higher than for maize over much of the Midwestern US region (VanLoocke et al., 2012).

The EWUE of the Midwestern US, however, overestimates the amount of carbon that stays in the ecosystem, thereby inflating the ecosystem services. Of the total NEP, a portion is harvest from the ecosystem resulting in only a small portion of carbon remaining each year, the NBP. The simulations of BWUE using NBP in the WUE calculation showed that the lower HWUE of switchgrass relative to maize for much of the Midwestern US was offset by the increased likelihood of switchgrass providing longer-term carbon sequestration. Of the three species used in their analysis, VanLoocke et al. (2012) showed that miscanthus had the highest total yield, the highest absolute water use, and the highest HWUE and EWUE but the BWUE for miscanthus is

not always higher than the other two species over the Midwestern US. Specifically, the western region of the study domain showed that total water use for miscanthus is high but carbon sequestration is low signifying that the higher HWUE comes at the expense of sequestered carbon. The simulations also showed little land area within the Midwest US where maize has a higher BWUE than either miscanthus or switchgrass, suggesting that in some locations, switchgrass may be the ideal feedstock from the perspective of WUE.

#### **4. Water Use, Surface Hydrology and Climate**

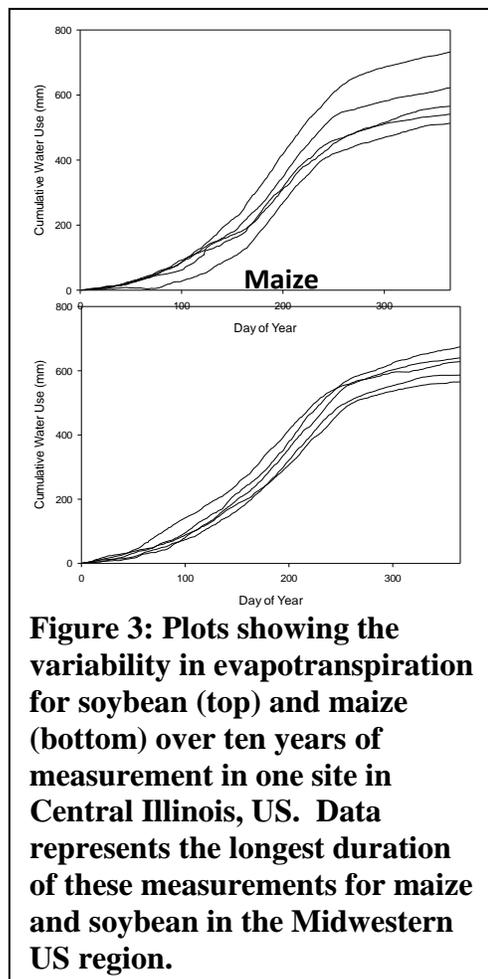
Land use change to accommodate production of miscanthus and switchgrass are likely to influence more than the quantity of water flowing through vegetation and other major components of the hydrologic cycle. Current agricultural practices result in large amounts of nitrogen fertilizer leaching out of maize/soybean fields through subsurface runoff (drainage) which reaches the Gulf of Mexico causing an area over 10000 km<sup>2</sup> of hypoxic conditions called the Hypoxic or “Dead Zone”. Since perennial grasses require less fertilizer than maize (e.g. Heaton et al., 2009, 2010), the potential exists for cellulosic feedstock production to decrease the leaching of nitrogen into the water improving water quality (Costello et al., 2009; McIsaac et al., 2010; Ng et al., 2010). Alternatively, if the hydrologic cycle is perturbed by an increase in rates of ET, less water flowing through streams and rivers could potentially be more concentrated in pollutants, thereby degrading water quality. In either case, large-scale changes in ET and nutrient application compared to existing land cover has the potential to alter the flux of nitrate through the Mississippi River Basin to the Gulf of Mexico. Current research focusing on water quality changes associated with these feedstocks is limited to point measurements of nitrate movement within the soil profile (McIsaac et al., 2010) and watershed scale measurements that do not include validated mechanistic growth and physiology modules for miscanthus and switchgrass (Costello et al., 2009; Ng et al., 2010). Hitherto, recent works also do not consider the potential for changes in ET to feedback on precipitation. Thus, the implications of land use change associated with the implementation of cellulosic biofuel production must go beyond climate and the hydrologic cycle toward understanding coupled climate-biogeochemical responses.

Vegetation, particularly in intercontinental areas, can strongly influence the climate, radiation balance, and hydrologic cycle of continental interior regions (e.g., Pielke et al., 1991; Zeng and Pielke, 1995a; Zeng and Pielke, 1995b; Copeland et al. 1996; Sellers et al., 1997; Stohlgren et al. 1998; Pielke 2001 and references therein; Pielke et al., 2002; Pielke et al., 2006; Douglas et al. 2006; Mahmood et al. 2010). Based on these pioneering works, recent research has addressed the question of how perennial feedstocks might modify climate in the Midwest US. Georgescu et al. (2009; 2011) performed the first studies to address this question using a community regional non-hydrostatic atmospheric model (Weather Research and Forecasting model or WRF, Skamrock et al., 1998). They conducted simulations where a maize model is re-parameterized to approximate miscanthus by adjusting the physical constants defining the interaction between plants and environmental conditions – albedo, LAI, minimum canopy resistance and rooting depth, as well as changing the length of the growing season. Their results showed that increased water use by perennial feedstocks may alter the exchange of heat and moisture between the land surface and the atmosphere and impact seasonal precipitation (Georgescu et al., 2009; 2011). They also showed that increased ET in biofuel feedstocks would have a surface cooling effect which has been predicted to have a much greater impact on the lower troposphere than the cooling due to decreased emissions of greenhouse gases for perennial grasses (Georgescu et al., 2011). Their analysis also showed that some regions in the Midwest would see an increase in precipitation due

to increased humidity and moisture availability whereas other areas would see a slight reduction (Georgescu et al., 2011). Through local to large-scale changes in ET and surface reflectivity compared to existing cover in their model simulations, these studies showed that large scale changes to feedstocks across the Midwestern US may have the potential to impact local and regional climate, specifically in temperature and precipitation.

## 5. Future directions

As discussed above, providing detailed and accurate assessments of the likely changes in hydrology under biofuel production scenarios is the Midwestern US is an important and challenging task. To date there is still limited data showing how water use and carbon uptake from inter-annually for the corn-soy rotation (e.g., Figure 3), one of the most studied agro-ecosystems. Moving forward, coupled biosphere-atmosphere-hydrology modeling studies will need to integrate all of the major components into a coupled-physically based modeling framework that allows for feedbacks and sensitivities to key processes in the hydrologic cycle (e.g., Lyon et al. 2008). It is likely that these models will require high spatial resolution to capture relevant scales of land use patterning as well as attendant atmospheric motions, clouds, and precipitation and the lateral redistribution of surface and ground water that result from those patterns. These modeling studies will require additional empirical data that are robust in space and time and represent the hydrologic dynamics of the evolving bioenergy agro ecosystems across species and climate regimes. These data are envisaged to provide not only for improving process understanding and parameterization development in models, but also for validation data for coupled simulations.



## References

- **Adegoke, J.O., Pielke R., Carleton A.M.**, 2007, Observational and modeling studies of the impacts of agriculture-related land use change on planetary boundary layer processes in the central US. *Agricultural and Forest Meteorology* 142, 203-215.
- **Anderson-Teixeira, K.J., Davis, S.C., Masters, M.D., DeLucia, E.H.**, 2009, Changes in soil organic carbon under biofuel crops. *Global Change Biol. Bioenerg.*, 1, 75-96.
- **Andrews S.S.**, 2006, Crop residue removal for biomass energy production: effects on soils and recommendations. USDA-Natural Resource Conservation Service. pp 1-15.
- **Blanco-Canqui H., Lal R.**, 2009, Crop residue removal impacts on soil productivity and environmental quality. *Crit. Rev. Plant Sci.*, 28, 139-163.
- **Chapin, III F.S., Woodwell, G.M., Randerson, J.T., Rastetter, E.B., Lovett, G.M., Baldocchi, D.D., Clark, D.A., Harmon, M.E., Schimel, D.S., Valentini, R., Wirth, C., Aber, J.D., Cole, J.J., Goulden, M.L., Harden, J.W., Heimann, M., Howarth, R.W., Matson, P.A., McGuire, A.D., Melillo, J.M., Mooney, H.A., Neff, J.C., Houghton, R.A., Pace, M.L., Ryan, M.G., Running, S.W., Sala, O.E., Schlesing, W.H., Schulze, E.-D.**, 2006, Reconciling carbon-cycle concepts, terminology, and methods. *Ecosystems*, 9, 1041-1050.
- **Chaves M.M., Oliveira M.M.**, 2004, Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture, *Journal of Experimental Botany*, 55, 2365-2384.
- **Copeland, J.H., Pielke R.A., Kittel T.G.F.**, 1996, Potential climatic impacts of vegetation change: A regional modeling study. *J. Geophys. Res.*, 101, 7409-7418.
- **Costello C., Griffin M.W., Landis A.E., Matthews S.H.**, 2009, Impact of biofuel crop production on the formation of hypoxia in the Gulf of Mexico. *Environmental Science and Technology*, 43, 7985-7991.
- **Davis S.C., Parton W.J., Dohleman F.G., Smith C.M., Del Grosso S., Kent A.D., Delucia E.H.**, 2010, Comparative biogeochemical cycles of bioenergy crops reveal nitrogen-fixation and low greenhouse gas emissions in a *Miscanthus x. giganteus* agroecosystem. *Ecosystems*, 13,144–156.
- **Dohleman F.G., Long S.P.**, 2009, More Productive than maize in the Midwest: how does miscanthus do it? *Plant Physiology*, 150, 2104-2115.
- **Dohleman F.G., Heaton E.A., Arundale R.A., Long S.P.**, 2012, Seasonal dynamics of above- and below-ground biomass and nitrogen partitioning in *Miscanthus × giganteus* and *Panicum virgatum* across three growing seasons. *Global Change Biol. Bioenerg.*, doi: 10.1111/j.1757-1707.2011.01153.x
- **Douglas E.M., Niyogi D., Frohling S., Yeluripati J.B., Pielke Sr. R.A., Niyogi N., Vörösmarty C.J., Mohanty U.C.**, 2006, Changes in moisture and energy fluxes due to agricultural land use and irrigation in the Indian Monsoon Belt. *Geophys. Res. Letts*, 33, doi:10.1029/2006GL026550.
- **Foley J.A., Prentice I.C., Ramankutty N. et al.**, 1996, An integrated biosphere model of land surface processes, terrestrial carbon balance, and vegetation dynamics. *Global Biogeochemical Cycles*,10, 603–628.
- **Georgescu M., Lobell D.B., Field C.B.**, 2009, Potential impact of US biofuels on regional climate. *Geophysical Research Letters*, 36, L21806, doi: 10.1029/2009GL040477.
- **Georgescu M., Lobell D.B., Field C.B.**, 2011, Direct climate effects of perennial bioenergy crops in the United States. *Proc. Nat. Aca. Sci.* 108, 4307-4312.

- **Hall R.L.**, 2003, Grasses for energy production. Hydrological guidelines. Department of Trade and Industry, New and Renewable Energy Programme - Centre for Ecology and Hydrology.pp 1-15.
- **Heaton E.A., Dohleman F.G., Long S.P.**, 2008, Meeting US biofuel goals with less land: the potential of miscanthus. *Global Change Biology*, 14, 2000–2014.
- **Heaton E.A., Dohleman F.G., Miguez F.E., Juvik J.A., Lozovaya V., Widholm J., Zabolina O.A., McIsaac G.F., David M.B., Voigt T.B., Boersma N.N., Long S.P.**, 2010, Miscanthus: A Promising Biomass Crop. *Advances in Botanical Research*. 56, 75-137.
- **Heaton E.A., Voigt T., Long S.P.**, 2004, A quantitative review comparing the yields of two candidate C-4 perennial biomass crops in relation to nitrogen, temperature and water. *Biomass & Bioenergy*, 27, 21–30.
- **Heaton E.A., Dohleman F.G., Long S.P.**, 2009, Seasonal nitrogen dynamics of *Miscanthus x giganteus* and *Panicum virgatum*. *Global Change Biol. Bioener.*, 1, 297-307.
- **Heaton E.A., Dohleman F.G., Miguez F.E., Juvik J.A., Lozovaya V., Widholm J., Zabolina O.A., McIsaac G. F., David M. B., Voigt T. B., Boersma N. N., Long S. P.**, 2010, Miscanthus: a promising biomass crop. *Adv. Bot. Res.*, 56, 75-137.
- **Hickman G.C., VanLoocke A., Dohleman F.G., Bernacchi C.J.**, 2010, A comparison of canopy evapotranspiration for maize and two perennial grasses identified as potential bioenergy crops. *GlobalChange Biology Bioenergy*, 2, 157–168.
- **Jackson R.B., Canadell J., Ehleringer J.R., Mooney H.A., Sala O.E., Schulze E.D.**, 1996, A global analysis of root distributions for terrestrial biomes. *Oecologia*, 108, 389-411.
- **Kahle P., Beuch S., Boelcke B., Leinweber P., Schulten H.R.**, 2001, Cropping Miscanthus in Central Europe: biomass production and influence on nutrients and soil organic matter. *Europe. J. Agron.*, 15, 171-184.
- **Khanna M., Dhungana B., Clifton-Brown J.**, 2008, Costs of producing miscanthus and switchgrass for bioenergy in Illinois. *Biomass & Bioenergy*, 32, 482-493.
- **Kim S., Dale B.E.**, 2008, Life cycle assessment of fuel ethanol derived from corn grain via dry milling. *Bioresource technology*, 99, 5250-5260.
- **Kim S., Dale B.E.**, 2009, Regional variations in greenhouse gas emissions of biobased products in the United States-corn-based ethanol and soybean oil. *International Journal of Life Cycle Assessment*, 14, 540-546.
- **Kucharik C.J., Brye K.R.**, 2003, Integrated biosphere simulator (IBIS) yield and nitrate loss predictions for Wisconsin maize receiving varied amounts of nitrogen fertilizer. *Journal of Environmental Quality*, 32, 247–268.
- **Kucharik C.J., Foley J.A., Delire C. et al.**, 2000, Testing the performance of a Dynamic Global Ecosystem Model: water balance, carbon balance, and vegetation structure. *Global Biogeochemical Cycles*, 14, 795–825.
- **Lambert D.M., Wilcox M., English A., Stewart L.**, 2008, Ethanol plant location determinants and county comparative advantage. *Journal of Agricultural & Applied Economics*, 40,117-135.
- **Lyon S.W., Dominguez F., Gochis D.J., Brunsel N.A., Castro C.L., Chow F.K., Fan Y., Fuka D., Hong Y., Kucera P.A., Nesbitt S.W., Salzmann N., Schmidli J., Snyder P.K., Teuling A.J., Twine T.E., Levis S., Lundquist J.E., Salvucci G.D., Sealy A.M., Walter M.T.**, 2008, Coupling terrestrial and atmospheric water dynamics to improve prediction in a Changing Environment. *Bull. Amer. Meteor. Soc.*, 89, 1275–1279.
- **Mahmood R., Pielke Sr. R.A., Hubbard K.G., Niyogi D., Bonan G., Lawrence P., Baker B., McNider R., McAlpine C., Etter A., Gameda S., Qian B., Carleton A., Beltran-Przekurat A., Chase T., Quintanar A.I., Adegoke J.O., Vezhapparambu S., Conner G., Asefi S., Sertel**

- E., Legates D.R., Wu Y., Hale R., Frauenfeld O.W., Watts A., Shepherd M., Mitra C., Anantharaj V.G., Fall S., Lund R., Nordfelt A., Blanken P., Du J., Chang H.-I., Leeper R., Nair U.S., Dobler S., Deo R., Syktus J.**, 2010, Impacts of land use land cover change on climate and future research priorities. *Bull. Amer. Meteor. Soc.*, 91, 37–46, DOI: 10.1175/2009BAMS2769.1
- **Mann L., Tolbert V., Cushman J.**, 2002, Potential environmental effects of corn (*Zea mays* L.) stover removal with emphasis on soil organic matter and erosion. *Agriculture, Ecosystems & Environment*, 89, 149-166.
  - **McIsaac G.F., David M.B., Mitchell C.A.**, 2010, Miscanthus and switchgrass production in central Illinois: impacts on hydrology and inorganic nitrogen leaching. *Journal of Environmental Quality*, 39, 1790-1799.
  - **McIsaac G.F., David M.B., Gertner G.Z., Goolsby D.A.**, 2002, Relating net nitrogen input in the Mississippi River basin to nitrate flux in the lower Mississippi River: a comparison of approaches. *J. Environ. Qual.* 31:1610-1622.
  - **Neukirchen D., Himken M., Lammel J., Czymionka-Krause U., Olf H-W.**, 1999, Spatial and temporal distribution of the root system and root nutrient content of an established Miscanthus crop. *European Journal of Agronomy*, 11, 301-309.
  - **Neukirchen D., Himken M., Lammel J., Czymionka-Krause U., Olf H.W.**, 1999, Spatial and temporal distribution of the root system and root nutrient content of an established Miscanthus crop. *Europe. J. Agron.*, 11, 301-309.
  - **Ng L.T., Wayland E.J., Cai X., Miguez F.**, 2010, Modeling miscanthus in the Soil and Water Assessment Tool (SWAT) to simulate its water quality effects as a bioenergy crop. *Environmental Science and Technology*, 44, 7138-7144.
  - **Oliver R.J., Finch J.W., Taylor G.**, 2009, Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO<sub>2</sub> and drought on water use and the implications for yield. *Global Change Biology Bioenergy*, 1, 97-114.
  - **Pielke R.A., Marland G., Betts R.A., Chase T.N., Eastman J.L., Niles O.J., Niyogi D.S., Running S.W.**, 2002, The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences* 360, 1705-1719.
  - **Pielke Sr. R.A.**, 2001, Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Rev. Geophys.*, 39, 151-177.
  - **Pielke Sr. R.A., Matsui T., Leoncini G., Nobis T., Nair U., Lu E., Eastman J., Kumar S., Peters-Lidard C., Tian Y., Walko R.**, 2006, A new paradigm for parameterizations in numerical weather prediction and other atmospheric models. *National Wea. Digest*, 30, 93-99.
  - **Pielke R.A., Dalu G., Snook J.S., Lee T.J., Kittel T.G.F.**, 1991, Nonlinear influence of mesoscale land use on weather and climate. *J. Climate*, 4, 1053-1069.
  - **Potter K.N., Torbert H.A., Morrison J.E.**, 1995, Tillage and residue effects on infiltration and sediment losses on vertisols. *Transactions of the Asae* 38, 1413-1419.
  - **Rowe R.L., Street N.R., Taylor G.**, 2009, Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable & Sustainable Energy Reviews*, 13, 260–279.
  - **Schenk H.J. Jackson R.B.**, 2002, Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. *Journal of Ecology* 90, 480-494.

- **Sellers P.J., Dickinson R.E., Randall D.A. et al.**, 1997, Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science*, 275, 502–509.
- **Sissine F.**, 2007, Energy Independence and Security Act of 2007: A Summary of Major Provisions. Congressional Research Service, Washington, DC.
- **Skamarock W. C., Klemp J. B., Dudhia J., Gill D. O., Barker D. M., Duda M. G., Huang X.-Y., Wang W., Powers J. G.**, 2008, A description of the Advanced Research WRF Version 3. NCAR Tech. Note, NCAR/TN-475+STR, 113 pp. [Available online at [http://www.mmm.ucar.edu/wrf/users/docs/arw\\_v3.pdf](http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf)]
- **Somerville C., Youngs H., Taylor C., Davis S.C., Long S.P.**, 2010, Feedstocks for lignocellulosic biofuels. *Science*, 329,790–792.
- **Stampfl P.F., Clifton-Brown J.C., Jones M.B.**, 2007, European-wide GIS-based modeling system for quantifying the feedstock from *Miscanthus* and the potential contribution to renewable energy targets. *Global Change Biology*, 13, 2283–2295.
- **Steduto P., Hsiao T.C., Fereres E.**, 2007, On the conservative behavior of biomass water productivity. *Irrigation Science*, 25, 189-207.
- **Stephens W., Hess T., Knox J.W.**, 2001, Review of the effects of energy crops on hydrology. Institute of Water and Environment, Cranfield University at Silsoe. 71pp.
- **Stohlgren T.J., Chase T.N., Pielke R.A., Kittel T.G.F., Baron J.**, 1998, Evidence that local land use practices influence regional climate and vegetation patterns in adjacent natural areas. *Global Change Biology*, 4, 495-504.
- **VanLoocke A., Bernacchi C.J., Twine T.E.**, 2010, The impacts of *Miscanthus x giganteus* production on the Midwest US hydrologic cycle. *GCB Bioenergy* 2, 180–191.
- **VanLoocke A., Twine T.E., Zeri M., Bernacchi C.J.**, 2012, A regional comparison of water-use-efficiency for miscanthus, switchgrass and maize. *Agricultural and Forest Meteorology*, in press.
- **Wallace J.S.**, 2000, Increasing agricultural water use efficiency to meet future food production. *Agriculture Ecosystems & Environment*, 82, 105-119.
- **Wuebbles D.J., Hayhoe K.**, 2004, Climate change predictions for the United States Midwest. *Mitigation and Adaptation Strategies for Global Change*, 9, 335-363
- **Zeng X., Pielke R.A.**, 1995a, Landscape-induced atmospheric flow and its parameterization in large-scale numerical models. *J. Climate*, 8, 1156-1177.
- **Zeng X., Pielke R.A.**, 1995b, Further study on the predictability of landscape-induced atmospheric flow. *J. Atmos. Sci.*, 52, 1680-1698.
- **Zeri M., Anderson-Teixeira K.J., Hickman G.C., Masters M., DeLucia E.H., Bernacchi, C.J.**, 2011, Carbon exchange by establishing biofuel crops in Central Illinois. *Agriculture, Ecosystems and Environment*. DOI: 10.1016/j.agee.2011.09.006.

## Abbreviations

BWUE	Biome based Water Use Efficiency
EPA	Environment Protection Agency
ET	Evapotranspiration
EWUE	Ecosystem based Water Use Efficiency
H	Heat Flux
HWUE	Harvest based Water Use Efficiency
IL	Illinois
LAI	Leaf Area Index

NBP	Net Biome Productivity
NEP	Net Ecosystem Productivity
PRG	Perennial Grass
RFS	Renewable Fuel Standard
US	United States
USDA	US Department of Agriculture
WUE	Water Use Efficiency

# Mapping the potential water use of biofuel feedstock production in South Africa

**R. Kunz and G. Jewitt**  
**Centre for Water Resources Research**  
**University of KwaZulu-Natal, Pietermaritzburg,**  
**South Africa**

## Abstract

South Africa is considered a water-scarce country since only 35 % of the country receives more than 500 mm of annual rainfall, which is regarded as the minimum annual total needed for dryland crop production. On average, only 9 % of the annual rainfall is transformed into stream flow, which results in strong competition for this limited resource. Many catchments within the country are already declared as water-stressed, i.e. almost all the available fresh water has already been allocated to various uses. This paper provides an overview of the emerging biofuels sector in South Africa and provides insight into a fundamental question currently facing land use planners, namely: “Does the country have sufficient water resources to produce, on a sustainable basis, the necessary feedstock to satisfy the proposed biofuel target volumes?” Apart from the increasing demand to produce biofuel feedstocks, the competition for water from other sectors is discussed, as well as the key role that land use change plays in determining sustainability.

## 1. Introduction

The world’s interest in biofuel production, particularly in developed countries, is driven by the need to reduce dependence on fossil fuel imports. Brazil is currently the leading producer of ethanol from sugarcane and arguably the most advanced country in the world in terms of security of transport fuel supply (Harvey and Pilgrim, 2011). However, recent years have also witnessed a growing interest in biofuels from developing countries.

Several SADC<sup>1</sup> countries have developed policies to encourage bioenergy production (including biofuels) at the national level. In addition to the to the often stated benefits of biofuels, specific advantages of biofuel production in developing countries include, inter alia, poverty alleviation and rural upliftment. In other words, biofuel development can stimulate agricultural and economic activity in rural areas (Funke et al., 2009). Not surprisingly, biofuels has been placed on the policy agenda of many developing countries (BEFS, 2010). Food security may also benefit from intensified agricultural production linked to biofuel feedstock cultivation in that a biofuel sector can create an alternative market for producers (e.g. for grain sorghum farmers) as well as increasing employment opportunities, thus positively affecting agricultural and economic growth (BFAP, 2008). However, progress towards developing national biofuel policies has generally been slow, with a lack of capacity and skills to develop such policies cited as a major constraint (BEFS, 2012).

According to Escobar et al. (2009) and Gnansounou (2011), the contribution of biofuels to transportation in the future should remain limited to a reasonable percentage and should only be based on sustainable pathways. The WWF (2011) stated that there is simply not enough land to sustainably grow biofuels to power all forms of transport. Cai et al. (2011) supported this argument by stating that the limited amount of land available for energy crop production poses a key constraint for expanding biofuel production to reduce the dependency on fossil fuels. However, Ravindranath et al. (2010) suggested that water scarcity, rather than land

<sup>1</sup>The Southern African Development Community (SADC) comprises of 14 countries which include South Africa and its neighbours (Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe).

availability, may prove to be the key limiting factor for biofuel production in many regions. Furthermore, biofuel feedstock production itself may impact on water use and consequently, aggravate catchment water stress.

South Africa is considered a water-scarce country since only 35 % of the country receives more than 500 mm of annual rainfall, which is regarded as the minimum annual total needed for dryland crop production (DAFF, 2010a). On average, only 9 % of the annual rainfall is transformed into stream flow (DWA, 1986), which results in strong competition for this limited resource. Many catchments within the country are already declared as water-stressed, i.e. almost all the available fresh water has already been allocated to various uses. This paper provides an overview of the emerging biofuels sector in South Africa and provides insight into a fundamental question currently facing land use planners, namely: “Does the country have sufficient water resources to produce, on a sustainable basis, the necessary feedstock to satisfy the proposed biofuel target volumes?” Apart from the increasing demand to produce biofuel feedstocks, the competition for water from other sectors is discussed, as well as the key role that land use change plays in determining sustainability.

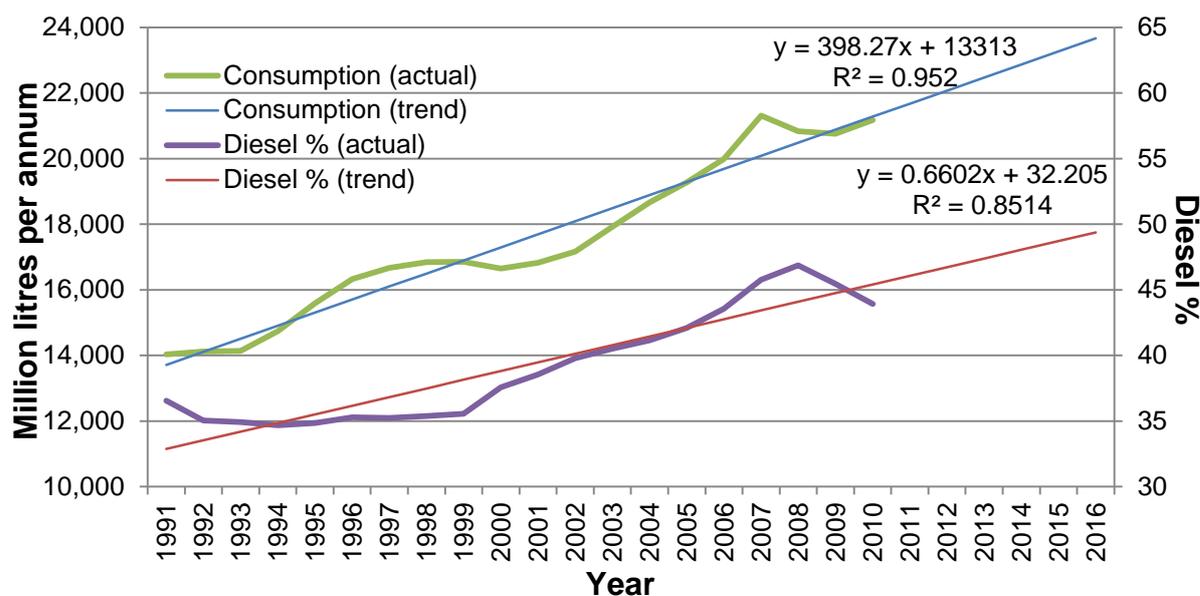
## **2. South Africa's biofuels industry: setting the scene**

In December 2007, the South African Cabinet approved the revised national biofuels industrial strategy (DME, 2007). The strategy adopted a short-term focus and proposed the production of 400 million litres of biofuel per annum. The proposed blending ratio for South Africa was B2 or 2 % biodiesel and E8 or 8 % bioethanol. However, this target was set with a limited appraisal of the country's biofuel production potential.

These blending rates were not mandated and together with no existing government incentives to produce biofuels, investment in the biofuels sector has been restrained (NAMC-DAFF, 2009; BFAP, 2009). However, the Department of Energy has finally published regulations regarding the mandatory blending of biofuels in the Government Gazette on 23<sup>rd</sup> August 2012 (DoE, 2012). The mandatory biodiesel blending is B5 and a permitted range of E2 up to E10 for bioethanol blending. It is important to note that the proposed mandatory blending rates have yet to be legislated.

### **2.1 Estimating the required biofuel volume**

If the mandatory blending rates were legislated in 2013, this may initiate the construction of the country's first two ethanol plants in early 2014, for completion in late 2015. Hence, demand for biofuel feedstock would begin from 2016 onwards. In Figure 1, a linear regression model estimates the petroleum demand from 2011 to 2016, based on petroleum consumption from 1991 to 2010. The portion of petroleum consumed as diesel increased from 36.5 % in 1990 to 43.9 % in 2010, which is estimated to increase to 49.4 % in 2016 (Figure 1). Based on these projections, the demand for petroleum in 2016 is approximately 23,668 million litres, of which 11,685 million litres is diesel. Hence, an E2 and B5 blending rate requires approximately 240 million litres of ethanol and 584 million litres of biodiesel respectively. This represents a substantial increase in biofuel volume compared to the 400 million litres proposed in the 2007 revised biofuels industrial strategy. Kotze (2012b) mentioned that owing to the government's delay in announcing the mandatory blending rates, only two of the six proposed biofuel plants are still in the “pipeline”. The combined capacity of these two biofuel plants is 240 million litres of ethanol, which is sufficient to satisfy the proposed E2 blending rate, but there would be a shortfall from 2017 if additional plants do not come online in the future.



**Figure 1: Petroleum consumption in South Africa from 1991 to 2010 (SAPIA, 2012), together with the diesel fraction. Projected increases in demand from 2011 to 2016 are shown as linear trend lines.**

## 2.2 The problem with unrealistic biofuel uptake targets

The rapid development of the worldwide biofuels industry is, arguably, driven by volume targets rather than by responsible land use planning (Tait, 2011). Mandatory national biofuel targets have encouraged producers to scale up biofuel production as quickly and easily as possible. This has sometimes resulted in human rights violations, especially when developed countries elect to produce their biofuel targets in developing countries that exhibit less rigorous human rights regulations. If biofuels targets are set too high, it encourages a rapid expansion of biofuel production. Such rapid expansion is unlikely to be environmentally sustainable because of well-documented impacts of certain land use changes on the greenhouse gas balance (Fargione et al., 2008; Searchinger et al., 2008; Lapola et al., 2010). The UK's International Development Committee released a report on global food security in June 2013 (HOC, 2013) which calls for the UK government to revise its Renewable Transport Obligation (RTFO). While the EU target requires 10 % of transport energy to be derived from renewable sources by 2020, the report proposes that no more than 5 % should come from food-based biofuels. The report highlights concerns regarding the impact of higher food prices on food security as well as the impacts of indirect land use change.

## 2.3 Potential biofuel feedstocks for South Africa

The national biofuels strategy (DME, 2007) highlighted two bioethanol (sugarcane and sugarbeet) and three biodiesel (sunflower, soybean and canola) feedstocks for biofuel production in South Africa. The strategy currently excludes maize due to food security concerns. This decision is justified considering that food products derived from maize in South Africa contribute 34.9 % of the total per capita calorie consumption (FAOSTAT, 2009).

*Jatropha curcas* and *Moringa oleifera* are two biodiesel tree feedstocks that were highlighted in the biofuels feasibility study (DME, 2006a) that preceded the publication of the strategy. However, *Jatropha* is also currently excluded as a feedstock in South Africa due to its possible

alien invasive threat (DME, 2007; Witt, 2010). A scoping study on water use of crops/trees for biofuels in South Africa (Jewitt et al., 2009) highlighted the potential of other feedstocks including sweet sorghum and cassava. More recently, grain sorghum has been targeted for ethanol production in South Africa (IDC, 2012).

The country's grain sorghum production has declined from 511,000 tons in the 1988/89 season (Kotze, 2012b), to around 200,000 tons in 2007/08 (DAFF, 2010b). It is envisaged that the emerging biofuels industry will provide a much needed boost for this market. Food products derived from grain sorghum in South Africa only contribute 0.6 % of the total per capita calorie consumption (FAOSTAT, 2009). Hence, if grain sorghum destined for human consumption is diverted to biofuel production, it would not pose a major threat to South Africa's food security.

Currently, South Africa produces sufficient quantities of maize, sugarcane, sorghum and potatoes to satisfy local demand. However, the country is a net importer of wheat, rice and most vegetable oils (sunflower, soybean, palm, canola and olive). The production of biofuel from imported feedstocks is generally considered economically unviable (Funke et al., 2009). Hence, ethanol production in South Africa is considered more economically viable than biodiesel production. In addition, food products derived from wheat, rice and sunflower oil contribute to 31.2 % of the total per capita calorie consumption (FAOSTAT, 2009) and thus may pose a rise to food security if feedstock is diverted to biofuel production. Little is known about emerging biofuel feedstocks such as sugarbeet and sweet sorghum.

The choice of feedstocks that will meet the biofuel production targets set by the mandatory blending rates plays an important role in determining the impact of biofuel production on the environment. Feedstock choice can therefore affect the land and water required for cultivation. Mfundisi (2012) stated that "...it is crucial to ensure that there is adequate land and water available for production of energy crops before indulging into the business of producing such crops".

#### **2.4 Arable land available for feedstock cultivation**

Assessing the agricultural potential of an environmentally diverse country such as South Africa is a complex issue. The important factors that are involved include environmental (related to climate, soils, topography and biodiversity), economic as well as socio-political. Only 4 % of South Africa's agricultural land is situated in areas characterised by ideal climate, soil and terrain conditions and thus classified as high cultivation potential (DAFF, 2010a). However, it is accepted that such highly arable land should not be used for energy production, but rather for food production.

Statistics provided by the national agricultural department indicate that 16.7 million ha (or 13.7 %) of the country's land is considered arable (DAFF, 2012). This land resource must produce sufficient food, feed (i.e. fodder), fibre and (bio)fuel to meet both existing and future demands. Of the 16.7 million ha, 14.2 million ha is classified as commercial agriculture, including industrial forestry plantations. The remaining 2.5 million ha is classified as "developing" agriculture and occurs mainly in marginal areas (characterised by lower rainfall and poorer soils). The national biofuels strategy (DME, 2007) also indicated that 3 million hectares of under-utilised arable land exists for feedstock production. The strategy deemed that approximately 300,000 ha of arable land was sufficient for the annual production of 400 million litres of biofuel. Consequently, the indications are that South Africa has sufficient land resources to produce feedstocks that satisfy the current and future biofuel demand. The government supports that at least 30 % of the required feedstock should be supplied by small-scale or developing farmers (IDC, 2011).

## 2.5 Arable land area required for feedstock cultivation

The 2008 biofuels report (BFAP, 2008) produced by the South African Bureau for Food and Agricultural Policy (BFAP) provide extraction yields in litres of biofuel per ton of crop for five feedstocks as shown in Table 1. These figures are similar to those published elsewhere in the South African literature (e.g. DME, 2006a; Meyer et al., 2008). Based on 2008 crop yields (BFAP, 2009; SASA, 2009), the land area required to produce one million litres of biofuel from various feedstocks is given in Table 1. These figures imply that biodiesel production is land use “inefficient” compared to ethanol production. For example, if land availability at the local scale is limited, it may be argued that biofuel production from soybean should be avoided.

Feedstock	Extraction yield (L t <sup>-1</sup> )	Crop mass (t)	Biomass yield (t ha <sup>-1</sup> )	Harvest area (ha)
Sugarcane	81 <sup>1</sup>	12,346	64.79 <sup>3</sup>	191
Maize	402 <sup>1</sup>	2,488	4.92 <sup>2</sup>	506
Sorghum	370 <sup>1</sup>	2,703	2.94 <sup>2</sup>	919
Sunflower	398 <sup>1</sup>	2,513	1.55 <sup>2</sup>	1,621
Soybean	194 <sup>1</sup>	5,155	1.60 <sup>2</sup>	3,222

**Table 1: Land area required to produce one million litres (or 1000 m<sup>3</sup>) of biofuel**  
**Data sources: <sup>1</sup>BFAP (2008); <sup>2</sup>BFAP (2009); <sup>3</sup>SASA (2009)**

As mentioned earlier, grain sorghum is the preferred feedstock for the annual production of 240 million litres of ethanol. Based on Table 1, each hectare of grain sorghum yields 1,088 litres of ethanol, whilst figures provided by Kotze (2012a; 2012b) suggest an ethanol yield of 1,175 litres per hectare. Hence, a further 205,000 to 220,000 ha of arable land would need to be planted to grain sorghum in order to produce the minimum required ethanol volume. These estimates show that land area calculations are “sensitive” to ethanol yields.

The actual land area required for biofuel production depends on the mix of feedstocks selected for cultivation. In addition, the difference in attainable grain yield between commercial farmers and developing farmers, as well as the supply potential of developing farmers, will determine the actual area planted to biofuel feedstocks. The majority of feedstock will need to be sourced from commercial farmers.

## 2.6 Irrigation of biofuel feedstock

The International Organisation for Standardisation (ISO) recognises that freshwater is an important natural resource which is becoming increasingly scarce (Raimbault and Humbert, 2010). Irrigation consumes more water than any other sector in 71 % of countries (FAO, 2010). It is therefore imperative that accurate estimates of crop water use are made to assist water resources planners in effective decision making.

Although the majority of South Africa’s arable land is dryland cultivated (Collett, 2008), approximately 10 % (≈1.5 million ha) is irrigated. According to the FAO (FAO, 2010), irrigated agriculture accounts for 62.7 % of the country’s total water use, which is double the quantity consumed by domestic users (31.2 %). The remaining 6.1 % is industrial water use (FAO, 2010). The Department of Water Affairs (DWA) current stance does not support the irrigation of biofuel crops. The DWA has taken the position that South Africa is a water-

scarce country which can “ill afford the use of current or potential irrigation water for fuel production rather than growing crops for food” (Yako, 2009). Despite this, there are private sector plans for the production of grain sorghum under irrigation in South Africa.

## **2.7 Water use of dryland feedstock cultivation**

Water is required throughout the entire biofuel supply chain, but mainly for the production of feedstock (WWF, 2011). Furthermore, competition for natural resources occurs whether edible or non-edible feedstocks are cultivated for biofuel purposes (FAO, 2008). The rapid expansion of cultivated feedstock and inappropriate cultivation systems may impact negatively on available water resources and thus reduce water availability for other uses. The likely increase in future demand for food and biofuel will require water, creating additional demand that must be carefully managed in view of competing users (Albaugh et al., 2013). Gush (2010) stressed that this is particularly important in countries where there is increasing competition for water, now virtually a global phenomenon. South Africa’s water sector already faces conflicts between environmental goals on one hand and food as well as livelihood goals on the other.

The impacts of bioenergy crops, as an emerging land use sector, on water use have barely been explored (WBGU, 2009). This issue requires careful consideration by decision makers when deciding the potential role of biofuels and assessing sustainability (Royal Society, 2008). It is important that biofuel strategies being developed for any country also consider water resource impacts together with all other relevant social, economic, and environmental considerations associated with development of this industry (Buyx and Tait, 2011). In particular, the need to assess the water use of potential biofuel feedstocks in developing countries was also highlighted by Jewitt and Kunz (2011). Water availability will be a key determinant of where and how much bioenergy feedstock can be produced, and thus the volume of biofuel being generated (King et al., 2013).

## **3. Quantifying feedstock water use**

The water footprint concept is often used to estimate crop water use. Although the concept may provide a useful “broad-brush” estimate of water use, it is not considered suitable for assessing the impact of feedstock cultivation on water resources (Jewitt and Kunz, 2011; Witmer and Cleij, 2012). Hence, an alternative approach has been adopted in South Africa to assess the hydrological impact of feedstock cultivation.

### **3.1 Reduction in stream flow generation**

Various local and international studies have shown that certain feedstocks established in former natural grasslands consume more water than the baseline vegetation, thus reducing the catchment’s water yield or stream flow. For example, Jewitt et al. (2009) reported that under dryland conditions, sweet sorghum and sugarcane may have the potential to use substantially more water than the natural vegetation they replace. Furthermore, the high water use of the *Eucalyptus* genus (as a lignocellulosic feedstock) in comparison to natural grassland is well documented (e.g. Dye and Versfeld, 2007; Albaugh et al., 2013). Hence, certain feedstocks are more water use intensive than others, meaning that their widespread cultivation may create greater competition for water, an already scarce resource in certain catchments of South Africa.

Competition for water resources results from the need to satisfy the requirements of:

- the ecological reserve (i.e. water to maintain ecological river health),
- basic human needs (i.e. water for drinking, food preparation and hygiene),
- irrigated agriculture (i.e. water for food production), and
- industrial water users (i.e. for cooling and other processes).

The challenge for water resources planners is the allocation of water for feedstock growth, whilst avoiding potentially negative impacts on downstream water users. The National Water Act of 1998 (NWA, 1998) prioritises water allocation for humanitarian and ecological needs. Principle 18 of the National Water Act states that “Since many land uses have a significant impact upon the water cycle, the regulation of land use shall, where appropriate, be used as an instrument to manage water resources within the broader integrated framework of land use management”. Section 36 of the National Water Act provides for the declaration of a Stream Flow Reduction Activity (SFRA) as one of 11 recognised water uses. If the feedstock’s consumptive water use is higher than that of the natural vegetation it replaces, then the feedstock may be declared an SFRA. Thus, all feedstocks will use water, whether they are irrigated or produced under dryland conditions, but may not be considered an SFRA if the feedstock’s water use is less than that of the natural vegetation.

There is a legal requirement in South Africa to determine the water resource impacts of a proposed land use change to feedstock cultivation. Should a land use be shown to have a significant impact on the country's water resources, declaration would require knowledge of actual water use, based on field measurements and/or estimation using hydrological simulation modelling. The paired catchment method has shown that the impact of afforestation on periods of low flow is significant (Smith and Scott, 1992). During the low flow period (i.e. dry period immediately prior to the rainy season onset), a reliable water supply is critical for downstream water users. Scott and Smith (1997) defined low flows as the driest three months of an average year, or as those monthly flows below the 75<sup>th</sup> percentile level. In South Africa, commercial afforestation is the only SFRA that has been recognised to date.

### **3.2 Approaches to measuring and modelling water use**

Various techniques have been used in South Africa to measure and model vegetation water use, across a wide range of temporal and spatial scales. Albaugh et al. (2013) provided a synopsis of such approaches which include paired catchment experiments, micrometeorological techniques (e.g. Bowen ratio; eddy correlation) and sapflow measurements (e.g. using heat pulse velocity) of stand-scale water use. Remote sensing techniques are typically used to estimate vegetative water use at larger spatial scales, but are not discussed in this chapter, as the focus is on modelling techniques.

Gush (2010) provided a step-by-step guide to evaluating the impacts of tree-based bioenergy feedstocks on catchment water resources. The methodology is considered sufficiently generic, allowing it to be applied to any bioenergy feedstock, grown at any spatial scale. Thus, in order to quantify the potential impacts of land use change on available water resources, the following approach is typically adopted in South Africa (for a particular geographical area of interest):

- select an appropriate hydrological response unit,
- identify the “baseline” vegetation cover,
- use an appropriate hydrological model to simulate stream flow and evapotranspiration under baseline and future land use scenarios, then
- draw conclusions on the likely water resource impacts of the proposed land use change.

This hydrological modelling approach is used to simulate evapotranspiration (i.e. green water) and stream flow (i.e. blue water) for the intended biofuel feedstock as well as for the natural vegetation in a given catchment. If the intended land use change causes a significant reduction in blue water generation, the feedstock may be declared a SFRA. The factors assessed in deciding whether a land use should be declared a SFRA or not, are a) the extent of stream flow reduction, b) its duration, and c) its impact on other water users (Jewitt et al., 2009). As mentioned earlier, the impact on low flows is of particular concern.

The ACRU (Agricultural Catchments Research Unit) agrohydrological model (Schulze, 1995) has been used extensively to quantify the impact of land use change on stream flow. ACRU is primarily a catchment-scale, daily time-step hydrological rainfall-runoff model. ACRU is a physical-conceptual model that inputs, inter alia, daily rainfall and reference evaporation, as well as various parameters that characterise the vegetation layer and soils layers. The model operates as a process-based, multi-soil layer water budget, to estimate daily evapotranspiration and stream flow.

A large-scale change in land use from natural vegetation to biofuel feedstock production could have significant hydrological implications for available water resources. Warburton et al. (2012) used the ACRU model to generate hydrological responses from three diverse, complex and operational South African catchments, under both current land use and a baseline land cover. The study showed that hydrological responses to land use change were complex and that contributions of different land uses to the stream flow generated from a catchment is not proportional to the relative area of that land use. Furthermore, the relative contribution of the land use to the catchment stream flow varies with the mean annual rainfall of the catchment.

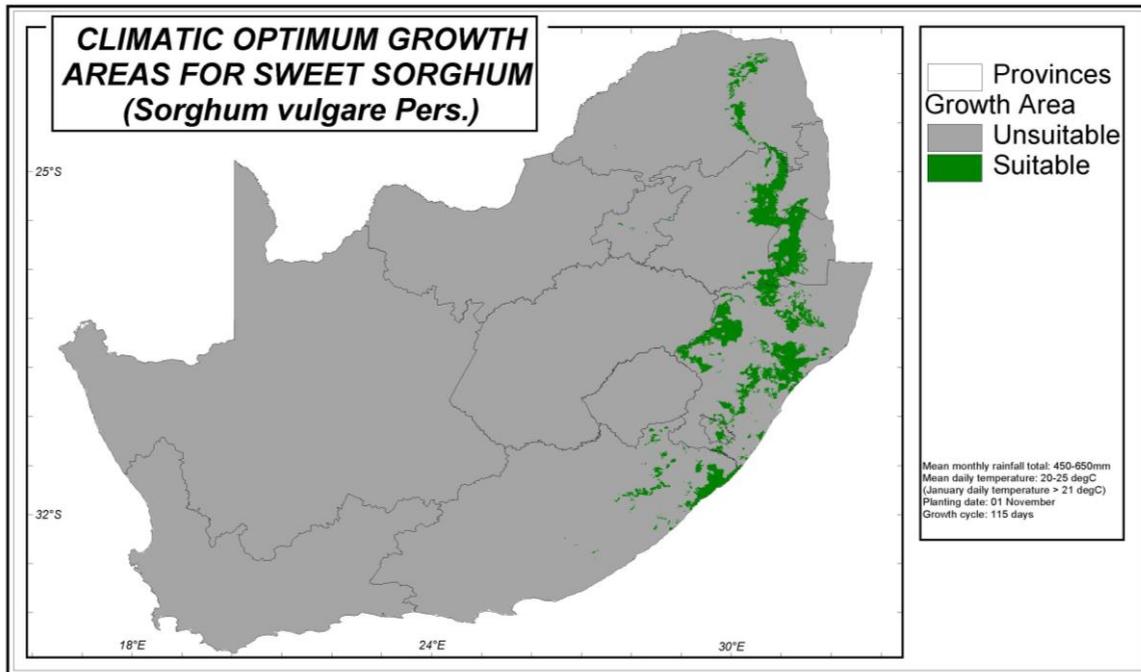
#### **4. Mapping feedstock water use**

The draft version of the biofuels strategy (DME, 2006b) urged the Water Research Commission (WRC) in South Africa to conduct research into the impacts of feedstock production on water quantity and water quality, prior to the roll out of the biofuels industrial strategy. In 2007, the WRC instigated a study to assess both the potential growing areas and water use of selected biofuel feedstocks in South Africa. In November 2009, the WRC published its report titled: “Scoping study on water use of crops/trees for biofuels in South Africa” by Jewitt et al. (2009). This report represented a two-year study that a) identified areas climatically suited to biofuel feedstock cultivation, and b) estimated the water use of selected feedstocks. A brief summary of this report follows, with sorghum as the example feedstock.

##### **4.1 Optimum growing areas for potential feedstocks**

A comprehensive literature review was undertaken by Jewitt et al. (2009) to identify the climatic growth criteria of all feedstocks that have potential to produce biofuel in South Africa. For example, sorghum requires a seasonal rainfall total of 450 to 650 mm. In addition, the monthly mean of average daily temperature should range between 20 and 25 °C, with the January value exceeding 21 °C.

A Geographic Information System (GIS) was then used to map areas climatically suited to feedstock growth based on rainfall and temperature constraints. The South African Atlas of Climatology and Agrohydrology (Schulze, 2007) provided the spatial climatic data for the mapping exercise. Gridded estimates of rainfall and temperature are available for every minute of a degree arc (i.e. 1.7 by 1.8 km;  $\approx 3.06 \text{ km}^2$ ), which totals over 437,039 grid cells across southern Africa.



**Figure 2: Climatic optimum growth areas for sorghum (Jewitt et al., 2009).**

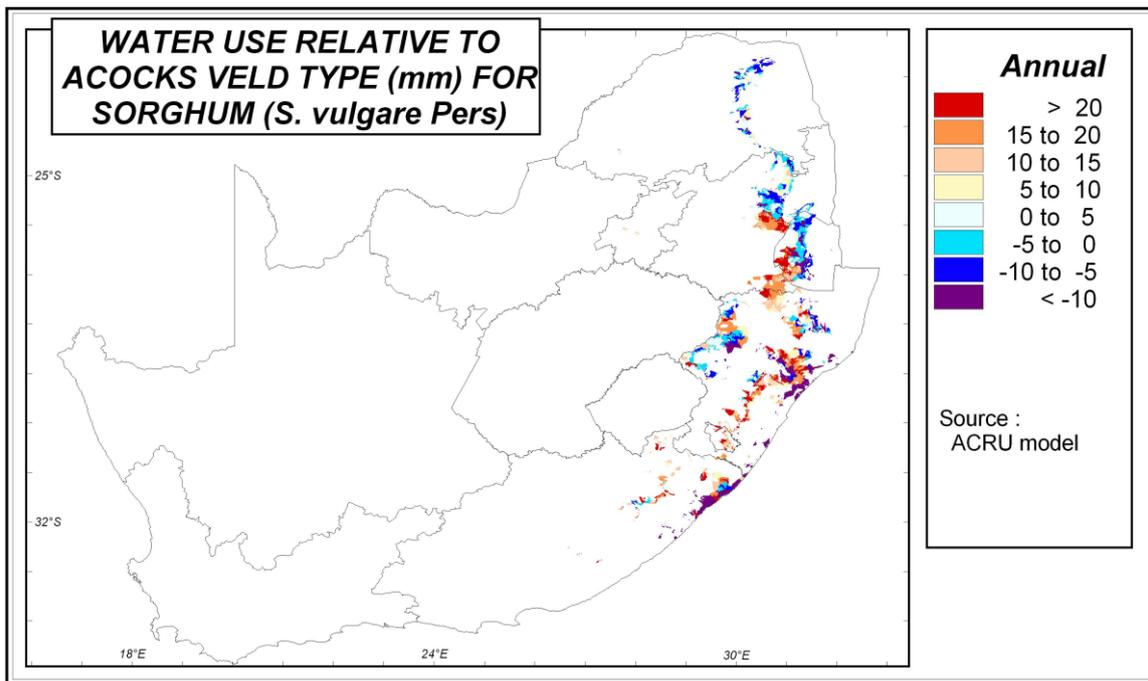
The study showed that based on climatological drivers only, canola, jatropha, sugarbeet and sorghum have the potential to expand production areas. However, the approach did not consider other biophysical constraints which may limit the production of feedstock. For example, areas with poor soils (e.g. too shallow) or steep slopes (> 30 %) are not considered suitable for crop growth under dryland conditions. In addition, the methodology does not consider other land use needs, either current or future. The ACRU agrohydrological modelling system (Schulze, 1995) was then used to estimate the water use of potential feedstocks.

#### **4.2 Modelling feedstock water use**

As discussed earlier, Section 36 of South Africa's National Water Act (NWA, 1998) quantifies crop water use as the reduction in stream flow that may result from a proposed land use change. Jewitt et al. (2009) used an approach similar to that suggested by Gush (2010) to produce maps illustrating the water use of potential biofuel feedstocks at a national scale. The quinary catchments of South Africa (Schulze et al., 2011) were used as the hydrological response unit in these maps.

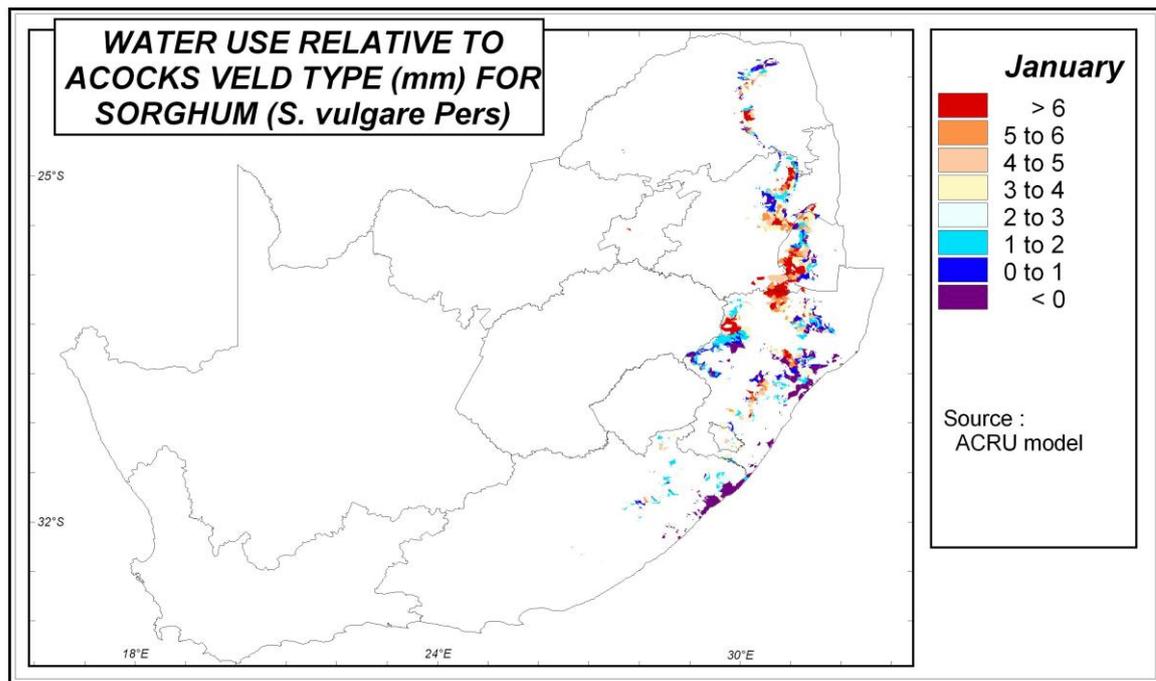
Quinary catchments are topographically based sub-divisions of the national quaternary catchments originally delimited by the Department of Water Affairs. Each fourth level quaternary catchment was sub-delineated into three fifth level quinary catchments according to altitude criteria. The upper, middle and lower quinary catchments of unequal area (but of similar topography) were sub-delineated according to “natural breaks” in altitude by applying the Jenks’ optimisation procedures, which is available within the ArcGIS software suite. This resulted in 5,838 quinary catchments deemed to be more homogeneous than the quaternaries in terms of their altitudinal range. Each quinary was assigned a rainfall and temperature station, from which 50 years of daily climate data is used to “drive” the hydrological processes within the catchment.

The ACRU agrohydrological model (Schulze, 1995) was used to simulate runoff response for both the baseline and proposed land uses, which were then compared to assess the impact of the proposed land use change. Feedstock water use was estimated relative to that of a reference land use, in this case natural vegetation, as depicted by the Acocks Veld Type map (Acocks, 1953). More specifically, feedstock water use is defined as the difference between median annual runoff (MAR; expressed in mm) generated under baseline conditions ( $MAR_{base}$  for natural vegetation), compared to that under cultivated conditions ( $MAR_{crop}$  for sorghum). The median statistic is used to negate the influence of extreme hydrological events such as droughts and floods. Output from this analysis was presented by Jewitt et al. (2009) as a series of maps which show that under dryland conditions, only sorghum and sugarcane may have the potential to use substantially more water than the reference natural vegetation.



**Figure 3: Median annual water use of sorghum relative to the dominant natural vegetation in each hydrological catchment (Jewitt et al., 2009).**

The water use of sorghum may influence where the feedstock can be grown and the spatial extent of planted area. It should be noted that the stream flow impact may be greater during months of the crop growing season when the plant is growing optimally and transpiring. For example, Figure 4 highlights those catchments where less median runoff is generated in January from a sorghum land cover than from natural vegetation.



**Figure 4: Median water use of sorghum in summer, relative to the dominant natural vegetation in each hydrological catchment (Jewitt et al., 2009).**

The maps shown above provide an indication of whether there would be an increase (i.e. negative reduction) or decrease (positive reduction) in stream flow generation, should any of the potential biofuel feedstocks be established under dryland (i.e. non-irrigated) conditions in “virgin” land. It must be emphasised that these maps do not depict “consumptive” water use (i.e. green water) by the plant during its growth cycle, which is the approach followed in the internationally popular “virtual water use” and “water footprint” articles.

## 5. The way forward

Jewitt et al. (2009) highlighted several inconsistencies in the available literature regarding the water use and yield of emerging biofuel feedstocks, in particular sweet sorghum and sugarbeet. They recommended the establishment of field trials to estimate the water use and yield of these feedstocks under South African growing conditions. The report ended with a summary of other key research needs regarding the water use of biofuel feedstocks in South Africa. The most significant of these are:

- A need for better knowledge of feedstock water use and in particular, water productivity (defined as yield per unit water use in  $\text{kg m}^{-3}$ ).
- More detailed mapping of biophysical constraints to feedstock growth at local scales, in order to facilitate an adequate assessment of the benefits and impacts.
- The potential impact of climate change on feedstock growth, which may result in shifting cropping patterns, yield, water use and thus water productivity.

Based on these recommendations, the WRC initiated a second, more detailed biofuels research project, which commenced in April 2009 and titled: “Water use of cropping systems adapted to bio-climatic regions in South Africa and suitable for biofuel production” (WRC, 2012). The main objective of this 6-year project is to refine the mapping and modelling approaches adopted in the previous scoping study.

## 5.1 Improving estimates of feedstock water use

The scoping study concluded that confidence in the water use estimates for emerging feedstocks (such as sugarbeet and sweet sorghum) is relatively low. This is because the ACRU hydrological model was parameterised using information gleaned from the international literature that may not adequately represent local growing conditions. This shortcoming is being addressed by the aforementioned research project (WRC, 2012) through on-going field trials which measure the water use and yield of emerging feedstocks such as sugarbeet, sweet sorghum, *Jatropha curcas* and *Moringa oleifera*. Furthermore, field trials to measure the water productivity of grain sorghum and soybean were finalised in May 2013 and another sugarbeet trial will be completed by October 2013. For the well-known feedstocks (e.g. maize and sugarcane) that are extensively grown in South Africa, sufficient knowledge exists in the local literature to assist with the parameterisation of hydrological and crop yield models. Furthermore, a review of available literature reveals that current research effort is focused on identifying biofuel feedstocks that use water more efficiently.

The next step is to re-run the ACRU model using the revised feedstock parameters. Water productivity for selected feedstocks will also be determined using estimates of water use and crop yield derived from simulation models. Finally, the potential impact of feedstock cultivation on downstream water availability will be assessed. This modelling component (simulation and analysis) should be finalised in early 2014 and thus, no new information is ready for presentation in this chapter.

## 5.2 Refining optimum feedstock growing areas

Blanchard et al. (2011) urged that biofuel production in South Africa should be environmentally sustainable. Biofuel feedstock production is deemed unsustainable if the environment is irreversibly harmed (UNEP, 2009). A review of current biofuel-related literature revealed a strong emergence of numerous sustainability issues pertaining to biofuel production and its use. Sustainability is predominately affected by land use change decisions concerning the cultivation of feedstock. More specifically, feedstock production is unsustainable if a change in land use results in one of the following impacts:

- food insecurity,
- loss of biodiversity,
- decline in land rights,
- increased carbon emissions, and
- reduction in available water resources.

The literature highlights the difficulties in determining which land uses are suitable for conversion to biofuel feedstocks, especially in light of growing concerns related to sustainable development. The key to responsible biofuels is therefore to identify land for the cultivation of biofuel feedstocks that does not compromise any of the above-listed issues.

Scarlat and Dallemand (2011) proposed an international agreement, based on widely accepted criteria that identified so-called “no-go” areas for biofuel production. Together with a robust mechanism to enforce compliance, this would contribute significantly to the sustainability of biofuels. From the literature, a list of current land uses that should be prohibited from conversion to biofuels is emerging. For example, the German Advisory Council on Global Change (WBGU, 2009) is opposed to the direct or indirect conversion of woodlands, forests or wetlands into agricultural land for bioenergy crops. The list of suggested land uses to avoid include:

- current agricultural cropland (to protect food security),
- zones suited to future urban area expansion (i.e. human development),

- land with high agricultural potential (to increase food production in the future),
- natural forested land (to protect biodiversity and fixed carbon stocks), and
- land protected by current and pending legislation (to protect biodiversity).

An objective of the current WRC-funded biofuels research project is to refine the mapping criteria used to identify suitable feedstock cultivation areas. Spatial information on land cover and land use is being used to filter out areas that should not be used for biofuel feedstock production in South Africa. The outcome will ensure the sustainable production of feedstock by protecting the environment and society from possible detrimental impacts.

## 6. Conclusion

The world's interest in biofuel development is driven by the depletion of global oil reserves, the need to reduce dependency on crude oil imports, the record crude oil price in 2008 and rising fossil-based fuel prices, concerns over increased CO<sub>2</sub> (and other greenhouse gas emissions) as well as the impact of climate change. Other more significant benefits for South Africa include increased agricultural output as well as poverty alleviation and upliftment in predominately rural areas.

Rising demand for land and water from the agricultural and biofuel sectors is leading to increasing pressures on these resources and, in some cases, to land and water scarcity (FAO, 2012). Competition for natural resources occurs whether edible or non-edible feedstocks are cultivated for biofuel purposes (FAO, 2008). Cultivating feedstocks in an area with land and/or water scarcity could further exacerbate these issues, posing a risk to food security and domestic water supply. In order to minimise such impacts, land use changes should be carefully assessed. How will South Africa find the balance between meeting its future energy needs without compromising food security, biodiversity protection and its scarce water resources, and at the same time, alleviating rural poverty and providing economic development? The key is careful and optimised land use planning, which is considered the hardest challenge in securing our renewable energy future.

To facilitate responsible decision making with regard to biofuel feedstock production, land use planners require information pertaining to land use and water use of biofuel feedstocks best suited to South Africa's landscape. Land use planning should strive towards maximising the efficient use of South Africa's natural resources, whilst minimising the environmental impacts associated with feedstock production. According to Blanchard et al. (2011), this approach would allow the country to move beyond reactive responses and towards a proactive integration of sound guidelines, policies and legislation that ensure sustainability and accountability from the outset.

The country's biofuels industry is still in the early stages of development and is hampered by a lack of information regarding feedstock yield and water use, which then determines biofuel production potential. It is envisaged that the knowledge gleaned from on-going research described in this chapter will assist land use planners in meeting South Africa's future energy needs using renewable resources in a sustainable manner, without burdening South Africa's valuable and scarce water resources. The South African government has adopted a cautious approach in promoting the development of its biofuels industry. This delay in implementing the biofuels strategy provides the opportunity to carefully consider all of the potential impacts associated with this industry and to plan accordingly (Blanchard et al., 2011).

## Acknowledgements

The research presented in this paper forms part of a solicited research project (Project K5/1784 - Water use of cropping systems adapted to bio-climatic regions in South Africa and suitable for biofuel production) that was initiated by the Water Research Commission (WRC) of South Africa in Key Strategic Area 4 on Water Utilisation in Agriculture. The project is managed and funded by the WRC. For further information, refer to Project No. 1874 on pages 198-199 of the WRC's Knowledge Review 2011/12 publication (WRC, 2012).

## References

- **Acocks J.P.H.**, 1953, Veld Types of South Africa. Memoirs of the Botanical Survey of South Africa 57: 1-146. Government Printer, Pretoria, RSA.
- **Albaugh J.M., Dye P.J. and King J.S.**, 2013, Eucalyptus and water use in South Africa. International Journal of Forestry Research 2013: 1-11. Article ID 852540. <http://dx.doi.org/10.1155/2013/852540>
- **BEFS**, 2010, Bioenergy and food security: The BEFS analysis for Tanzania. Eds: I Maltoglou and Y Khwaja. Environment and Natural Resources Management Working Paper No. 35, The Bioenergy and Food Security Project (BEFS). Food and Agricultural Organisation (FAO), Rome, Italy. 240 pp. ISSN: 2071-0992. <http://www.fao.org/docrep/015/i2596e/i2596e00.pdf> [Accessed 28 September 2012]
- **BEFS**, 2012, SADC Capacity Development Forum: Forum summary. Bioenergy and Food Security Project, 22-24 February 2012, Johannesburg, South Africa. <http://www.fao.org/bioenergy/33726-0f8792434b618d68391bdba7786b220b9.pdf> [Accessed 14 October 2012]
- **BFAP**, 2008, Impact analysis of the Biofuels Industrial Strategy on the South African Agricultural and Biofuel Subsectors. BFAP Biofuels Report 03/2008. Bureau for Food and Agricultural Policy, Pretoria, RSA. [http://www.bfap.co.za/reports/BFAP\\_Biofuels\\_report\\_no3.pdf](http://www.bfap.co.za/reports/BFAP_Biofuels_report_no3.pdf) [Accessed 13 December 2009].
- **BFAP**, 2009, The South African Agricultural Baseline: 2009, Bureau for Food and Agricultural Policy (BFAP), Pretoria, RSA. [http://www.bfap.co.za/reports/BFAP\\_baseline\\_2009.pdf](http://www.bfap.co.za/reports/BFAP_baseline_2009.pdf) [Accessed 12 December 2009].
- **Blanchard R., Richardson D.M., O'Farrell P.J. and von Maltitz G.P.**, 2011, Biofuels and biodiversity in RSA. South African Journal of Science 107(5/6): 1–8.
- **Buyx A and Tait J.**, 2011, Ethical framework for biofuels. Science 332(6029): 540–541.
- **Cai X., Zhang X. and Wang D.**, 2011, Land Availability for Biofuel Production. Environmental Science and Technology 45(1): 334–339.
- **Collett A.**, 2008, The determination, protection and management of high potential agricultural land in RSA with special reference to Gauteng. [Internet]. Unpublished MSc dissertation. University of Pretoria, Pretoria, RSA. Available from: <http://upetd.up.ac.za/thesis/available/etd-08042009-171427/> [Accessed 05 August 2011].
- **DAFF**, 2010a, South African Agricultural Production Strategy. Department of Agriculture, Forestry and Fisheries (DAFF), Pretoria, RSA. Concept document draft version 6. [http://www.daff.gov.za/daaDev/doc/IGDP/AGRIC\\_PRODUCTION\\_STRATEGY\\_FRAMWK.pdf](http://www.daff.gov.za/daaDev/doc/IGDP/AGRIC_PRODUCTION_STRATEGY_FRAMWK.pdf) [Accessed 01 August 2011].

- **DAFF**, 2010b, Grain sorghum market value chain profile. National Department of Agriculture (NDA), Pretoria, RSA.  
<http://www.nda.agric.za/docs/AMCP/GrnSorghumMVCP2009-2010.pdf> [Accessed 16 October 2010].
- **DAFF**, 2012, Abstract of agricultural statistics: 2012. Department of Agriculture, Forestry and Fisheries. Pretoria, RSA. <http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf> [Accessed 21 September 2012].
- **DME**, 2006a, Department of Minerals and Energy, National Biofuels Study: An investigation into the feasibility of establishing a biofuels industry in the Republic of South Africa. Final report prepared to assist the development of an industrial strategy. 114 pp. [http://www.dme.gov.za/pdfs/energy/bio\\_feasible\\_study.pdf](http://www.dme.gov.za/pdfs/energy/bio_feasible_study.pdf) [Accessed 17 November 2009].
- **DME**, 2006b, Department of Minerals and Energy, Draft biofuels industrial strategy of the Republic of South Africa, Pretoria, RSA. 16 pp. [http://www.dme.gov.za/pdfs/energy/renewable/Biofuels\\_Strategy\\_SA.pdf](http://www.dme.gov.za/pdfs/energy/renewable/Biofuels_Strategy_SA.pdf) [Accessed 17 November 2009].
- **DME**, 2007, Biofuels industrial strategy of the Republic of RSA. Department of Minerals and Energy, Pretoria, RSA.  
[http://www.dme.gov.za/pdfs/energy/renewable/biofuels\\_indus\\_strat.pdf\(2\).pdf](http://www.dme.gov.za/pdfs/energy/renewable/biofuels_indus_strat.pdf(2).pdf) [Accessed 17 November 2009].
- **DoE**, 2012, Regulations regarding the mandatory blending of biofuels with petrol and diesel. RSA Government Gazette No. 35623, 23 August 2012. Amendment no. R.671 of the Petroleum Products Act of 1977, Pretoria, RSA.  
<http://www.info.gov.za/view/DownloadFileAction?id=173022> [Accessed 29 Aug 2012].
- **Dye P. and Versfeld D.**, 2007, Managing the hydrological impacts of South African plantation forests: an overview. *Forest Ecology and Management* 251(1-2): 121-128.
- **DWA**, 1986. Management of the water resources of the Republic of South Africa. Department of Water Affairs. CTP Book Printers, Cape Town. ISBN:0 621 11004 3.
- **Escobar J.C., Lora E.S., Venturini O.J., Yanez E.E., Castillo E.F. and Almazan O.**, 2009, Biofuels: Environment, technology and food security. *Renewable and Sustainable Energy Reviews* 13: 1275–1287.
- **FAO**, 2008, Bioenergy, food security and sustainability–Towards an international framework. High-level conference on world food security, 3 -5 June 2008, Rome, Italy. Food and Agricultural Organisation, Rome, Italy.  
[http://www.fao.org/fileadmin/user\\_upload/foodclimate/HLCdocs/HLC08-inf-3-E.pdf](http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/HLC08-inf-3-E.pdf) [Accessed 28 September 2012].
- **FAO**, 2010, FAO statistical yearbook 2010, Food and Agricultural Organisation of the United Nations, Rome, Italy. <http://www.fao.org/economic/ess/ess-publications/ess-yearbook/ess-yearbook2010/en/> [Accessed 05 August 2011].
- **FAO**, 2012, Impacts of Bioenergy on Food Security - Guidance for Assessment and Response at National and Project Levels. Environment and Natural Resources Working Paper No. 52, Food and Agricultural Organisation, Rome, Italy. 68 pp. ISBN: 978-92-5-107151-9.  
<http://www.fao.org/docrep/015/i2599e/i2599e00.pdf> [Accessed 28 September 2012].
- **FAOSTAT**, 2009, Food Balance Sheet for South Africa: 2009. Food and Agricultural Organisation, Rome, Italy  
<http://faostat.fao.org/site/368/DesktopDefault.aspx?PageID=368#anchor> [Accessed 01 November 2012].
- **Fargione J., Hill J., Tilman D., Polasky S. and Hawthorne P.**, 2008, Land clearing and the biofuel carbon debt. *Science* 319 (5867): 235–1238.

- **Funke T., Strauss P.G. and Meyer F.**, 2009. Modelling the impacts of the industrial biofuels strategy on the South African agricultural and biofuel subsectors. *Agrekon* 48(3): 223–244.
- **Gnansounou E.**, 2011, Assessing the sustainability of biofuels: A logic-based model. *Energy* 36(4): 2089–2096.
- **Gush M.**, 2010, Assessing hydrological impacts of tree-based bioenergy feedstock. In: eds. Amezaga JM, von Maltitz G and Boyes S, *Assessing the Sustainability of Bioenergy Projects in Developing Countries: a Framework for Policy Evaluation*, Chapter 3, 37–51. University of Newcastle, Newcastle, UK.
- **Harvey M. and Pilgrim S.**, 2011, The new competition for land: Food, energy and climate change. *Food Policy* 36(1): 40–51.
- **IDC**, 2011, Request for the proposal to perform owner’s engineer services for the Cradock ethanol project. Tender Document T03/01/11. Industrial Development Corporation of RSA. [http://www.idc.co.za/Content/Tenders/RFP-Owners\\_Engineer\\_Services\\_for\\_the\\_Arengo\\_316\\_T030111.pdf](http://www.idc.co.za/Content/Tenders/RFP-Owners_Engineer_Services_for_the_Arengo_316_T030111.pdf) [Accessed 19 February 2011].
- **IDC**, 2012, An analysis of South Africa’s grain sorghum industry. Industrial Development Corporation of South Africa Ltd. Department of Research and Information. Compiled by T Mashabela. ISBN: 978-1-920639-02-0. <http://idc.co.za/tenders2012/latest-tenders2012/32-publications/research-reports> [Accessed 28 September 2012].
- **HOC**, 2013, Global Food Security: First Report of Session 2013-14. The International Development Committee, House of Commons, United Kingdom. Report HC 176, <http://www.publications.parliament.uk/pa/cm201314/cmselect/cmintdev/176/176.pdf> [Accessed 4 June 2013].
- **Jewitt G. and Kunz R.**, 2011, The impact of biofuel feedstock production on water resources: a developing country perspective. *Biofuels, Bioproducts and Biorefining* 5(4): 387–398.
- **Jewitt G.P.W., Kunz R.P., Wen H.W. and van Rooyen A.M.**, 2009, Scoping study on water use of crops/trees for biofuels in South Africa. Report No. 1772/1/09. Water Research Commission, Pretoria, RSA. ISBN: 978-1-77005-884-2.
- **King J.S., Ceulemans R., Albaugh J.M., Dillen S.Y., Domec J.C., Fichot R., Fischer M., Leggett Z., Sucre E., Trnka M. and Zenone T.**, 2013, The challenge of lignocellulosic bioenergy in a water-limited world. *Bioscience* 63(2): 102-117.
- **Kotze C.**, 2012a, DoE’s mandatory blending regulations welcomed by grain producers. *Engineering News* 32(06). Creamer Media (Pty) Ltd, Johannesburg, RSA. 21-27 September 2012, p 67.
- **Kotze C.**, 2012b, SA biofuels industry awaits implementation of regulations. *Engineering News* 32(06). Creamer Media (Pty) Ltd, Johannesburg, RSA. 21-27 September 2012, p 68.
- **Lapola D.M., Schaldach R., Alcamo J., Bondeau A., Koch J., Koelking C. and Priess J.A.**, 2010, Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *Proceedings of the National Academy of Sciences (PNAS)* 107(8): 3388–3393.
- **Meyer F., Strauss P.G. and Funke T.**, 2008, Modelling the impacts of macro-economic variables on the South African biofuels industry. *Agrekon* 47(3): 1-19.
- **Mfundisi K.B.**, 2012, Assessing the availability of land and water resources for the production of energy crops in southern Africa. *Journal of Sustainable Bioenergy Systems* 2: 37-42. doi:10.4236/jsbs.2012.23006 <http://www.scirp.org/journal/PaperInformation.aspx?paperID=22737#abstract> [Accessed 24 October 2012].
- **NAMC-DAFF**, 2009, The South African Food Cost Review: 2008. National Agricultural Marketing Council and Department of Agriculture, Forestry and Fisheries, Pretoria, RSA.

- ISBN: 978-0-9802741-4-1. 151 pp. [http://www.namc.co.za/ASSETS/October\\_09/Food\\_Cost\\_Review\\_\(August\\_2009\).pdf](http://www.namc.co.za/ASSETS/October_09/Food_Cost_Review_(August_2009).pdf) [Accessed 7 December 2009].
- **NWA**, 1998, National Water Act of 1998. Department of Water Affairs, RSA. [http://www.dwaf.gov.za/Documents/Legislature/nw\\_act/NWA.pdf](http://www.dwaf.gov.za/Documents/Legislature/nw_act/NWA.pdf) [Accessed 27 January 2012].
  - **Raimbault M. and Humbert S.**, 2010, ISO considers potential standard on water footprint. International Organisation for Standardisation (ISO). [http://www.iso.org/iso/iso-focus-plus\\_index/iso-focusplus\\_online-bonus-articles/isofocusplus\\_bonus\\_water-footprint.htm](http://www.iso.org/iso/iso-focus-plus_index/iso-focusplus_online-bonus-articles/isofocusplus_bonus_water-footprint.htm) [Accessed 14 March 2011].
  - **Ravindranath N.H., Lakshmi C.S., Manuvie R. and Balachandra P.**, 2010, Biofuel production and implications for landuse, food production and environment in India. *Energy Policy* 39(10): 5737-5745. <http://www.sciencedirect.com/science/article/pii/S0301421510005744> [Accessed 18 February 2011].
  - **Royal Society**, 2008, Sustainable biofuels: prospects and challenges. Royal Society Policy Document 01/08. Royal Society, London, UK. ISBN: 978 0 85403 662 2. 88 pp.
  - **SAPIA**, 2012, 2011 Annual Report. South African Petroleum Industry Association, Johannesburg, RSA. [http://www.sapia.co.za/literature\\_141171/SAPIA\\_2011\\_Annual\\_Report](http://www.sapia.co.za/literature_141171/SAPIA_2011_Annual_Report) [Accessed 25 September 2012].
  - **SASA**, 2009, Sugarcane crop data. South African Sugar Association, Mt. Edgecombe, KwaZulu-Natal, RSA. [http://www.sasa.org.za/Uploads/993e5c3d-48b3-445e-9180-9c0588b079e6/Crop\\_Data.pdf](http://www.sasa.org.za/Uploads/993e5c3d-48b3-445e-9180-9c0588b079e6/Crop_Data.pdf) [Accessed 12 December 2009].
  - **Scarlat N. and Dallemand J.F.**, 2011, Recent developments of biofuels/bioenergy sustainability certification: A global overview. *Energy Policy* 39(3): 1630–1646.
  - **Schulze R.E.**, 1995, Hydrology and agrohydrology: a text to accompany the ACRU 3.00 Agrohydrological Modelling System. Water Research Commission, Pretoria, RSA. WRC Report TT69/95.
  - **Schulze R.E.**, 2007, South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA. WRC Report 1489/1/07 (On DVD).
  - **Schulze R.E., Hewitson B.C., Barichiev K.R., Tadross M.A., Kunz R.P., Horan M.J.C. and Lumsden T.G.**, 2011, Methodological approaches to assessing eco-hydrological responses to climate change in South Africa. Water Research Commission, Pretoria, RSA. WRC Report 1562/1/10. ISBN: 978-1-4312-0050-4. 197 pp.
  - **Scott D.F. and Smith R.E.**, 1997, Preliminary empirical models to predict reductions in annual and low flows resulting from afforestation. *Water SA* 23: 135–140.
  - **Searchinger T., Heimlich R., Houghton R.A., Dong F., Elobeid A., Fabiosa J., Tokgoz S., Hayes D. and Yu T.**, 2008, Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319 (5867): 1238–1240.
  - **Smith R.E. and Scott D.F.**, 1992, The effects of afforestation on low flows in various regions of South Africa. *Water SA* 18: 185–194.
  - **Tait J.**, 2011, The ethics of biofuels. *GCB Bioenergy* 3: 271–275.
  - **UNEP**, 2009, Towards sustainable production and use of resources: Assessing biofuels. International Panel for Sustainable Resource Management. United Nations Environment Programme, France. ISBN: 978-92-807-3052-4. Job Number: DT/1213/PA. 36 pp.
  - **Von Maltitz G. and Brent A.**, 2008, Assessing the biofuel options for Southern Africa. Science real and relevant: 2nd CSIR Biennial Conference, Pretoria, RSA. 17–18 November 2008. <http://researchspace.csir.co.za/dspace/handle/10204/2579> [Accessed 27 July 2011].
  - **Warburton M.L., Schulze R.E. and Jewitt G.P.W.**, 2012, Hydrological impacts of land use change in three diverse South African catchments. *Journal of Hydrology* 414–415: 118–135.

- **WBGU**, 2009, Future bioenergy and sustainable land use. German Advisory Council On Global Change, Earthscan, Vancouver, US, ISBN 978-1-84407-841-7. 365 pp.
- **Witmer M.C.H. and Cleij P.**, 2012, Water Footprint: Useful for sustainability policies? PBL Publication 500007001, PBL Netherlands Environmental Assessment Agency, The Hague. 56 pp.  
[http://www.pbl.nl/sites/default/files/cms/publicaties/pbl\\_2012\\_Waterfootprint\\_873.pdf](http://www.pbl.nl/sites/default/files/cms/publicaties/pbl_2012_Waterfootprint_873.pdf)  
[Accessed 21 February 2013].
- **Witt A.B.R.**, 2010, Biofuels and invasive species from an African perspective – a review. GCB Bioenergy 2(6): 321–329.
- **WRC**, 2012, WRC Knowledge Review 2011/2012, Water Research Commission, Pretoria, RSA, 198-199, [http://www.wrc.org.za/Pages/KH\\_KnowledgeReviews.aspx?dt=8&ms=59](http://www.wrc.org.za/Pages/KH_KnowledgeReviews.aspx?dt=8&ms=59); [Accessed 13 November 2012].
- **WWF**, 2011, The Energy Report: 100% Renewal Energy by 2050, World Wildlife Fund, Ecofys and the Office of the Metropolitan Architecture (OMA). Editor S.Singer. ISBN 978-2-940443-26-0. 256 pp.
- **Yako P.**, 2009, Development of a biofuel industry in RSA. Communication to the Department of Agriculture, Forestry and Fisheries. Ref: 16/3/4/104. Department of Water Affairs, Pretoria, RSA.

## Abbreviations

ACRU Model	Agricultural Catchments Research Unit (Natal University, SA)
BEFS	Bioenergy & Food Security Project
BFAP	Bureau for Food and Agricultural Policy (SA)
DAFF	Department of Agriculture, Forestry and Fisheries (SA)
DME	Department of Minerals & Energy (SA)
DWA	Department of Water Affairs (SA)
FAO	Food & Agriculture Organisation of the United Nations
IDC	Industrial Development Corporation (SA)
ISO	International Organisation for Standardisation
MAR	Median Annual Runoff
NWA	National Water Act (SA)
SA	South Africa
SADC	Southern African Development Community
SAPIA	South African Petroleum Industry Association (SA)
SASA	South African Sugar Association (SA)
SFRA	Stream Flow Reduction Activity
UNEP	United Nations Environment Programme
WBGU	German Advisory Council on Global Change
WRC	Water Research Commission (SA)
WWF	World Wildlife Fund

# The water footprint of biofuels from microalgae

P.W. Gerbens-Leenes, G.J. de Vries, L. Xu,  
University of Twente, The Netherlands

## Abstract

Microalgae are receiving much interest as a possible biofuels feedstock, resulting in increasing research and development efforts. Biofuels from microalgae are potentially important sources of liquid renewable energy carriers, replacing petrol. Algae are not produced on a large-scale yet, but research shows promising results. Biofuel production needs water, an increasingly scarce resource. The interest in biofuels, in combination with an increasing global water scarcity, causes a need for knowledge of the water footprint (WF) of this new energy resource. This chapter gives an indication of the water footprint (WF) of algae-based biofuels. It uses the WF method as an indicator of water use. We aim to give an overview of the methods used for the cultivation, harvesting and conversion to biofuels of microalgae and the related WF. The results from our case study for microalgal biodiesel produced in California, USA, show a blue WF between 16 and 172 m<sup>3</sup>/GJ and a grey WF of 0. The results, however, show large variation and depend on the water recycling during the harvest and dewatering process. Compared to biofuels from crops, the green and grey WFs of biofuels of microalgae are favorable, but blue WFs might be larger in some cases. There is a need to assess the impact of the microalgae biofuels production on fresh water resources, because fresh water of adequate quality is an important criterion for assessing the physical, economic and environmental viability of energy systems.

## 1. Introduction

At present, microalgae receive much interest as a possible feedstock for biofuels. Possibly, biofuels will supply large amounts of liquid fuels for transportation in 2030 (European Commission, 2011). In the European Union in 2000, around 27 percent of the total energy demand was attributed to transportation, which is expected to increase to about 33 percent by 2030 (European Commission, 2010). The majority of liquid biofuels today, the so termed first generation biofuels (Nigam & Singh, 2011), is produced from food crops such as sugar cane, maize, soybean, rapeseed or jatropha (Gerbens-Leenes et al., 2009). Drawbacks of using food crops as fuel feedstock include a great water use, a high arable land usage and the competition with food (Nigam & Singh, 2011). Microalgae as an alternative feedstock for biofuels is attracting more attention lately because of the advantages compared to terrestrial crops with respect to:

- a relatively high production (tons per hectare per year);
- the high oil content (30-70 percent of the dry mass);
- and the opportunity to develop a completely closed CO<sub>2</sub> and mineral cycle.

Early work on microalgae focused on strains selection, open-pond cultivation (Sheehan et al., 1998), extraction and lipid esterification. More recently, new developments on the complete chain from microalgae cultivation to biofuel production have been carried out. Examples include new photobioreactor designs (Zijffers et al., 2008), efficient harvesting technologies, effective cell disruption techniques, as well as new conversion routes. In the past, most

microalgae biorefinery systems aimed at producing biodiesel via an esterification process. Lately, other technologies such as hydrothermal liquefaction, supercritical water gasification (Chakinala et al., 2010) and catalytic hydrogenation have been applied to microalgae for producing other types of biofuels such as green diesel, ethanol, hydrogen or biogas (Xu et al., 2011).

Microalgae grow in water, in open ponds or in photobioreactors, and need water for growth. The rising interest in microalgal biofuels generates the need for knowledge of the environmental impacts, for example the water requirements, of this energy source. Because water scarcity is a growing problem, efficient use of this limited source is an important characteristic for biofuel crops. Recently, several life cycle analyses (LCAs) of microalgal biofuels have been accomplished (Clarens et al., 2011; Brentner et al., 2011). However, these provide limited information on the water use of microalgal biofuels. We estimate that the water footprint is one of the aspects which might restrict the scaling up of the production of biofuels from microalgae, because freshwater is scarce in many parts of the world. Therefore, the objective of this chapter is to give an overview of the current state of the art of technologies for making biofuels from microalgae, with a specific focus on the water footprint (WF) of microalgal biofuels. Gerbens-Leenes et al. (2009) and Mekonnen and Hoekstra (2010) applied the WF concept for bio-energy and reported WFs for bio-ethanol and biodiesel crops. Those studies excluded microalgae, meaning there are no data on the WF of microalgae available at present. To determine the water footprint of microalgal biofuels, we use the WF concept as proposed by Hoekstra et al. (2011).

This paper gives an overview of the current state of technology in microalgal biofuel production. Next, it gives a literature overview of water use in microalgae production. Finally, it applies the WF concept for the calculation of the WF of microalgal biodiesel for one specific case. The result can be compared with the WFs of other biofuels as presented in chapter xx. This gives an indication of the possible advantages of biofuels from microalgae from a water perspective.

## **2. Microalgae: the third generation biomass**

The development of biofuels is classified into three generations according to their feedstock. The first generation biofuels uses the carbohydrate or oil fraction of food crops as a feedstock. In this way, the first generation biofuels compete with food. The second generation biofuels is produced from lingo-cellulosic biomass, either the non-edible residues of food crops or from the non-edible whole plant biomass, for example, switchgrass. In the case of the application of residues, there is no competition with food supply, and the land use efficiency is improved. Presently, ongoing research of the second generation biofuels focusses on the improvement of the process efficiency and the fuel quality. Biofuels from microscopic organisms, such as microalgae, are classified as the third generation biofuels. In general, this type of biofuel is expected to be a more sustainable energy resource.

Microalgae are unicellular photosynthetic micro-organisms, living in aquatic environments that convert sunlight, oxygen (O<sub>2</sub>) and carbondioxide (CO<sub>2</sub>) to algal biomass (Demirbas, 2010). Microalgae include a large diversity of different strains. They contain lipids, proteins, carbohydrates and nucleic acids (Lee, 1989). Despite the huge potential as an energy crop, at present the worldwide production of microalgae is still limited. The global microalgae production is approximately 5000 tons of dry algal biomass, with a price of 250 euro/kg (Pulz

& Gross 2004). For comparison, the world production of palm oil is around 40 million tons, with a market value of 0.50 euro/kg (Wijffels & Barbosa, 2010).

### 3. Biofuel production from microalgae

The entire chain of biofuel production from microalgae includes five major steps: cultivation, harvesting, dewatering, oil extraction and oil upgrading.

#### 3.1 Microalgae cultivation

There are two types of microalgae, the autotrophic and the heterotrophic microalgae. The autotrophic algae use CO<sub>2</sub> as the main carbon source for the algae cell growth in the photosynthesis process. Heterotrophic algae do not apply the photosynthesis process, but use a carbon source like glucose instead. At present, microalgae cultivation takes place in two types of autotrophic cultivation systems: open-pond systems and closed photobioreactors. Table 1 gives a comparison between open ponds and photobioreactors for the cultivation of microalgae.

Variable	Open ponds	Photobioreactors	Reference
Costs	Cheap	Expensive	Brennan & Owende, 2010
Maintenance and cleaning	Easy	Difficult	Ugwu et al., 2008
Land use	High	Low	-
Growing environment	Well controlled	Poorly controlled	-
Productivity	Low	High	Chisti, 2007
Oil yield	35-45 m <sup>3</sup> ha <sup>-1</sup> yr <sup>-1</sup>	50-60 m <sup>3</sup> ha <sup>-1</sup> yr <sup>-1</sup>	
Biomass concentration	0.14 kg m <sup>-3</sup>	4.00 kg m <sup>-3</sup>	
Water evaporation	High	Low	Brennan & Owende, 2010

**Table 1: A comparison between open ponds and photobioreactors for the cultivation of microalgae.**

#### 3.2 Harvesting and dewatering

Microalgae slurry contains much water, about 99.9 percent of the fresh weight in open ponds. Before being used for biofuel production, the microalgae need to be condensed and dried to a certain dryness. This process generally requires one or more solid-liquid separation steps. Bulk harvesting techniques, such as flocculation, ultrasonic aggregation, flotation and gravity sedimentation, reach a total solid matter concentration of two to seven percent (Brennan & Owende, 2010). After that, the dewatering process requires a number of mechanical thickening methods, such as centrifugation and filtration to reach a total solid matter concentration of about 15 percent (US-DOE, 2010). Finally, thermal techniques dry the algae slurry to a higher solid matter concentration of at least 85 percent. Traditional thermal drying techniques, such as shelf spray or drum drying, are energy intensive, however, and may result in a negative energy balance (Xu et al., 2011). Despite efforts on efficiency improvement and heat recovery, thermal drying consumes significantly more energy than mechanical solid-

liquid separation. An energy efficient and reasonably cheap drying method needs to be developed to make microalgae production attractive.

### **3.3 Technical routes for biofuel production**

There are several technical routes to convert microalgae into biofuels. Thermochemical processes produce oil and gas; biochemical processes make bio-ethanol and biodiesel, while combustion generates heat and electricity (Amin, 2009). Due to the specific focus on water use of microalgal biofuels, we distinguish the wet and dry route technologies. The wet route technologies keep the entire microalgal biofuel chain in the wet phase, while the dry route technologies minimize the energy consumption in the dewatering process.

#### - Wet route technologies

Fermentation. Algae biomass is converted to ethanol by yeasts.

Anaerobic digestion. In the absence of oxygen, organic material is digested to produce biogas consisting of methane (CH<sub>4</sub>) and CO<sub>2</sub>. The biogas can be directly used for combustion.

Hydrothermal liquefaction. This technology converts wet algal biomass to bio-oil with an energy content comparable to that of biodiesel. The bio-oil can be upgraded to a liquid fuel like biodiesel (US-DOE, 2010).

Gasification. This technology partially oxidizes biomass into synthesis gas (a mixture of CO, CO<sub>2</sub>, N, CH<sub>4</sub> and H<sub>2</sub>) at high temperatures (800-1000 °C) (Brennan & Owende, 2010).

Supercritical Water Gasification (SWG). SWG gasifies wet biomass at a pressure and temperature above the supercritical point of water, producing hydrogen or synthesis gas.

#### - Dry route technologies

Direct combustion. Power plants can use algal biomass with a moisture content below 50 percent dry weight for co-firing and produce electricity and heat (Brennan & Owende, 2010). The high pretreatment costs before combustion, combined with relatively low value end products, makes the technique unattractive for microalgae.

Pyrolysis. This technology thermally cracks the biomass in the absence of oxygen and produces charcoal, condensable vapors and pyrolysis gasses. The condensable vapors can be condensed to pyrolysis oil, while the pyrolysis gasses and charcoal can be used as fuels.

## **4. The water footprint of microalgae**

The water footprint (WF) is a multi-dimensional indicator, giving water consumption volumes by source and polluted volumes by type of pollution. The WF of a product is defined as the volume of freshwater used for its production at the place where it was actually produced (Hoekstra et al., 2011). Water footprints include three components—green, blue and grey water—and distinguish between direct and indirect water use. More information on the concept is provided in another part of the present publication. This paper contains a case study for a microalgal biodiesel production system in California using an open pond for cultivation.

### **4.1 Water footprint of microalgal biodiesel in an open pond in California**

#### **4.1.1 Cultivation characteristics**

This case study calculates the WF of biodiesel from a specific microalgae strain, *Chlorella Vulgaris*, cultivated in an open pond in California. *Chlorella Vulgaris* is an autotrophic, freshwater microalgae that grows in open pond production systems. Yang et al. (2010) described the cultivation method of *Chlorella Vulgaris* in an open pond in California. For the

calculation of the WF, we use information from Yang et al. (2010). Table 2 gives the characteristics for the cultivation of this microalgae strain.

Characteristic	Values
Growth rate	17 g/m <sup>2</sup> /day
Pond evaporation rate	3,4 mm/day
Growth period	10 days
Lipid content	40% (dry weight)
Pond depth	0,20 m
Pond area	10.000 m <sup>2</sup>

**Table 2: Cultivation characteristics of Chlorella Vulgaris in California (Source: Yang et al. 2010).**

#### 4.1.2 Water footprint calculation

The WF of biofuels from microalgae has two components: grey water and blue water. When all nutrients are recycled, the grey water component is zero. In a case that all the best practices are applied, we assume that there is no water pollution and that the grey WF is zero. The blue WF calculation consists of four steps:

- calculation of the blue WF of the microalgal biomass production;
- assessment of the blue WF of harvesting and dewatering;
- assessment of the biodiesel energy yield;
- calculation of the blue WF of microalgal biodiesel.

Step 1: the calculation of the blue WF of biomass production

The water footprint of the production process  $WF_{pro,blue}$  is given by:

$$WF_{pro,blue} = \frac{CWU_{blue}}{Y} \quad [m^3/ton]$$

where Y is the crop yield (ton/ha) calculated as:

$$Y = growth\ rate * lg\ P * \frac{1}{100} \quad [ton/ha/day]$$

where the growth rate is in g/m<sup>2</sup>/day, lgP is the growth period in days and the factor 1/100 is applied to convert g/m<sup>2</sup>/day to ton/ha/day.

$CWU_{blue}$  is the blue crop water use (m<sup>3</sup>/ha) calculated as (Hoekstra et al., 2011):

$$CWU_{blue} = 10 \times \sum_{d=1}^{lg\ p} LER \quad [m^3/ha]$$

where LER is the pond evaporation rate (mm/day). The factor 10 is used to convert millimeters to m<sup>3</sup>/ha.

Step 2 : the assessment of the blue WF of harvesting and dewatering

Harvesting and dewatering is performed in four steps (Xu et al. 2011). The blue WF of this process,  $WF_{harvest}$ , is calculated by:

$$WF_{harvest} = \left( \frac{1}{BC,i} - 1 \right) - \left( \frac{1}{BC,e} - 1 \right) \quad [m^3/ton]$$

where BC,i is the biomass concentration before harvest in percentage and BC,e is the biomass concentration after drying in percentage.

Step 3: the assessment of the biodiesel energy yield

The assessment of the biodiesel energy yield,  $E_{biodiesel}$  is calculated using the method of Gerbens-Leenes et al. (2009):

$$E_{biodiesel} = DMF * f_{fat} * f_{diesel} * HHV_{biodiesel} \quad [\text{GJ/ton}]$$

where DMF is the dry-mass fraction of the crop yield (g/g),  $f_{fat}$  is the fraction of fats in the dry mass,  $f_{diesel}$  is the amount of biodiesel obtained per unit of fat (g/g), and  $HHV_{biodiesel}$  the higher heating value of biodiesel (kJ/g). Table 3 gives the input data.

Dry mass fraction (DMF)	0,85 g/g
Fraction of fats dry mass ( $f_{fat}$ )	0,4
biodiesel per unit of fat ( $f_{diesel}$ )	1,0
Higher heating value biodiesel ( $HHV_{biodiesel}$ )	37,7 kJ/g

**Table 3: Input data for the energy yield calculation**  
(Source: Gerbens-Leenes et al., 2009)

Step 4: the calculation of the blue WF of microalgal biodiesel

Finally, the WF of microalgal biodiesel,  $WF_{biodiesel}$ , is calculated by:

$$WF_{biodiesel} = \frac{WF_{tot}}{E_{biodiesel}} = \frac{WF_{proc} + WF_{harvest}}{E_{biodiesel}} \quad [\text{m}^3/\text{GJ}]$$

#### 4.1.3 Results

We give two values for the blue WF of microalgal biodiesel. The first value includes the full recycling of the blue water from the harvest and dewatering steps, while the second value excludes the recycling. Table 4 presents the results for the blue WFs of microalgal biodiesel produced in an open pond in California with and without the recycling of the blue water. The blue WFs are expressed as blue WFs for the production process, for harvesting and dewatering, and for the biodiesel per unit of energy. The table also includes the biodiesel energy yield.

Recycling		WF <sub>proc, blue</sub> (m <sup>3</sup> /ton)	WF <sub>harvest</sub> (m <sup>3</sup> /ton)	E <sub>biodiesel</sub> (GJ/ton)	WF <sub>biodiesel</sub> (m <sup>3</sup> /GJ)
No recycling	water	205	2000	12,8	172
Full recycling	water	205	0	12,8	16

**Table 4: Blue water footprints of microalgal biodiesel expressed as blue WFs for the production process, for harvesting and dehydration, and blue WF for biodiesel per unit of energy. The table includes the biodiesel energy yield.**

The results indicate that the water recycling in the harvest and dewatering process has a large impact on the final result. The blue WF for microalgal biodiesel is 172 m<sup>3</sup>/GJ for the process without recycling and 16 m<sup>3</sup>/GJ for the process with full water recycling. The difference between these two values is more than a factor ten.

#### 4.1.4 Discussion

In the calculation of WFs, we made four assumptions:

- (1) the calculation is based on one growth period, assuming a year-round operation. This might underestimate WFs, however;
- (2) we assumed that the evapotranspiration rate is equal to the pond evaporation rate;
- (3) the water recycling can interfere with the nutrient balance. We assumed that all the water from harvesting and dewatering can be recycled. However, additional efforts may be needed to ensure the water quality;
- and (4) we assumed the full conversion of lipids to biodiesel.

#### 4.1.5 Comparison with WFs of biodiesel from crops

Other contributions from the present publication present the findings of the WFs of first generation biofuels, bio-ethanol and biodiesel. Table 5 gives the global average WFs for the main crops for first generation bio-ethanol and biodiesel, as well as the blue WFs for third generation microalgal biodiesel.

	<b>Green WF</b>	<b>Blue WF</b>	<b>Grey WF</b>
	m <sup>3</sup> /GJ ethanol	m <sup>3</sup> /GJ ethanol	m <sup>3</sup> /GJ ethanol
Sugar beet	31	10	10
Sugar cane	60	25	6
Maize	94	8	19
	m <sup>3</sup> /GJ biodiesel	m <sup>3</sup> /GJ biodiesel	m <sup>3</sup> /GJ biodiesel
Rapeseed oil	145	20	29
Palm oil	150	0	6
Jatropha oil	239	335	-
Soybean oil	326	11	6
Microalgal biofuels	0	16-172	0

**Table 5: Weighted global average green, blue and grey WFs for the main crops for first generation bio-ethanol and biodiesel (Source: Mekonnen and Hoekstra, 2010) and for microalgal biodiesel (Source: this article, Table 4)**

Table 5 shows that biofuels from microalgae are favorable in terms of green and grey WFs. With the exception of the blue WF of jatropha oil, the blue WF of algae oil can be larger than the blue WFs of the other crops, however.

#### 4.1.6 Further research

This paper presents the findings of the WF of biofuels from microalgae based on one specific case. Further research should:

- Take different latitudes into account to study the effect of climate on productivity and the WF.
- Consider co-production systems that produce biofuels and other high value products.
- Model different algae species with their respective productivities, lipid contents etc.
- Compare PBR and open-pond cultivation.

## 4.2 Water footprints from earlier studies

Through literature review, we found three studies reporting the blue WFs of microalgae biodiesel production. Table 6 gives their main results in cubic meters of water per unit of energy.

Blue WF of microalgal biodiesel (m <sup>3</sup> /GJ)	Source
16 - 97	Yang et al., 2010
1555	Murphy & Allen, 2011
570 - 760	Clarens et al., 2010
16 - 172	This chapter

**Table 6: The blue water footprints of microalgae biodiesel production.**

Yang et al. (2010) have studied biodiesel production from microalgae. They have used common growth rates and lipid contents with cultivation in open ponds in California. Results from their analysis show that the WF of biodiesel varies between 591 and 3650 m<sup>3</sup>/ton. The difference is caused by the water recycling ratio. The best case recycles the water from a settling pond, and the worst case discharges all harvest water. Assuming the biodiesel energy density of 37.8 GJ/ton, we estimate a blue WF between 15.6 and 96.6 m<sup>3</sup>/GJ biodiesel.

Murphy and Allen (2011) have investigated the energy inputs for upstream operations like pumping water for cultivation in open ponds. They reported an US average water use of 11 m<sup>3</sup>/kg of algal biomass. We calculated the blue WFs based on their data. That study has reported an US average net yield of algae cultivation systems of 35,000 kg/ha per year. For water use, they have reported the US average annual water input of 39 m<sup>3</sup>/m<sup>2</sup>/year. This means 11 m<sup>3</sup>/kg of algal biomass. Considering an average algal biomass energy content of 18 MJ/kg (Murphy & Allen, 2011), this gives a blue WF of 619 m<sup>3</sup>/GJ. That study, however, excluded the downstream conversion process which makes the chain incomplete. We assumed that 40% of the primary energy in the algal biomass is converted to biodiesel. This gives a blue WF of 1555 m<sup>3</sup>/GJ (assuming a biodiesel energy content of 38 MJ/kg).

Clarens et al. (2010) have compared the environmental impacts of microalgae and conventional crops. They also have excluded the conversion process. Based on the data from their study, we estimate the blue WF of microalgae cultivation to be 378.5 m<sup>3</sup>/GJ for a case in an open pond in Virginia. With the consideration of the conversion of microalgae biomass into biodiesel, the blue WF value would increase by about 50-100%.

When comparing the results from this chapter with the earlier reported results, one may notice that our WFs for microalgal biodiesel are within a similar range as the results from Yang et al. (2010), while the other two studies reported in Table 6 give much higher WFs. All these results, however, show large variation and depend on the recycling of the water during the harvest and dewatering process. Future efforts need to analyze the water recycling process in detail in order to achieve more reliable blue WF results.

## 5. Conclusions

Microalgae are a versatile feedstock and the field is rapidly developing. At present, the majority of microalgae is grown for human and animal food, or for extraction of high value products. However, microalgae as an alternative feedstock for biofuels is attracting more

attention because of their high yield and low land use. Most ongoing research is carried out at lab-scale, with a few pilot plants being developed presently. Results from small-scale cultivation indicate a microalgal oil yield of three to four times that of other oil crops such as palm oil. Researchers expect that the yields and energy contents can be greatly improved in the near future. With current oil prices, a co-production system of microalgal biodiesel and high value products is estimated to be economically viable. With rising oil prices and improvements in the production, extraction and conversion techniques, it is expected that algae will become an interesting alternative biofuel resource in the future.

The rising interest in biofuels, in combination with an increasing global water scarcity, causes a need for knowledge of the water footprint of this new energy resource. The results from our case study for microalgal biodiesel produced in California, USA, show a blue WF between 16 and 172 m<sup>3</sup>/GJ. The results, however, show large variation and depend on the recycling of the water during the harvest and dewatering process.

This paper also indicated that there is a large amount of work being done on the microalgae cultivation and downstream conversion processes. However, less attention has been paid to the water footprint of microalgal biofuels. To be able to evaluate this new technology in the light of increasing water scarcity, it is suggested to take the water footprint into account.

## References

- **Brennan L. & Owende P.**, 2010. Biofuels from microalgae--A review of technologies for production, processing, and extractions of biofuels and co-products. *Renewable and Sustainable Energy Reviews*, 14(2), pp.557-577.
- **Brentner L. B., Eckelman M. J., Zimmerman J. B.**, *Environ Sci Technol* 2011, 45, 7060.
- **Clarens, A. F., Nassau, H., Resurreccion, E. P., White, M. A., Colosi L. M.**, *Environ Sci Technol* 2011, 45, 7554.
- **European Commission**, 2010, Trends to 2030 update. Available at: [http://ec.europa.eu/energy/observatory/trends\\_2030/doc/trends\\_to\\_2030\\_update\\_2009.pdf](http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf) [Accessed September 26, 2011]
- **Gerbens-Leenes W., Hoekstra A.Y. & Van der Meer T.H.**, 2009, The water footprint of bioenergy. , 106(25), pp.10219-10223.
- **Hoekstra A.Y., Chapagain A.K., Aldaya M.M., Mekonnen M.M.**, 2011, *The Water Footprint Assessment Manual: Setting the Global Standard*, Routledge.
- **Hoekstra A.Y. & Chapagain A.K.**, 2008, *Globalization of Water: Sharing the Planet's Freshwater Resources* 1st ed., Wiley-Blackwell.
- **Mekonnen M.M., Hoekstra A.Y.**, 2010, The green, blue and grey water footprint of crops and derived crop products. *Value of Water Research Report Series No. 47*, IHE, Delft, The Netherlands.
- **Murphy C.F. & Allen D.T.**, 2011, Energy-Water Nexus for Mass Cultivation of Algae. *Environ. Sci. Technol.*, 45(13), pp.5861-5868.
- **Sheehan J. et al.**, 1998, A look back at the US Department of Energy's Aquatic Species Program: Biodiesel from algae, National Renewable Energy Laboratory Denver, CO. Available at: <http://www.nrel.gov/docs/legosti/fy98/24190.pdf>.
- **US-DOE**, 2010, National Algal Biofuels Technology Roadmap. *Renewable Energy*, (May). <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:National+Algal+Biofuels+Technology+Roadmap#0>. [Accessed: October 4, 2011]
- **Wijffels R. H & Barbosa M.J.**, 2010, An Outlook on Microalgal Biofuels. *Science*, 329(5993), pp.796-799.

- **Xu L., Brilman D.W.F., Withag J.A.M., Brem G., Kersten S.**, 2011, Assessment of a dry and a wet route for the production of biofuels from microalgae: Energy balance analysis. *Bioresource Technology*, 102(8), pp.5113-5122.
- **Yang J., Xu M., Zhang X., Hu, Q., Sommerfeld M., Chen Y.**, 2010, Life Cycle Analysis on Biodiesel Production from Microalgae: Water Footprint and Nutrients Balance. *Bioresource Technology*, 102(1), pp.159–165.

## Abbreviations

CH <sub>4</sub>	methane
CO	carbon mono-oxide
CO <sub>2</sub>	carbon dioxide
H <sub>2</sub>	hydrogen
HHV	higher heating value
N	nitrogen
O <sub>2</sub>	oxygen
PBR	photobioreactor
US-DOE	US Department of Energy
WF	water footprint

# **EU legislative tools to protect water resources**

**F.Bouraoui**

**Joint Research Centre of the European Commission**

**Institute for Environment & Sustainability**

**Water Unit TP 450**

**I-21027 Ispra (Va) Italy**

## **Abstract**

Protecting water resources is high on the European Commission and several pieces were enacted to protect the quality and the quantity of the resource. The Water Framework Directive (WFD) is the key policy in the field of water protection and it requires Member States to achieve good ecological and chemical status by 2015. Other legislations are also in place to protect pollution from point and diffuse sources. Despite the large body of environmental legislation actually in place, local and large scale eutrophication are still occurring in Europe's waters, and large parts of Europe's transitional and coastal waters are likely to fail to achieve the good chemical status required by the WFD by 2015. In 2012, the European Commission completed the Blue Print to Safeguard Europe's Water Resources with three specific objectives: to improve the implementation of the current legislation, to foster the integration of water policy with other policies objectives, and to seek the completion of the current policy framework.

## **1. Introduction**

In Europe, about 3% of the arable land was used for energy crop production in 2005, acreage that will have to increase significantly in order to reach the renewable energy target of the Renewable Energy Directive of the European Commission (EC, 2009a). Clearly the cultivation of energy crop will have a significant impact on water resources both in terms of quantity and quality (fertilizer and herbicide application) and will alter significantly the land use. We will address in this chapter the legislations that are impacting directly or indirectly water resources management in terms of water quality and quantity.

Protecting European water resources is high on the agenda of the European Commission because of their ecological and economic importance. The key policy instrument to protect inland (surface and groundwater), transitional and coastal water resources is the Water Framework Directive (WFD) that entered into force in 2000. In this effort, the Commission established new ecological objectives for all European waters, aiming at more integrated and coherent approach for water protection. This Directive complemented a panoply of existing legislations that address main key pressures including the Nitrates Directive dealing with nitrate pollution from agricultural activities (diffuse sources) and the Urban Waste Water Directive which controls pollution from waste water treatment plants (point sources). It also strengthened earlier initiatives by individual countries that joined to tackle in harmonised way water pollution problems (OSPAR, HELCOM, MEDPOL conventions). This paper deals with the legislative framework aiming at protecting water resources in the context of biofuels production including both biodiesel and bioethanol production.

## **2. Protecting Water Resources**

### **2.1 Water status and legislation**

#### **2.1.1 Water Framework Directive**

Directive 2000/60 establishing a Framework for Community Action in the Field of Water Policy OJ [2000] L327/1 (Water Framework Directive; WFD) was introduced to rationalise and update existing water legislation. As such two Directives were repealed in 2007 (Drinking Water Directive and Sampling Drinking Water Directive) and four more will be repealed in 2013 (Shellfish Directive, Freshwater Fish Directive, Groundwater Directive, and Dangerous Substances Directive). The Water Framework Directive requires Member States to prevent the deterioration and enhance the status of all water bodies with the aim of achieving good ecological and chemical status for all waters by 2015. The ecological status includes the abundance of aquatic life, nutrient availability, pollution by chemicals, and morphological characteristics. The ecological status is broken down into five categories ranging from high status with low or no human impact to bad status. In addition the WFD requires Member States to protect and enhance all artificial and heavily modified water bodies with the aim of achieving good ecological potential and good chemical status by 2015.

The WFD was a breakthrough in the field of water management by putting forward many novel aspects calling for “Sustainable approach to manage an essential resource”, “Holistic ecosystem protection”, “Integration of planning”, the “polluter pays principle,” and the “right geographical scale”, (CEC, 2007). Indeed, the Directive requires the management to be performed at a river basin level. By going beyond the administrative boundaries, the WFD led to a new reorganization of water management where river basins became the central geographical unit of analysis. The first task required by the Directive was thus the identification of river basins and their assignment to unique River Basins Districts (RBDs), and notification to the EC of competent authorities, all to be completed by December 2003. In the first implementation report produced by the European Commission (CEC, 2007) 110 RBS were designated, 40 of which are trans-boundary, with sizes ranging from 1000 km<sup>2</sup> to more than 800,000 km<sup>2</sup>.

The subsequent task to be performed within the implementation of the WFD was a status review (Articles 5 and 6). It consisted in analysing the characteristics of RBDs concerning significant pressures and economics of water use, and producing a register of areas requiring protection. In more details, Article 5 required Member States to identify and characterise in terms of magnitude and types significant anthropogenic pressure categorized as follows (IMPRESS, 2003):

- Point sources including waste water, industry, mining, contaminated land agricultural point, waste management
- Diffuse sources including urban drainage, agricultural diffuse, forestry, and other diffuse (sewage sludge, shipping, etc.)
- Flow regime alteration including flow reduction and artificial recharge
- Morphological alteration including flow regulation, river management.

The first assessment of Article 5 led to the conclusion that 40% of surface water bodies are at risk and 30% not at risk of achieving the environmental objective by 2015. Among the recurrent dominant pressure are diffuse sources that are often linked to agricultural activities.

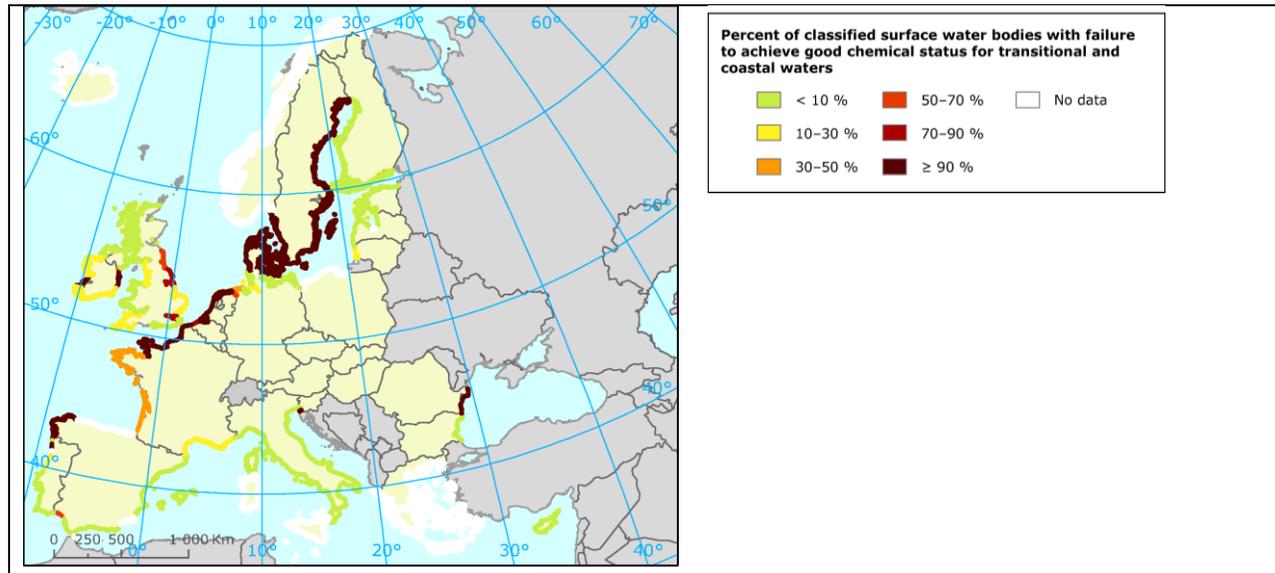
Indeed, agricultural activities through fertilizers application have been shown to be responsible for environmental degradation, in particular eutrophication of surface water due to nutrient enrichment. Indeed there is a tendency in Europe to have large nutrient (nitrogen and phosphorus) application excess (Bouraoui and Grizzetti, 2011) in agricultural areas. Increasing biomass production will require additional fertilizer application with large environmental consequences ranging from eutrophication, greenhouse gas emission, loss of biodiversity and ecosystem services, if not managed properly (Erisman et al., 2010). For instance concerning rapeseed cultivation, the fourth most important crop by area in the EU, Van der Velde et al. (2009) have shown that in EU15, eleven countries exhibit an excessive nitrogen application when compared to optimal crop requirements. Agriculture has been estimated to contribute to about 60% of total nitrogen found in all European surface waters, and about 25% of total phosphorus, with large geographical differences. For instance Behrendt (2004) estimated the contribution of agriculture to nitrogen load to be close to 80% in the Ems river basin (Germany) to about 33% for the Danube. Similar values are also reported by Grizzetti et al. (2012).

### **2.1.2 Nitrates Directive**

It is important to stress that excess nitrogen in surface water was identified very early as a potential problem and led to the adoption in 1991 of The Nitrates Directive (OJ 1991 L375/1) that deals with the protection of waters against pollution caused by nitrates from agricultural sources. The Directive aims at reducing pollution from nitrate coming from agriculture and preventing any further pollution. To achieve these objectives Member States (MS) are required to identify waters affected by pollution or potentially affected if no action is taken. Pollution, as defined in Annex I of the Directive, refers to waters where nitrate concentrations are larger than 50 mg-NO<sub>3</sub>/L and water bodies affected by eutrophication or will be affected if no action is taken. The second step of the implementation consists in identifying Nitrate Vulnerable Zones (NVZ) which are the areas draining in the previously identified areas and which contribute to pollution. The following step consists in protecting waters against pollution by requiring MS to establish a Code of Good Agricultural Practices to be implemented on a voluntary basis. The implementation of this code is mandatory on all NVZ in addition to other measures such as manure management which limit the application of organic N at 170kg/ha, etc. The Directive also requires MS for the purpose of designation and revising the designation of the NVZ to set up monitoring programmes. This Directive establishes control at the source of pollution by limiting the amount of applied manure and also sets standard water quality limits.

After 20 years of implementation of the Nitrates Directive, water quality has shown significant improvements. The European Environment Agency (EEA; 2009) reported that 35% of surface water monitoring stations from the European network EUROWATERNET showed decreasing trends of nitrate concentration for the period 1992-2005. The European Commission (EC, 2007) indicated that 14% of the surface water stations used to monitor the implementation of the Nitrates Directive between 1996 and 2003 exhibited increasing concentrations while 55% had decreasing trends. In its latest report concerning the period 2004-2007 the European Commission (2010) indicates that 70% of the freshwater monitoring stations show stable or decreasing nitrate concentrations. However, problems still exist in many places in Europe and the nitrate concentration of many streams remains high and some rivers are even exhibiting increasing trends (Bouraoui and Grizzetti, 2011), and local and large scale eutrophication are still occurring

in Europe's waters, and large parts of Europe's transitional and coastal waters are likely to fail to achieve the good chemical status required by the WFD by 2015 (Figure 1).



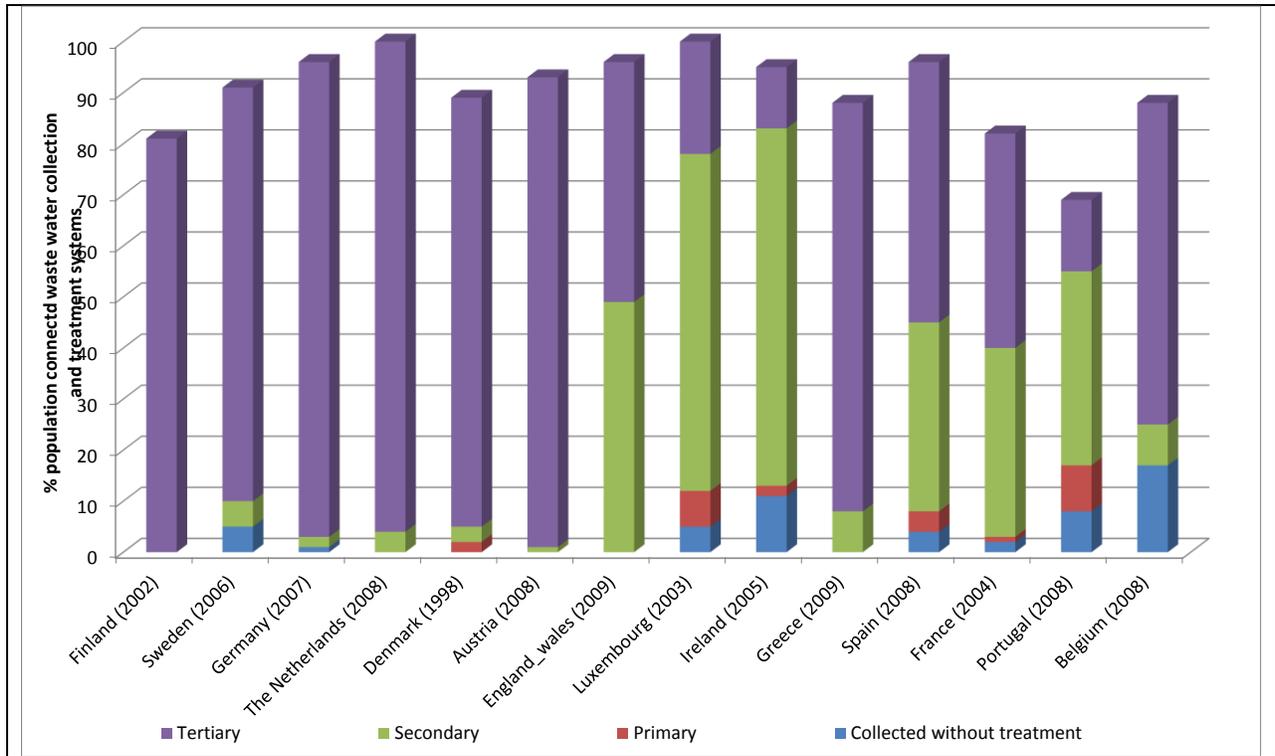
**Figure 1: Map of potential failure of achieving good chemical status of Europe's coastal and transitional waters (EEA, 2013).**

### 2.1.3 Urban Waste Water Treatment Directive

Point sources are also identified as a significant pressure on water resources in many Status Reviews published by Member States despite the adoption in 1991 of Directive L271/40 dealing with urban waste water treatment. The Urban Waste Water treatment Directive was adopted to protect the environment from discharges from urban waste and waste of certain food processing industries. The Directive requires that all agglomerations with 2,000 population equivalent (p.e.) and higher are equipped with collecting systems, and that all waste water discharged be subject to at least secondary treatment. To further protect endangered waters, the Directive requires MS to designate Sensitive Areas which include: freshwater bodies, estuaries and coastal waters which are eutrophic or which may become eutrophic if protective action is not taken; surface freshwaters used for drinking purpose that contains or are likely to contain more than 50 mg/l  $\text{NO}_3$ ; and areas where further treatment is necessary to comply with other Council Directives such as the Directives on fish waters, on bathing waters, on shellfish waters, on the conservation of wild birds and natural habitats, etc. The Directive requires that waste water discharged into these sensitive areas must undergo a more stringent treatment than secondary level. The Urban Waste Water Directive has been effective in reducing the amount of nutrients discharges in European rivers (EEA, 2010; Bouraoui and Grizzetti, 2011).

However, a full implementation of the Nitrates and the Urban Waste Water Treatment Directives has not been achieved. Infringement cases of the Nitrates Directive (EC, 2010) are reported for several countries of EU15 including France, Luxembourg and Spain. Concerning the Urban Waste Water Treatment Directive, the European Commission states that 'secondary treatment needs to be improved in some EU15 Member States', and that 'compliance rates for more

stringent treatment are very low in some EU15 countries and, overall greater efforts in implementation are needed' (EC, 2009b). The collection and treatment levels for some of EU 15 are displayed in Figure 2 (all data retrieved from EEA).



**Figure 2 : Connection and treatment level for the countries of EU 15 (data retrieved from EEA, Italy is not included as no data was available).**

### 2.1.3 Other Directives and Policies Protecting Water Resources

The previous analysis highlighted the large impact of agriculture on water resources. It is widely recognised that past agricultural intensification in Western Europe led to increased emission of nutrients and pesticide in surface and groundwater, and resulted in an increased demand for irrigated agriculture. The Common Agricultural Policy (CAP) reform by decoupling subsidies from production levels and linking them to the protection of the environment is promoting a cleaner agriculture and a more sustainable use of resources. Agricultural subsidies are now linked to application of cross compliance that includes statutory management requirements (SMR) that are requirements to be implemented under EU laws by Member States and Good and Agricultural Environmental Conditions (GAEC). Farmers willing to go beyond SMR can get additional payments through Rural Development Programs by implementing “Good Farming Practices”. Until recently, GAEC dealt mostly with soil protection. However, after the Health Check of the CAP, GAEC also deal with water management issues, including the establishment of buffer strips along watercourses and the management of water use.

Another directive complementing the WFD (extension of the media protected) and aiming at protecting marine resources is the Marine Strategy Framework Directive (EC, 2008). The aim of the Marine Strategy Framework Directive is to protect the marine environment, prevent its deterioration, or where practicable, restore marine in areas where they have been adversely affected. The implementation is ecosystem based with four Marine regions to be considered: Baltic, the North East Atlantic Ocean, the Mediterranean Sea, and the Black Sea. Each Member State shall develop a “Marine Strategy” with the aim of achieving or maintaining Good Environmental Status of their waters within that region by 2020. The implementation similarly to the WFD includes the analysis of the “essential characteristics and current environmental status”, and an analysis of the predominant pressures and impacts, which include, among others, nutrient enrichment coming from direct discharges from point sources and/or losses from diffuse sources including agriculture and atmospheric deposition. The Marine Directive complements also existing Marine Conventions including OSPAR for the North Sea, HELCOM for the Baltic Sea, MEDPOL for the Mediterranean Sea, and the Black Sea Convention. Many of these conventions have addressed the nutrient problems for many decades. For instance, the OSPAR Convention established the reduction of nitrogen and phosphorus inputs to areas affected or likely to be affected by eutrophication in the order of 50% compared to input levels in 1985, to be achieved by 1995 (PARCOM Recommendation 88/2 and 89/4). Similarly, in the HELCOM convention, the Contracting Parties committed to reduce nitrogen and phosphorus loads to the Baltic Sea according to country specific reduction targets (Baltic Sea Protection Plan). Despite the multiplicity of efforts to control pollution from anthropogenic activities, local and large scale pollution cases are still reported in Europe.

Beside fertilizer application, cultivation of crops for biomass will also require as for the cultivation of food crop the application of plant protection products (PPP), and herbicides in particular (Scholz et al., 2010). Scholz et al. (2010) cite a loss of 20% of methane yield from a non-pure crop (crop plus weed) vs. the pure crop (sorghum). PPPs have been found in surface and groundwater in concentration exceeding sometimes the drinking water limit. The European Directive on Drinking Water 80/778/EEC (amended by Directive 98/83/EC) sets the maximum allowable concentrations for pesticides in water for human consumption to 0.1 µg/L for individual substances and for total amount of pesticides and their residues to 0.5 µg/L. The Environmental Quality Standard Directive (2006/118/EC) in the field of water policy, a daughter Directive of the WFD, sets out the standards for chemical status in surface waters concerning the presence of certain pollutants and substances or groups of substances identified as priority on account of the substantial risk they pose to or via the aquatic environment as defined by the WFD. Groundwater protection against pollution and deterioration is provided by Directive 2006/118/EC, another WFD daughter Directive. Despite the ban of several pesticides including atrazine and simazine (both herbicides classified as priority substances in the EQS Directive) they are still found in many groundwater bodies around Europe at concentrations above the 0.1 µg/L standard due to their intrinsic properties.

The cultivation of crops for biofuels production has also a significant impact on water resources in terms of water use. For instance, in 2005 biofuels accounted for 2.5% and 1.2 % of total water crop evapotranspiration in UK and Germany, respectively (de Fraiture et al., 2008). De Fraiture et al. (2008) further estimated that biofuels will account for 17% of total crop evapotranspiration in Europe and for about 1% of the water used for irrigation. So clearly under climate change

scenarios, the cultivation of crops for biofuels production will contribute also to significant depletion of water resources leading in some places to increased drought risks and water scarcity. It has been reported that at least 11% of the population and 17% of the territory have been affected by water scarcity. The European concerns about water scarcity and drought were addressed in the Communication COM(2007) 414 final (Addressing the challenge of water scarcity and droughts in the European Union). The Communication of the EC identified sets of options on how to adapt to water scarcity and drought and provides some good practices put in place by several Member States.

## **2.2 Improving water resources: River Basins Management Plans**

The Water Framework Directive after the pressure and impact analysis required MS to establish surveillance, operational and investigative monitoring networks by 2006. Such monitoring programmes are established to ensure a comprehensive view of the water status, maintain under observation water bodies at risk of not meeting the environmental objectives by 2015, and then if required to investigate the reasons of not meeting such objectives. Then by 2009 MS had to draw and publish river basin management plans detailing how the water status improvement will be achieved and to develop programmes of measures needed to achieve the good status objective. Such plans are to be updated every six years. Programmes of Measures include compulsory requirements of other Directives dealing with water protection such as Bathing water, Drinking water, Sewage sludge, Urban Waste Water, Plant Protection Product, Nitrates, Habitat, Birds Directives (non exhaustive list). If the objectives are not met then the Programme of Measures should identify complementary measures that range across legislative, administrative and economic instruments. So far 23 countries have adopted their river basin management plans and four countries (Spain, Portugal, Greece, and Belgium) have not started their public consultation (on-going consultation) of the river basin management plans (Internet site of DG ENV updated on December 22 2011). The European Commission is actually evaluating these plans. An independent evaluation of the plans was performed for 9 regions by the European Environmental Bureau (a federation of environmental citizen's organization; EEB, 2010). Their evaluation focused mostly on nutrients for four major reasons: eutrophication is a major environmental concern in Europe, nutrient assessment is available throughout Member States, they are important in establishing WFD objectives, and they also include an agricultural component and thus are representative of the integration of the WFD with other directives. The analysis by the EEB (2010) of the River Basin Management Plans confirms that nutrients are a major reason of failure of surface water bodies to achieve good status. They state that the RBMP request for an extension of the 2015 deadline to achieve good status is the "rule rather than the exception" underlining again the difficulty in controlling diffuse pollution. EEB also regrets that the long term solutions (target period 2021-2027) proposed by the River Basin Management Plans to tackle the nutrient problem. A comprehensive overview of all submitted River Basin Management Plans by the European Commission should be available during 2012.

## **3. The Way Forward: the Blue Print**

Major weaknesses are found in the implementation of the legislation and the potential conflicts between the different pieces of legislation (CAP, WFD) might delay a coherent and efficient implementation of the various environmental directives. The European parliament also

recognised the big ambition of the WFD, the improvement of water quality as the result of the implementation of the WFD; however it noted the slow and uneven rate of implementation across Member States (Seeber, 2012). It further highlights the need for a new legislation that should fill specific gaps. The European Commission took the initiative to start reviewing through a fitness check from 2010 and onward the entire body of legislation in selected fields to identify “excessive burden, overlaps, gaps, inconsistencies, and/or obsolete measures”. In this context, the Blue Print to Safeguard Europe’s Water Resources to be prepared for 2012 aims at resolving these limitations in order to ensure by 2020 the availability of good quality water for sustainable and equitable use. The Blue Print (EC, 2012) aims at fulfilling three major objectives:

- Improve implementation of current legislation;
- Foster the integration of water policy with other policies objectives;
- Seek the completion of current policy framework in relation to water quantity, efficiency and adaptation to climate change.

The Blue print will rely on the on-going fitness check, and on the RBM Plans submitted by the Member States, along with the review of other water related policies. The Blue Print will put forward a tool box that can be tailored at national, regional or river basin level to take into account the various specificity linked to water management. Seeber (2012) put already some potential solutions that could improve water resources such as the use of innovative technologies and practices to improve water resources in the agricultural sector, and a cost and energy efficient re-use of waste water for irrigation.

#### **4. Conclusion**

The WFD introduced new concepts and radically changed water management in many countries in Europe. For the first time in the European water legislation, the concept of water pricing and the polluter-pay principle was introduced. Water management has to be done at the River Basin Level and no longer on an administrative level, as was formally done in many European countries. A large effort was dedicated to ensure during the development and implementation phase of the river management plans coherency with other legislations, in particular with the Common Agricultural policy. For instance, the Communication on Water Scarcity and Droughts, adopted in 2007, emphasises the strong link between agriculture and water resources, highlighting that agricultural production, including biomass production, should be adapted to locally available water resources. Despite these efforts, the implementation of water related legislation is still not fully achieved today. The Blue Print should provide a solution and answer this problem.

## References

- **Behrendt H.**, 2004, Past, present and future changes in catchment fluxes. Deliverable 4.4 of Eurocat project.
- **Bouraoui F., Grizzetti B.**, 2011, Long term change of nutrient concentrations of rivers discharging in European seas. *Science of the total Environment*, 409 (23), pp. 4899-4916.
- **European Commission (EC)**, 2007, Communication from the Commission to the European Parliament and the Council. 'Towards Sustainable Water Management in the European Union'. COM(2007) 128 final
- **European Commission (EC)**, Directive 2000/60/EC of the European Parliament and the Council establishing a framework for community action in the field of water policy, Official Journal, European Communities 2000; 327.
- **European Commission (EC)**, Report from the Commission to the council and the European Parliament on implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources for the period 2000-2003; 2007.
- **European Commission (EC)**, Directive 2008/56/EC of the European Parliament and the Council establishing a framework for community action in the field of marine environmental policy. Official Journal, European Communities 2008; L 164; 2008.
- **European Commission (EC)**, Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal, European Communities 2008; L 140/16, 2009b.
- **European Commission (EC)**, 5th Commission summary on the implementation of the Urban Waste Water Treatment Directive. Commission Staff Working Document SEC(2009) 1114 final; 2009b.
- **European Commission (EC)**, Report from the Commission to the Council and the European Parliament on implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2004-2007. COM/2010/0047 final; 2010.
- **European Commission (EC)**, 2012, A Blue Print to safeguard Europe's water resources. Consultation Document.
- **European Environment Agency (EEA)**, 2013, <http://www.eea.europa.eu/data-and-maps/figures/chemical-status-of-transitional-and>, last accessed May 15, 2013.
- **European Environmental Agency (EEA)**, 2009. Nutrients in freshwater: EEA Assessment CSI 020. Copenhagen.
- **European Environmental Agency (EEA)**, 2010, Freshwater quality, In State of the Environment SOE 2010, Copenhagen.
- **De Fraiture C., Giordano M., Liao Y.**, 2008, Biofuels and implications for agricultural water use: Blue impacts of green energy. *Water Policy*, 10 (SUPPL. 1), pp. 67-81.
- **EEB**, 2010, 10 years of the Water Framework Directive. A toothless tiger? A snapshot assessment of EU environmental ambitions.
- **Grizzetti B., Bouraoui F., Aloe A.**, 2012, Changes of nitrogen and phosphorus loads to European seas. *Global Change Biology*, 18 (2), pp. 769-782
- **IMPRESS**, 2003, Common Implementation Strategy for the Water Framework Directive. Guidance Document no 3: Analysis of Pressures and Impacts.

- **Scholz V., Heiermann M., Kaulfuss P.**, 2010, Sustainability of energy crop cultivation in Central Europe. *Sociology, Organic Farming, Climate Change and Soil Science* pp. 109-145
- **Seeber R.**, 2012. Draft Report on the implementation of EU water legislation, ahead of a necessary overall approach to European water challenges. 2011/2297(INI)
- **Van der Velde M., Bouraoui F., Aloe, A.**, 2009, Pan-European regional-scale modelling of water and N efficiencies of rapeseed cultivation for biodiesel production. *Global Change Biology*, 15 (1), pp. 24-37.

## Abbreviations

CAP	Common Agriculture Policy (European Union)
CEC	Commission of the European Communities
EC	European Commission
EU	European Union
GAEC	Good Agricultural and Environmental Condition
HELCOM	Helsinki Commission, Baltic Marine Environment Protection Commission
MEDPOL	Programme for the assessment and control of pollution in the Mediterranean Region
NVZ	Nitrate Vulnerable Zones
OJ	Official Journal (European Union)
OSPAR	Convention for the protection of the Marine Environment of the North East Atlantic
PPP	Plant Protection Products
RBD	River Basin Districts
RBMP	River Basins Management Plans
SMR	Statutory Management Requirements
WFD	Water Framework Directive (European Union)

# **U.S. Federal and State Water Laws' Impact on Bioenergy Policy**

**Jody M. Endres, J.D., M.A.**

**The University of Illinois College of Agricultural, Consumer and Environmental Sciences  
Department of Natural Resources and Environmental Sciences**

## **Abstract**

Debates surrounding the sustainability of bioenergy have emerged in recent years with regard to water quality and quantity. In the United States, aggressive measures by the U.S. Environmental Protection Agency to clean-up polluted waterways present valuable incentives for perennial biomass cropping to play a major role in reducing pollution run-off. Water use likely will be a primary concern, particularly where irrigation occurs in areas already under stress from drought and irrigation withdrawals from depleted underground aquifers. In the U.S., these areas primarily lie in the Great Plains. Complex state laws, such as those exemplified in Texas, govern future water competition. Federal laws also overlay water allotment and protection of endangered and threatened species. Sustainability certification for biofuels may be one way to measure and address water quality and quantity impacts.

## **1. Introduction**

Renewable energy incentives have led to expansive growth in demand for biomass-based feedstocks from both cropping and forestry systems. The biomass sector increasingly has come under pressure, however, to demonstrate social and environmental benefits befitting its “renewable,” “sustainable,” and “green” monikers. While debates have raged around biomass’ carbon footprint and impacts on food security, growing worries about future fresh water supplies (Fingerman et al. 2010; Gerbens-Leenes et al., 2009) place bioenergy squarely in the cross-hairs of public skepticism. Perennial biomass cropping systems’ potential effect on water quality and supplies lies in evapotranspiration, irrigation and nutrient run-off from biomass production (Berndes 2008), as well as water withdrawals for, and pollution discharges from, biorefineries.

Strategies more favorable to biomass-based energy in relation to water quality are evolving. In the United States, the Obama Administration is pursuing aggressive regulation to clean-up waterways impaired by agricultural pollution. Although the agricultural lobby historically has fought any environmental regulation, biomass producers actually may stand to profit from nutrient trading regimes being put in place to meet more stringent water quality standards because perennial systems require less inputs and foster better soil conditions. Where cropping systems uptake larger amounts of water in the growing process, erosion that transports nutrients may be reduced (Van Looke et al. 2010). Sustainability standards being built by stakeholders within the biofuels supply-chain anticipate growing competition for, and constraints on, ground water supplies by disfavoring irrigation and rewarding less water use in the biorefining process. The standards also require best management practices to avoid water pollution. A few biorefineries in the U.S. have achieved certification.

Accordingly, this paper examines the landscape of U.S. water quality policies that likely will influence whether biomass can live up to sustainability expectations and achieve successful commercialization. Part one looks at ground-breaking U.S. federal strategies at improving

waterways impaired by agricultural pollution, and biomass' potential role in these programs. Part two reviews the complex system of water rights in the U.S. and mounting constraints on all users within watersheds that necessarily support bioenergy system efficiency improvements wherever possible.

## **2. Part One. U.S. Federal Strategies Related to Water**

### **2.1. Water Quality Improvements Sought by the Obama Administration**

In early 2010, U.S. Environmental Protection Agency (EPA) Administrator Lisa Jackson told a group of stakeholders gathered to discuss innovative solutions to improve water quality that she seeks “a huge leap forward in water quality as [was seen] in the 1970s after passage of the Clean Water Act” (U.S. EPA, 2011a). State reporting on impaired waterways supports the need for such bold action. Of the over 75,000 impairments nationwide, approximately 20% are attributable to nutrient pollution (U.S. EPA, 2011b). Many of America’s estuaries have shown little improvement in eutrophic conditions, with over two-thirds of the estuaries suffering from moderate to high eutrophication (Bricker et al., 2007). EPA’s strategy to restore impaired waters centers on identifying numeric nutrient loading reductions and through cooperative efforts with states, implementing plans to improve both local and downstream watersheds. EPA singles out the agricultural sector for an increased dialogue to reduce phosphorus, nitrogen and sediment pollution, in collaboration with the U.S. Department of Agriculture (USDA). EPA’s approach further encourages adoption of trading and other market-based tools to help achieve those reductions.

The Clean Water Act (CWA) is the main statutory tool available to EPA to achieve its goal of cleaning up agricultural water pollution. Section 101 of the Act states that Congress’ goal in enacting the CWA was to “restore & maintain the chemical, physical and biological integrity of the Nation’s waters” and attain “water quality which provides for the protection of fish, shellfish and wildlife.” Reflective of the American federalist system, states play a primary role in water pollution prevention. Section 303(c) requires states to construct comprehensive water quality standards (WQS) establishing quality goals for all intrastate waters, with state review every three years. To guide the process, states designate “uses” of waterways within their jurisdiction, such as “fishable” and “swimmable.” To support these uses, states develop water quality “criteria” that can be either narrative or numeric. Criteria designate the amount of pollutants that may be present in a waterbody without impairing its designated uses. When designated uses are impaired, states must measure and set total maximum daily loadings (TMDLs) under section 303(d). EPA maintains criteria guidance for pollution concentrations to assist states, but generalized, national standards are not suitable for nutrient pollution because of the localized nature of nutrient pollution problems.

Congress’ main focus in the CWA is on “point sources”—discernible, defined, and discrete conveyances of pollution discharges such as pipes, ditches or channels. Agricultural sources, on the other hand, are classified as “non-point” sources through an exemption in the definition of point source, and are primarily addressed through state management plans and best management practices. States receive federal funding to support these programs.

In 1998, the Clinton administration issued a National Strategy for the Development of Regional Nutrient Criteria because the majority of states had no numeric WQS at all, and 17 states had no numeric standards for nitrates and phosphorus (U.S. EPA 1998). The strategy set 2003 as the deadline for states to develop numeric nutrient criteria and standards, with U.S. EPA review and

approval if "scientifically defensible." National Water Quality Inventories, required to be conducted by states every two years under section 305(b), help EPA track states' progress. Some headway was made throughout the Bush Administration years, but by 2008 delays and shortfalls in state numeric criteria development led environmental groups to pursue legal action against EPA to accelerate the process. And, as the quote from Lisa Jackson above demonstrates, at the same time a new Democratic administration under President Barack Obama portended a more aggressive strategy toward nutrient pollution in the nation's waterways.

Three types of scenarios currently playing out in regulatory and court proceedings provide interesting insight on the future role of energy biomass in finally achieving water quality goals—some 40 years after the enactment of the Clean Water Act. Litigation has driven EPA to commandeer development of numeric nutrient criteria in the State of Florida. A coalition of environmental groups recently expanded their litigation strategy beyond individual states (such as Florida), seeking EPA action within the entire Mississippi Basin to reduce Gulf of Mexico hypoxia. Perhaps most prominently, EPA has ramped up considerably its role in a long-standing collaboration to clean-up the Chesapeake Bay. Agricultural interests, however, have resisted the establishment of more concrete nutrient limitations and have filed suit against U.S. EPA alleging flawed modeling and lack of jurisdiction, among other claims. The following elaborates in more detail these three significant developments at the nexus of bioenergy and water policy in the U.S.

## 2.2 U.S. EPA “Takeover” of Florida’s Water Quality Standards Development for Nutrients

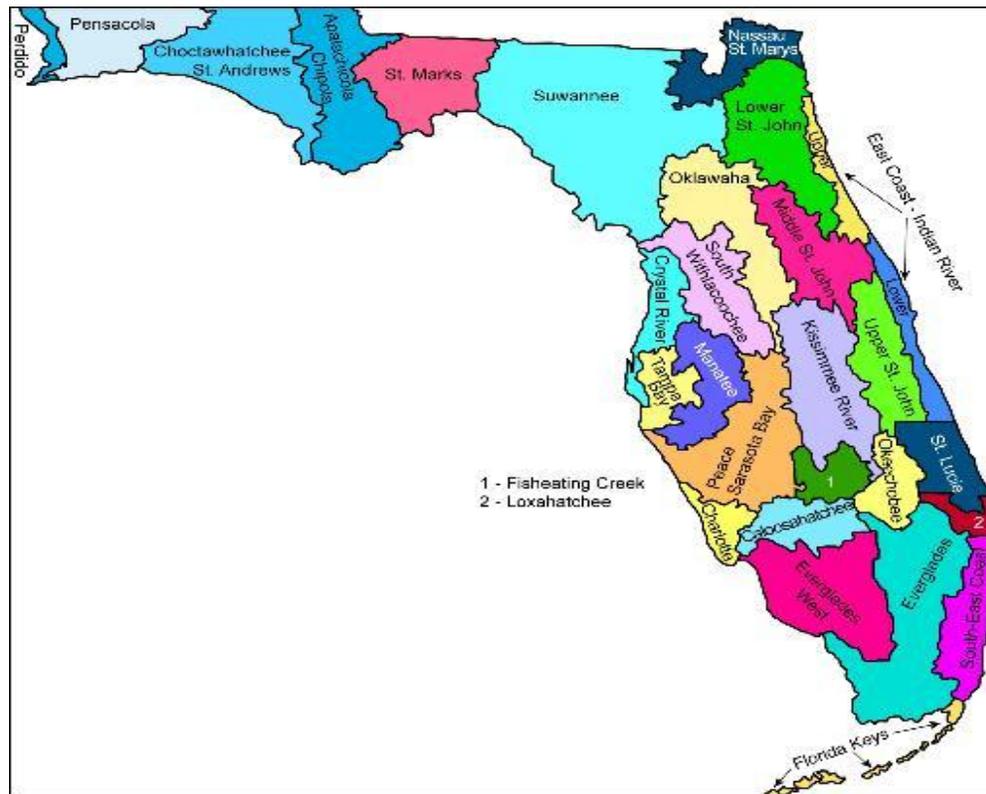


Figure 1: Major Florida Watersheds, courtesy of the University of Florida Extension,

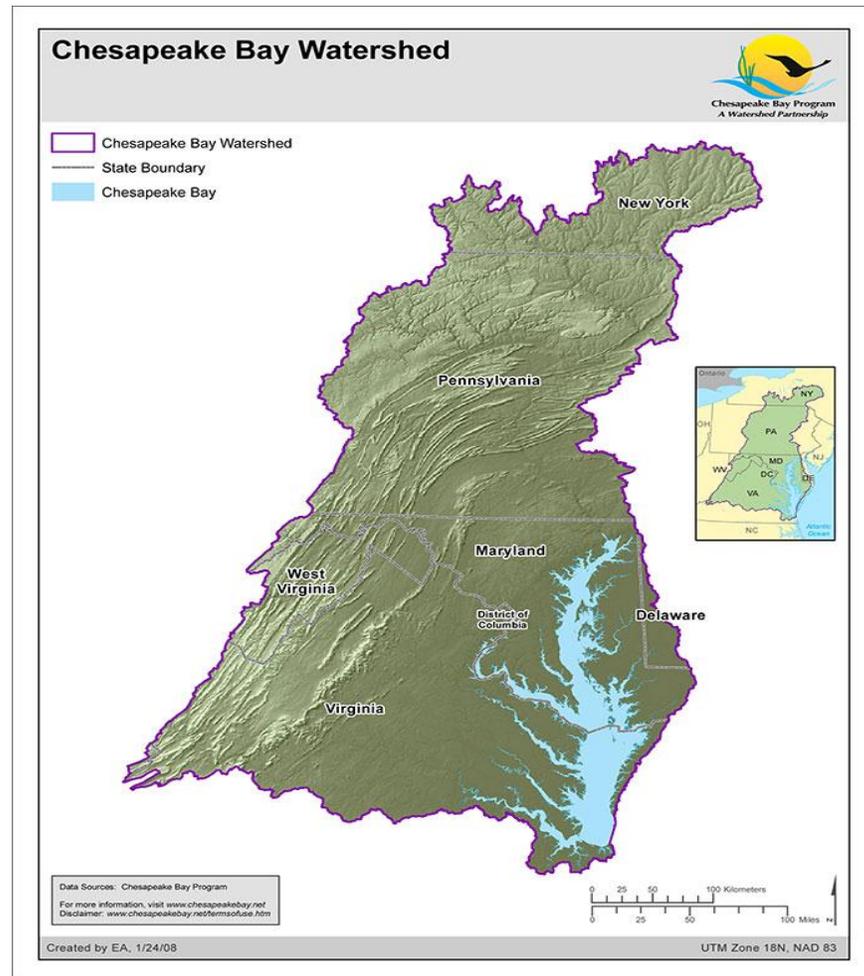
Tired of what they perceived as foot-dragging by the Bush Administration, environmentalists filed suit against EPA alleging that the 1998 National Strategy triggered a non-discretionary, oversight duty under section 303 for EPA to promptly propose numeric nutrient criteria (Florida Wildlife Federation, Inc. et al. 2008). Florida only maintained a narrative criterion that stated “in no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.” Arguably this nebulous standard had not been successful, as Florida’s own 305(b) bi-annual reporting indicated that 8% of streams, 28% of lakes, and 21% of estuaries were impaired for nutrients. The new EPA under Administrator Jackson quickly determined that new standards were indeed necessary and entered into a consent decree with the environmental groups. Agricultural and other interests attempted to intervene against entering a final decree, asserting that deadlines contained in the proposed settlement were too tight to develop scientifically defensible criteria. A federal district judge accepted the consent decree, which was appealed to a Federal Court of Appeals. The Court denied the appeal as moot, because by 2010, EPA had issued numeric criteria for Florida. Both environmentalists and industry interests sued EPA over these criteria, but in February 2012 a federal district court upheld the criteria applying a deferential “arbitrary and capricious” standard to EPA’s conclusions. In the meantime, Florida has attempted to develop its own numeric criteria that it would use to interpret its narrative criterion. If “scientifically defensible,” EPA has agreed to consider those criteria. Otherwise, EPA’s standard will be final in July 2012. At the same time the court upheld EPA’s criteria, a National Academy of Sciences Report concluded that EPA’s incremental cost assessment had misled the public into believing that its study represented total costs of compliance, including the full costs of implementing best management practices in agriculture (NAS 2012).

The entire process over the past four years has come at significant cost to EPA politically, which likely justifies its historical reluctance to exercise oversight authority over section 303 state water quality programs, and in turn is likely one reason why nutrient impairment has not significantly improved generally throughout the U.S. when left to states. While states have worked hard to complete their assessments of impaired waterways, these tasks have proven costly and have received equal if not more pushback from agricultural and industry interests. From an institutional perspective, agricultural stakeholders view EPA’s actions as overreaching because USDA has traditionally taken the lead on agri-environmental initiatives. Recent scientific studies demonstrate, however, that USDA programs have achieved reductions in soil erosion, but that much more effort and application to all of agriculture (versus only those with highly erodible land) is necessary to reduce nutrient pollution (Endres 2011). EPA is facing this type of intense criticism from agriculture in the Chesapeake Bay.

### **2.3 EPA’s Chesapeake Bay Strategy**

The Chesapeake Bay is the U.S.’s largest and most biologically diverse estuary. Nutrient pollution problems, however, have persisted for over 30 years, despite countless governmental efforts to solve them (Houck, 2011). Prized fisheries and livelihoods have been lost or severely restricted, and with that a web of life upon which other species depend. After EPA issued a ground-breaking report in the late 1970s raising alarm about the continued ecosystem viability of the Bay, various levels of government attempted to respond to the problem. These included the formation of the Chesapeake Bay Commission and Agreement by tributary states in 1983, the addition by Congress in 1987 of section 117 to the Clean Water Act, and the Chesapeake 2000 agreement (Chesapeake 2000). All of these efforts have attempted to solve the problem through

formal collaboration between the several states surrounding the Bay and EPA, but it is widely acknowledged that its efforts did not achieve desired results. The provision expired in 2005 and has not yet been reauthorized by Congress. While the proliferation of concentrated animal feeding operations constitutes a large percentage of nutrient releases, other agricultural practices contribute to nutrient pollution of the Bay as well (U.S. EPA, 2010a).



**Figure 2: Map of The Chesapeake Bay Watershed, courtesy of The Chesapeake Bay Foundation,**

As with the case in Florida—only at a multi-state watershed level—environmentalists sued EPA in 2009 to force federal action on nutrient pollution in the Chesapeake Bay (Fowler 2009). The same year, the Obama Administration issued an Executive Order establishing a federal leadership committee to develop strategies to restore the Chesapeake Bay, including the exercise of federal authority and setting concrete deadlines (The White House, 2009). The order also dictates that the USDA Secretary to develop agricultural non-point pollution controls in cooperation with state agencies. Under the terms of the court settlement, EPA must develop TMDLs and ensure that states develop proper watershed implementation plans (WIPs). The agencies' final strategy, published in 2010 and as required by the Executive Order, incorporates EPA's completion of a TMDL and oversight of WIPs (U.S. EPA 2010b) as essential elements.

Under the Executive Order and memorialized in the final strategy, two-year milestones must be set by federal agencies in order to achieve measures ultimately to be put in place by 2025. Interim measures must be put in place by 2017 to achieve a 60% reduction in nutrients over the 2009 baseline. The agencies' first set of milestones for 2012-2013 include application of agricultural conservation practices to over 540,000 acres in conjunction with USDA High Priority Performance Goals for water quality improvement.

EPA issued its expectations for two-phased state WIPs in 2009 (U.S. EPA, 2009). EPA used Phase I WIPs to develop its final TMDL allocating loading limits that became final in December 2010 (U.S. EPA 2010c). State WIPs must contain implementation strategies (including allocations for non-point sources) and concrete deadlines. Phase II WIPs focus in on local stakeholder involvement, and strengthening pollution control strategies where EPA "back-stop" authority was exercised. That is, if states failed to submit Phase I WIPs consistent with EPA's instructions, EPA reserved the right to take various punitive actions ("back-stopping") against states including reducing load allocations under the TMDL, more stringent conditions on point-source discharges, and withdrawing federal funds. Phase II WIPs must contain more granular division of non-point source target loading by county, conservation district, sub-watersheds, or in some cases, by individual facility. EPA also requires that political subdivisions use load allocations in its land use planning, which historically and constitutionally is typically the prerogative of state and local governments.

States have completed submission of their WIPs and their own two-year milestones to reach the goal of having all practices in place by 2025 to meet WQS. The WIPs contain detailed plans and actions to address agricultural non-point source pollution, with a focus on best management practices (BMPs) and deploying those practices in nutrient credit exchange programs. For example, Virginia has enumerated agricultural best management practices that qualify for nutrient credit exchange, including continuous no-till, a 15% yield reserve (applying 85% of recommended nitrogen application rate), early cover crops, and converting land to less nutrient intensive uses (e.g. converting agricultural land to forest or converting cropland to pastureland) (Virginia 2013; Stephenson et al., 2009). Significantly, EPA demonstrates in "letters" to the states, which summarize their review of WIPs and milestones, its level of detailed oversight of state efforts. Such micro-management is an absolute first for EPA in the agricultural realm, and likely represents the only step possible to achieve pollution reduction goals that have languished for over 30 years. Many of the BMPs embedded in states' strategies favor biomass cropping systems, albeit with no specific reference to bioenergy's benefits directly at this time. What energy biomass advocates must do, therefore, is work at the state level to educate regulators on the environmental benefits of perennial biomass so that biomass-specific practices can be incorporated more broadly into nutrient credit regimes and other incentives.

Agricultural interests filed suit in 2011 against U.S. EPA's use of modeling to determine loading allocations within the watershed (American Farm Bureau Federation (AFBF) 2011). AFBF also alleges that U.S. EPA exceeded its jurisdiction under CWA sections 117 and 303 by directing how states implement strategies to achieve WQS. Houck (2011) speculates that U.S. EPA has exercised authority carefully to avoid the claim it is unlawfully commandeering state prerogatives. Any question regarding EPA's authority could be cleared up if Congress would reauthorize section 117 and incorporate the provisions included in the Executive Order. Plaintiffs may have an easier time convincing a court to overturn complex modeling because "the conclusions reached are always questionable, and where the consequences are significant, they are always questioned" (Houck 2011). Noticeably absent in the litigation are the affected states. One could speculate that states have acquiesced in EPA's approach in order to gain

“cover” from constituent backlash that otherwise would not be available had they pursued such tough policies on their own. Also, the AFBF’s lawsuit exposes the formation of potential rift between its stakeholders—commodity agriculture and its “business as usual” attitude, versus biomass farmers whose practices benefit the environment while generating increased income.

## 2.4 The Mississippi-Atchafalaya River Watershed and Hypoxia in the Gulf of Mexico

The Mississippi-Atchafalaya River watershed shares many similarities to the Chesapeake Bay. It empties waters from 31 states, constituting the third largest watershed in the world. Myriad scientific studies confirm that an expansive dead zone has formed in the Gulf of Mexico (U.S. EPA Science Advisory Board 2007) leading to loss of fishing and tourism jobs that rely on a functioning ecosystem. USDA’s Conservation Effects Assessment Project (CEAP) concludes that although agricultural practices to prevent nutrient pollution have improved, much still remains to be done to reduce non-point source pollution in the central U.S. (USDA 2010). Like the Chesapeake Bay, Congress has ordered federal agency and state cooperation in order to take action against Gulf hypoxia but these institutions basically have failed to significantly reduce the problem (National Research Council 2008; Ruhl & Salzman 2010).



**Figure 3: Map of the Mississippi-Atchafalaya River Watershed, courtesy of U.S. Environmental Protection Agency,**

In early 2012, a coalition of environmental groups sued EPA for denying their request that it establish, under its CWA section 303 authority, revised water quality standards for the states lying within the Mississippi River watershed (Gulf Restoration Network 2012). In its denial of the plaintiffs' petition, EPA agreed with the plaintiffs' concerns regarding nutrient pollution and Gulf hypoxia, and states that reducing nutrient pollution is and should be a high priority for the agency. It counters, however, "that the most effective and sustainable way to address widespread and pervasive nutrient pollution . . . is to build on existing technical support efforts and work cooperatively with states and tribes to strengthen nutrient management programs." EPA acknowledges that while it exercised its section 303 authority in Florida, for the Gulf it favors its current approach of collaboration with states to reduce point and non-point source nutrient pollution. Environmental groups counter in their lawsuit that EPA did not provide any reason why revised WQSs are not necessary to meet the requirements of the CWA, and thus under the Administrative Procedure Act, EPA acted arbitrarily and capriciously. It remains to be seen whether the aggressive approaches taken by EPA over the past four years will result in actual water quality improvements. Interestingly, EPA has taken different approaches to cleaning up nutrient pollution, depending on the watershed. If EPA exerts its "backstop" authority and survives court challenges, states can pursue non-point source pollution with less pressure from local constituencies who likely have stood in the way of progress over several decades. Unlike the individual state strategy in Florida, the Gulf of Mexico litigation would force EPA to develop numeric criteria for multiple states within the Gulf's watershed. This would be without the formal, multi-state agreements that the EPA has co-signed (and Congress has blessed) as a foundation for the Chesapeake Bay clean-up. The Chesapeake Bay litigation portends powerful Midwestern agricultural interests' likely objection to any formal attempt by EPA to tighten non-point source controls. From an energy biomass perspective, much is at stake. Corn-based ethanol (whether kernel or stover-based) would be drastically affected by constraints on nitrogen fertilization. Perennial cropping systems, on the other hand, could play a valuable role in reducing nutrient pollution because of less input demand and soil protection qualities.

### **3. Part Two. The Complex System of Water Rights in the U.S**

#### **3.1 Emerging Water Quantity Concerns**

##### **3.1.1 Background**

In the U.S., a perfect storm is on the horizon that may lead to severe water conflicts between agricultural and urban users. On the one hand, the U.S. Drought Monitor recently concluded that every state in the U.S. except for Ohio and Alaska is under some form of drought. The year 2011 marked the state of Texas' worst drought in history. On the other hand, "it is difficult to imagine a legal and policy regime as fractured as that used to govern water resources in the United States" (Adler & Straube 2000). This is due to the separation between: (1) water quantity rights (a mostly state-level prerogative tempered by superior federal rights in some cases) and water quality concerns (largely governed by the federal Clean Water Act); (2) surface and subsurface rights; (3) land use and ecosystem decisions and water resource decisions; and, (4) the application of English law in the East (riparian rights) and that applied in the West (the prior appropriation doctrine) (Adler & Straube 2000). As policymakers, stakeholders and courts recognize that watershed-level approaches are essential to solving grand pollution and species

extinction challenges, these divides may be narrowing. For example, U.S. EPA's approach in the Chesapeake includes a level of oversight of local land use strategies in state WIPs not seen before under the CWA. In addition, environmentalists have challenged in federal court the Texas Commission on Environmental Quality's (TCEQ) failure to regulate surface water rights to the detriment of the whooping crane protected under the Endangered Species Act (ESA). And, legislatures have created various forms of local governance to better referee between rights' owners and protect the public interest against otherwise unfettered withdrawals.

Still, water rights law in the U.S. continues to be based on geography and thus can differ dramatically between states. The divergence of water law into east and west reflects climatic, economic, political and hydrological conditions (Adler & Straube 2000). The riparian rights doctrine, adopted mainly in rain-fed eastern states, is considered a looser standard of "reasonable use" by all persons who share a riparian resource. In a time of scarcity, each person must reduce withdrawals proportionally. The common law governs what is "reasonable." Adoption of the prior appropriation doctrine in western states, on the other hand, initially provided more certainty to agricultural producers in more arid environments. Each user's priority is first-in-time, first-in-right to use as much water it can appropriate for a "beneficial use." Under some laws, if water is not used (and restrictions may exist on the re-selling of water), the right is lost. If ground water is tied to a surface water tributary, then groundwater also may be subject to the doctrine. If not, then in some states the priority system may not apply, and instead the right is tied to the land. An owner may operate under the "rule of capture" and be allowed to withdraw groundwater without limit. Depending on the state, exceptions to the capture rule include that withdrawals are not willfully done in a wasteful manner to injure those who share the resource, and that public water districts that may overlie the resource can regulate uses (Schwartz, 2006). A number of states, including California, take a hybrid approach to water rights, where priority rights are given under the prior appropriation doctrine, but use limited by reasonableness inherent in the riparian doctrine (Giuda 2007).

### **3.1.2 The Texas Example**

Because much of the U.S. production of energy biomass likely will lie in the central U.S. (USDA 2010), western-style water laws likely will apply. Texas' water law demonstrates just how complex state water rights can be, and thus the great challenge in seeking watershed-level solutions to water quantity and quality problems and mediation of disputes between uses. Texas applies the rule of capture to "percolating" groundwater. Withdrawals are unlimited, privately owned, and severable from the land estate, subject to some level of local governmental control for conservation and recharge. Surface water, on the other hand, is owned by the state in the public's interest, with a prior appropriation first-in-time first-in-right allocation of rights overseen by the Department of Environmental Quality. A third type of water right lies in the ability to capture limited amounts of diffuse surface water prior to channelization, into an impoundment (Schwartz 2006). Texas also has a weather modification statute that requires permits for weather modification operations, such as cloud seeding.

In early 2012, the Texas Supreme Court issued a land-mark decision regarding the rights landowners have in ground water for irrigation—whether farmers hold merely a use right, or a property right compensable under the U.S. Constitution's Fifth Amendment Takings provision (Edwards Aquifer 2012). The Texas Legislature created the Edwards aquifer authority to protect terrestrial and aquatic life, domestic and municipal water supplies, operation of existing industries, and for economic development. Statutory withdrawal limits are placed on the aquifer.

Two farmers applied for a permit to withdraw water for irrigation, but the authority limited the withdrawal based because the farmers could not show “historical use.” The court sided with the two farmers that any permit condition by the aquifer authority that restricted withdrawal has to be compensated. Unless the Texas legislature amends the statute underlying the court’s determination that a property right exists, aquifer authorities likely will exert less control over water usage, or be forced to exercise eminent domain. The limitation also will affect the government’s ability to manage groundwater resources for protection of wildlife and aquatic species. On the other hand, farmers facing drought conditions will have increased access to ground water for irrigation. The ground water at issue serves the seventh largest metropolitan area in the U.S., setting the stage for future battles between urban and rural residents for access to water. Such competition likely will repeat itself wherever aquifers are under pressure. Governments’ exercise eminent domain over water resources likely will result in less compensation than a taking because administrative procedures to determine fair market value in an eminent domain case are more favorable to the government than a court-adjudicated takings damages claim.

### **3.1.3 Issues with Irrigation**

Agriculture, therefore, will be forced to adapt to increasing restrictions on irrigation such as has occurred on the one of the largest aquifers in the world, the Ogallala Aquifer (Sophocleous, 2010). The Ogallala spans an eight-state area in the central U.S., raising the issue of interstate conflicts over rights to water. Indeed, states have sued other states for rights to the aquifer’s water. The federal government has the power, under the Commerce Clause of the U.S. Constitution, to regulate interstate groundwater including during times of scarcity. Arguably, just like U.S. EPA’s Chesapeake Bay regulation for water quality purposes, the federal government could exercise its discretion and lead regulation of multi-state aquifers that continue to be depleted at alarming rates (Hesser, 2011). States, however, may regulate the export of its territory’s ground water out-of-state only if the regulation does not interfere with interstate commerce and serves the public interest, thus avoiding the dormant Commerce Clause. States within the Ogallala Aquifer have approached the problem of groundwater depletion in varying ways, including focusing on improved modeling to guide allocation decisions, closing areas to new withdrawal permits, and user reporting. Nebraska, the state that uses the most Ogallala water for irrigation, historically has been aggressive in recruiting corn ethanol facilities. On the biorefining side, a Poet facility in South Dakota has successfully gained a permit to capture storm water, thus decreasing its use of municipal water supplies (Biofuels Digest 2011). This calls into question, however, the ability of underground aquifers to recharge.

Using irrigated corn for ethanol may be a risky proposition as uncertainty of groundwater supplies mounts for both growing and refining biomass. That is not to say that perennial systems will not pose problems, too, due to increased water uptake (and thus less percolation for recharge) and changes in evapotranspiration rates (Hickman et al. 2010). Conceivably, under Texas’ weather modification statute, biomass cropping could be restricted if it significantly alters the climatic cycle in a region although the right to atmospheric moisture is unclear under the statute. The specter of climate change may focus increasing importance on application of these types of statutes.

If biomass growers obtain federal Bureau of Reclamation water, which is typical in the far west, the right of use when withdrawals may jeopardize species federally protected under the ESA has been litigated. Just like the Edwards aquifer case in Texas where withdrawals were limited under

state law but deemed a compensable 5<sup>th</sup> Amendment taking, one federal appeals court has held that when the federal Bureau of Reclamation requires irrigators to take steps to protect endangered fish, the request amounts to a regulatory taking that requires compensation (Casitas 2008). The federal Court of Claims also has ordered compensation when water is withheld from irrigators by the Bureau to protect the habitat of endangered fish (Tulare 2001). Because state water law has designated irrigation as a “beneficial use,” claims in common-law nuisance to protect other uses (e.g., ecosystems) likely fail (Shepard, 2009).

#### **4. Part Three: Sustainability Standards**

At least one American biofuels producer seeking access to the European bioenergy market has achieved private sustainability certification under the International Sustainability and Carbon Certification (ISCC) program (ISCC 2012). The certification requires reducing the possibility of erosion, and if the farmer uses ground water for irrigation, existing water rights are “respected” and must be justified with regard to accessibility of water for human consumption. Producers must also follow “local legislation,” which arguably would include local water district orders to reduce withdrawals. It is unclear, however, whether the standard would preclude pursuit of takings compensation like that explained above as violative of the spirit of sustainability. Producers must have a management plan in place that aims for “sustainable water use” and pollution prevention with yearly documentation of good agricultural practices that address efficient water usage, responsible use of agro-chemicals, and waste discharge.

USDA awards Biomass Crop Assistance Program (BCAP) funding based, in part, on impacts to water resources (USDA 2010). Producers also must have a conservation plan in place. The details of the award analyses and accompanying conservations plans are not publically available. If based on a USDA Natural Resources and Conservation Service (NRCS) plan, practice standards are used to combat soil erosion and “optimize” available water supplies. USDA’s NRCS also recently announced a National Water Quality Initiative for “priority” watersheds to improve water quality and aquatic habitats, which will provide additional funding for nutrient management systems, erosion control, conservation tillage, pest management, and buffer systems (NRCS 2012).

#### **5. Conclusion**

Sustainability standards for energy biomass, particularly in Europe, are driving changes in biomass practices in the U.S. These efforts to reduce the environmental footprint of biomass production, coupled with the *per se* benefits of perennial cropping over annual systems, coincide within federal efforts to reduce nutrient and sediment pollution. Increased regulatory pressure on agriculture is certain, as demonstrated by EPA actions in the Chesapeake Bay and the State of Florida. Pressure is mounting for EPA to take action to combat the Gulf of Mexico dead zone. Biomass producers in the central U.S. should anticipate these trends and put in place practices that benefit water quality, and pursue benefits from nutrient trading or other incentives. Water quantity, particularly in light of severe drought in Texas, can no longer be taken for granted by producers that are accustomed to unlimited water withdrawals. As quality and quantity are reduced, competition for remaining useable water resources goes up between agricultural, ecological and urban uses. Biomass cropping systems, therefore, should be proactive in reducing or eliminating dependency on irrigation. Many biomass sustainability standards existing or in development require such reduction. The take-away lesson from this review is that the future of

biomass cropping will be increasingly constrained by regulatory efforts to reduce pollution and consumption, and thus the sector would be best off taking a proactive, voluntary stance.

## References

- **Adler R., Straube M.** (2000). Watersheds and the Integration of U.S. Water Law and Policy: Bridging the Great Divides, 25 Wm. & Mary Env'tl. L. & Pol'y Rev. 1, <http://scholarship.law.wm.edu/wmelpr/vol25/iss1/3>
- **American Farm Bureau Federation et al. v. U.S. EPA**, Case No. 11-CV-00067 (M.D. Penn. 2011)
- **Berndes G.** (2008). Water demand for global bioenergy production: trends, risks and opportunities 12, [http://www.wbgu.de/wbgu\\_jg2008\\_ex02.pdf](http://www.wbgu.de/wbgu_jg2008_ex02.pdf).
- **Biofuels Digest**, Poet develops technology to use stormwater in its ethanol process (July 26, 2011), <http://www.biofuelsdigest.com/bdigest/2011/07/26/poet-develops-technology-to-use-storm-water-in-ethanol-process/>.
- **Bricker S., Longstaff B., Dennison W., Jones A., Boicourt K., Wicks C. and Woerner J.** (2007). Effects of Nutrient Enrichment In the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26, National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.
- **Chesapeake 2000: The Renewed Agreement**, [http://dnrweb.dnr.state.md.us/bay/res\\_protect/c2k/agreement.asp](http://dnrweb.dnr.state.md.us/bay/res_protect/c2k/agreement.asp).
- **Edwards Aquifer Authority, v. Day**, Case No. 08-0964 (Tx. Sct. 2012), <http://www.supreme.courts.state.tx.us/historical/2012/feb/080964.pdf>.
- **Endres J.** (2011). Agriculture at a Crossroads: Energy Biomass Standards and a New Sustainability Paradigm? 2011 Ill. L. Rev. 503-547.
- **Fingerman K., Torn M., O'Hare M., Kammen D.** (2010) Accounting for the water effects of ethanol production, Environ. Res. Lett. 5.
- **Florida Wildlife Federation, Inc. et al., 2008 v. U.S. EPA**, Case No. 4:08-cv-00324 (N.D. Fl.).
- **Fowler, v. U.S. EPA**, Case No. 1:09-cv-00005-CKK (D.D.C. 2009).
- **Gerbens-Leenes, W., Hoekstra, A.Y, Van der Meer, T.H.,** 2009. The water footprint of bioenergy. Proceedings of the National Academy of Science (PNAS) (106) 25, 10219-10223.
- **Giuda A.** (2007). The Central Valley Improvement Act: Who Says Environmental Uses Are Not Beneficial ? 11 Alb. L. Env'tl. Outlook 304.
- **Gulf Restoration Network et al. (2012) v. U.S. EPA**, Case No. 2:12-cv-00677 (E.D. La. 2012).
- **Hesser J.** (2011). The Nature of Interstate Groundwater Resources and the Need for States to Manage the Resource Through Interstate Compacts, 11 Wyo. L. Rev. 25.
- **Hickman G., VanLoocke A., Dohleman F., Bernacchi C.** (2010). A comparison of canopy evapotranspiration for maize and two perennial grasses identified as potential bioenergy crops, 2 GCB Bioenergy 157-168.
- **Houck O.** (2011). The Clean Water Act Returns (Again): Part I, TMDLs and the Chesapeake Bay. 41 ELR 10208.
- **International Sustainability and Carbon Certification (ISCC)**, Certificates and Statements of Conformity, [http://www.iscc-system.org/certificates/index\\_eng.html](http://www.iscc-system.org/certificates/index_eng.html) (search term Poet).
- **NAS (National Academy of Sciences)** (2012). Review of the EPA's Economic Analysis of Final Water Quality Standards for Nutrients for Lakes and Flowing Waters in Florida,

- <http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/EPA-Econ-Analysis-Florida-Final.pdf>.
- **National Research Council** (2008). Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico.
  - **NRCS (Natural Resources Conservation Service)**, 2012, Environmental Quality Incentives Program, National Water Quality Initiative, <http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/financial/eqip/?&cid=STELPRDB1047761>
  - **Ruhl J.B. & Salzman J.** (2010). Climate Change, Dead Zones, and Massive Problems in the Administrative State: A Guide for Whittling Away. 98 Cal. L. Rev. 59.
  - **Schwartz S.** (2006). Whiskey Is for Drinking, Water Is for Fighting: A Texas Perspective on the Issues and Pressures Relating to Conflicts Over Water, 38 Tex. Tech L. Rev. 1011.
  - **Shepard S.** (2009). The Unbearable Cost of Skipping the Check: Property Rights, Takings Compensation & Ecological Protection in the Western Water Law Context, 17 N.Y.U. Envtl. L.J. 1063.
  - **Sophocleous M.** (2010). Review: groundwater management practices, challenges, and innovations in the High Plains aquifer, USA—lessons and recommended actions, 18 Hydrology Journal 559-575.
  - **Stephenson K., Aultman S., Metcalfe T., Miller A.** (2009). An Evaluation of Nutrient Trading Options in Virginia: A Role for Agriculture? [http://ageconsearch.umn.edu/bitstream/46779/2/ReviewVAPointSourceOffsets\\_Stephenson%20et%20al.pdf](http://ageconsearch.umn.edu/bitstream/46779/2/ReviewVAPointSourceOffsets_Stephenson%20et%20al.pdf).
  - **Tulare Lake Basin Water Storage District v. U.S.**, 49 Fed. Cl. 313 (Fed. Cl. 2001).
  - U.S. Department of Agriculture (USDA) (2010). Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin, [http://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/stelprdb1042093.pdf](http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042093.pdf).
  - **U.S. EPA** (2011b). EPA Water Quality Standards Academy, Nutrient Criteria, [http://water.epa.gov/learn/training/standardsacademy/upload/module\\_nutrient.pdf](http://water.epa.gov/learn/training/standardsacademy/upload/module_nutrient.pdf).
  - **U.S. EPA** (2010a). Chesapeake Bay Compliance and Enforcement Strategy, <http://www.epa.gov/oecaerth/civil/initiatives/chesapeake-strategy-enforcement.pdf>.
  - **U.S. EPA** (2010b). Strategy for Protecting and Restoring the Chesapeake Bay Watershed, <http://executiveorder.chesapeakebay.net/file.axd?file=2010%2f5%2fChesapeake+EO+Strategy%20.pdf>.
  - **U.S. EPA** (2010c). Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment, [http://www.epa.gov/reg3wapd/pdf/pdf\\_chesbay/FinalBayTMDL/CBayFinalTMDLExecSumSection1through3\\_final.pdf](http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/FinalBayTMDL/CBayFinalTMDLExecSumSection1through3_final.pdf).
  - **U.S. EPA** (2009). Letter to Chesapeake Program's Principles' Staff Committee, [http://www.epa.gov/reg3wapd/pdf/pdf\\_chesbay/tmdl\\_implementation\\_letter\\_110409.pdf](http://www.epa.gov/reg3wapd/pdf/pdf_chesbay/tmdl_implementation_letter_110409.pdf).
  - **U.S. EPA** (1998). National Strategy for the Development of Regional Nutrient Criteria, [http://water.epa.gov/scitech/swguidance/standards/upload/2009\\_01\\_21\\_criteria\\_nutrient\\_strategy\\_nutstra3.pdf](http://water.epa.gov/scitech/swguidance/standards/upload/2009_01_21_criteria_nutrient_strategy_nutstra3.pdf).
  - **U.S. EPA Scientific Advisory Board** (2007). Hypoxia in the Northern Gulf of Mexico, [http://yosemite.epa.gov/sab/sabproduct.nsf/C3D2F27094E03F90852573B800601D93/\\$File/EPA-SAB-08-003complete.unsigned.pdf](http://yosemite.epa.gov/sab/sabproduct.nsf/C3D2F27094E03F90852573B800601D93/$File/EPA-SAB-08-003complete.unsigned.pdf).
  - **U.S. Department of Agriculture (USDA)** (2010). Biomass Crop Assistance Program: Final Rule, 75 Fed. Red.66240, § 1450.202.

- **U.S. Department of Agriculture (USDA)** (2010). Programmatic Environmental Impact Statement, [http://www.fsa.usda.gov/Internet/FSA\\_File/bcapfinalpeis062510.pdf](http://www.fsa.usda.gov/Internet/FSA_File/bcapfinalpeis062510.pdf).
- **Van Loocke A., Bernacchi C., Twines T.,** (2010). The impacts of *Miscanthus giganteus* production on the Midwest US hydrologic cycle, *GCB Bioenergy* (2010) 2, 180–191.
- **U.S. EPA** (2011a). Coming Together for Clean Water: EPA’s Strategy for Achieving Clean Water. <https://blog.epa.gov/waterforum/wp-content/uploads/2011/04/ComingTogether-for-Clean-Water-FINAL.pdf>.
- **Virginia Soil and Water Conservation Board** (2013). Resource Management Plan Regulations. [http://www.dcr.virginia.gov/laws\\_and\\_regulations/documents/lr7-rmp-final-regulations-03-27-13.pdf](http://www.dcr.virginia.gov/laws_and_regulations/documents/lr7-rmp-final-regulations-03-27-13.pdf).
- **The White House** (2009). Executive Order 13508: Chesapeake Bay Protection and Restoration, [http://www.whitehouse.gov/the\\_press\\_office/Executive-Order-Chesapeake-Bay-Protection-and-Restoration](http://www.whitehouse.gov/the_press_office/Executive-Order-Chesapeake-Bay-Protection-and-Restoration).

## Abbreviations

CWA	Clean Water Act (federal)
U.S.	United States of America
USDA	United States Department of Agriculture
EPA	(United States) Environmental Protection Agency
TMDL	Total Maximum Daily Loadings
WQS	Water Quality Standards
WIP	Watershed Implementation Plan

# **Certification systems and other schemes for bioenergy-related water impacts**

**H.Fehrenbach**  
**IFEU - Institut für Energie und Umweltforschung**  
**Heidelberg, Germany**

## **Abstract**

This paper discusses how several certification schemes are addressing effects on water. Most of the analyzed schemes (RSB, RSPO, RTRS, Bonsucro, ISCC, SAN, AWS, FSC...) cover three key items: excessive water consumption, water scarcity, and protection of water quality.

Water quality is well-covered by nearly all of the schemes. Regarding effluents from processing processes, useful water quality indicators for customary and legal threshold values are mostly in place. Certification schemes benefit from legal references.

Negative impacts of agricultural activities, such as the application of fertilizers or pesticides, are more complex. Good agricultural practice is considered to provide protection. However, impacts on surface and groundwater bodies are time-delayed, and tracing measured pollution to a specific source (the polluter) may be inconclusive in many cases. Thus, controlling and auditing agricultural practice assumes a key role in assuring protection of water quality. Almost all of the analyzed schemes address that point.

Furthermore most schemes address avoidance of excessive water consumption, since they require water management plans, efficient use and re-use, and optimization of irrigation if used. The criteria and indicators in place appear to be useful, effective and practical. On the other hand, even efficient and sparing use of water can be excessive if the consumer is large enough to absorb modest water resources. Without taking availability and the entire consumer context into account, negative impacts cannot be avoided through good management.

The final and most crucial point is how to define and encircle areas where water is scarce. Scarcity exists, but is notably difficult to standardize. Physical scarcity can be categorized easily in terms of volume of available water resources per year and capita, or a withdrawal-availability ratio. There are useful approaches, such as the Water Availability Index or Water Scarcity Index, to classify levels of availability and scarcity that can support the basic global definition of areas where water is physically scarce.

Certification of bioenergy-related water impacts will remain a challenge. Ambitious schemes are in place, such as RSB, SAN or the Alliance for Water Stewardship. However, in the following years there will be a need to verify the practicability of schemes and consider how to successfully avoid adverse effects. It can be assumed that successful implementation will need to be fostered through regional, national and international policy, as well as overarching stakeholder involvement at least at the watershed level.

## 1. Introduction

Water is one of the key topics whenever sustainable production and use of bioenergy is on focus. Thus approximately all relevant sustainability schemes for bioenergy enclose criteria referring to potential water impacts. Certification is one of the customary processes to assess and to verify conformity with ambitious standards at on-site level. Some certification systems exist for a long time, when sustainability requirements for products have been claimed and requested only by a specified niche market. In meantime such markets have moved mainstream. Policymakers have started to implement sustainability requirements in legal schemes, such as the European Renewable Energy Directive (RED). Unlike the European regulation most of the voluntary certification schemes suitable for bioenergy include criteria referring to water impacts.

A selection of notable voluntary certification schemes has been described within the UNEP publication about the Bioenergy and Water Nexus (UNEP, OEKO, IEA 2011)<sup>1</sup>. This brief article refreshes the work done for that publication by revising and updating it and to complement it with two processes of international relevance: the Global Bioenergy Partnership (GBEP) and its sustainability indicators (GBEP 2011)<sup>2</sup> and the work on the International standard on Sustainability criteria for bioenergy. The latter is still on the level of a draft document.

## 2. Overview of certification schemes addressing bioenergy and water stress/pollution

### 2.1 RSB: Roundtable on Sustainable Biomaterials

#### Background

Through a multi-stakeholder consultation based on consensus among members the RSB was initiated as “The Roundtable on Sustainable Biofuels” in 2007 by the Ecole Polytechnique Fédérale de Lausanne (EPFL). At the beginning of the year 2013 the RSB formally shifted to being an autonomous non-profit based in Geneva, Switzerland changing its name for “The Roundtable on Sustainable Biomaterials”.

The RSB has developed a third-party certification scheme for sustainable biofuels which has expanded its scope on any type of products derived from biomass (e.g. biochemicals, textiles, food additives, etc.). The RSB sustainability standards<sup>3</sup> encompass environmental, social and economic principles and criteria through an open, transparent, and multi-stakeholder process. To address these impacts, the RSB Principles & Criteria are divided into 12 Principles, which are further developed as Criteria (with minimum and progress requirements) and Indicators that can be measured by auditors (RSB, 2010 a and b). The RSB Standard concerns stakeholder consultation, free prior informed consent, gender equity, and benefits sharing in the areas of operations. By complying with the RSB Standard, certified operators make sure their biofuels are not produced at the expense of valuable ecosystems, conservation values, ecological services,

<sup>1</sup> UNEP, OEKO, IEA – United Nations Environmental Programme, Oeko-Institute, IEA Bioenergy Task 43: the Bioenergy and Water Nexus; 2011; ISBN 978-92-807-3157-6

<sup>2</sup> <http://www.globalbioenergy.org/programmeofwork/task-force-on-sustainability/gbep-report-on-sustainability-indicators-for-bioenergy/pt/>

<sup>3</sup> Global standard: RSB-STD-01-001 (Version 2.0) RED conform standard: RSB –STD -11-001-01-001 (Version 2.0)  
<http://rsb.org/sustainability/rsb-sustainability-standards/>

soil health or air quality. Finally, biofuel operations cannot threaten local food security. Certificates have to be delivered by third party auditors.

The global set of standards applies to any type of feedstock worldwide, whereas the RSB EU-RED consolidated standards is an adaptation of the RSB standards developed for compliance with the RED. With respect to water issues there is no difference between the two versions.

### **RSB requirements with respect to water issues**

Principle 9 of the RSB standard is dedicated to water. It is further developed into four criteria, which describe the operator's requirements to:

- identify and respect the existing water rights of the local population;
- implement a water management plan to reduce consumption and contamination;
- not contribute to the depletion of the water resources used for the operations;
- maintain water quality or enhance it wherever possible.

The main challenge of the RSB certification system is to combine a robust standard with the reality of operators in terms of access to technology and the cost of compliance. Furthermore, auditing costs may become a barrier if not reduced to the strictly necessary. The RSB tries to balance robustness and flexibility. Biofuel operators are not allowed to infringe on existing water rights (formal and customary), contribute to the withdrawal of water resources beyond replenishment capacity, or contribute to contaminating these resources. On the other hand, compliance is not assessed in the same way for small scale and non-small scale operators during the audit conducted by independent certification bodies. The RSB also uses a risk management approach (RSB, 2010b), which evaluates the risk class of operations based on implemented practices and the context of operations (high biodiversity, political instability, food insecurity, etc.). The risk class determines the frequency and stringency of audits.

Water-related risk factors take the hydrological situation into account, as well as the water requirements of the crop (in the case of feedstock producers). Ultimately, farmers growing rain-fed crops in regions with a low risk of drought will be assigned a low risk factor for water, whereas freshwater-intensive operations will be assigned a higher risk factor, especially in drought-prone regions. Certification and compliance costs will therefore be lower for farmers.

## **2.2 RSPO: Roundtable on Sustainable Palm Oil**

### **Background**

Driven by ever increasing demand for edible oils, rapid expansion of palm oil production has occurred in the past few decades. From the 1990s to the present, the area under oil palm cultivation has increased by about 40%, mostly in Indonesia and Malaysia. Along with rapid expansion to eco-sensitive areas, other environmental pressures related to palm oil production have been recognized.

In 2001, WWF began to explore the possibilities for a Roundtable on Sustainable Palm Oil. The result was informal cooperation in 2002 among Aarhus United UK Ltd, Golden Hope Plantations Berhad, Migros, the Malaysian Palm Oil Association, Sainsbury's and Unilever, together with WWF. These organizations formed a committee to organize the first Roundtable meeting, and to prepare the foundation for the organizational and governance structure for the formation of the RSPO.

## The RSPO standard

The stated goal of the RSPO is “to promote the growth and use of sustainable palm oil through co-operation within the supply chain and open dialogue with its stakeholders”. For this purpose, principles and criteria were developed. These must be met in order for a company to have its product successfully certified.

The RSPO started certifications in 2008. Water aspects of performed certification processes have mainly focused on effluent (and therefore water quality) aspects, as oil palm plantations are located in wet tropical zones where water scarcity is mostly not a regional issue.

### RSPO requirements with respect to water issues

Two of eight principles address water-related issues:

- Principle 4: Use of appropriate best practices by growers and mills
- Principle 7: Responsible development of new plantings

The table below lists requirements directly focusing on water, defined in the still valid key document RSPO Principles and Criteria for Sustainable Palm Oil Production, which was published in October 2007 (RSPO, 2007).<sup>4</sup>

Criterion	Indicators
Criterion 4.4: Practices maintain the quality and availability of surface and ground water.	<ul style="list-style-type: none"><li>- An implemented water management plan.</li><li>- Protection of watercourses and wetlands, including maintaining and restoring appropriate riparian buffer zones.</li><li>- Monitoring of effluent BOD (biological oxygen demand).</li><li>- Monitoring of mill water use per tonne of FFB (fresh fruit bunches).</li></ul>
Criterion 7.2: Soil surveys and topographic information are used for site planning in the establishment of new plantings, and the results are incorporated into plans and operations.	<ul style="list-style-type: none"><li>- Soil suitability maps or soil surveys adequate to establish the long-term suitability of land for oil palm cultivation should be available.</li><li>- Topographic information adequate to guide the planning of drainage and irrigation systems, roads, and other infrastructure should be available.</li></ul>

The RSPO standard contains a number of further criteria and indicators indirectly focusing on water, such as Criterion 4.3, Practices minimize and control erosion and degradation of soils (effective and documented water management programme) and 7.4, Extensive planting on steep terrain, and/or on marginal and fragile soils, is avoided.

## 2.3 RTRS: Roundtable on Responsible Soy

### Background

In a situation similar to that of palm oil, the RTRS was initiated to develop and promote a standard of sustainability for production, processing, trading and use of soy. Founded in 2006, the RTRS currently has more than 100 members in over 20 countries. The wide range of

4

[http://www.rspo.org/files/resource\\_centre/keydoc/2%20en\\_RSPO%20Principles%20and%20Criteria%20for%20Sustainable%20Palm%20Oil%20Production%20%282007%29.pdf](http://www.rspo.org/files/resource_centre/keydoc/2%20en_RSPO%20Principles%20and%20Criteria%20for%20Sustainable%20Palm%20Oil%20Production%20%282007%29.pdf)

stakeholders comes, for example, from the areas of production, processing and trade. Besides individual businesses and their associations, NGOs are represented.

### **The RTRS standard**

The criteria comply with the internationally accepted rules of the ISEAL Alliance, a global association for social and environmental standards (<http://www.isealalliance.org/>). The central document is RTRS Standard for Responsible Soy Production (Version 1.0, June 2010) (RTRS, 2010).<sup>5</sup>

Five principles cover the legal and good practice aspects of business activities, labour and community issues, environmental responsibility in general, and agriculture in particular. Under Principle 5: Good Agricultural Practice, the first criterion focuses on water: Criterion 5.1: The quality and supply of surface and ground water is maintained or improved.

### **RTRS requirements with respect to water issues**

The concrete requirements/recommendations are listed as follows:

- 5.1.1 Good agricultural practices are implemented to minimize diffuse and localized impacts on surface and ground water quality from chemical residues, fertilizers, erosion or other sources and to promote aquifer recharge.
- 5.1.2 There is monitoring, appropriate to scale, to demonstrate that the practices are effective.
- 5.1.3 Any direct evidence of localized contamination of ground or surface water is reported to, and monitored in collaboration with, local authorities.
- 5.1.4 Where irrigation is used, there is a documented procedure in place for applying best practices and acting according to legislation and best practice guidance (where this exists), and for measurement of water utilization.

An additional note specifies:

“For group certification of small farms – Where irrigation is used for crops other than soy but is not done according to best practice, a plan is in place and is being implemented to improve practices. The group manager is responsible for documentation.”

In Criterion 5.1, the following is stated:

- 5.1.2 Where appropriate there should be monitoring of parameters such as pH, temperature, dissolved oxygen, turbidity and electrical conductivity. Monitoring should be considered at watershed level.
- 5.1.2 Where there are wells these should be used to monitor ground water.
- 5.1.4 When using irrigation, attention should be paid to other potential uses such as household use or use by other food crops and if there is a lack of water priority should be given to human consumption.

Implementation of the RTRS has just begun. For the 2011 harvest season, it is assumed that it will be possible to obtain responsible soy on the international market through Chain of Custody options designed for the RTRS. Irrigation is a widespread issue in soy production. The large number of indicators addressing irrigation and monitoring of household water demonstrates the attention RTRS is giving this issue.

<sup>5</sup> RTRS\_STD\_001\_V1-0\_ENG\_for responsible soy production <http://www.responsiblesoy.org/>

## 2.4 Bonsucro

### Background

Similarly to the RSPO and RTRS, Bonsucro (originally founded under the name “the Better Sugarcane Initiative (BSI)”) is a global, multi-stakeholder, non-profit initiative dedicated to reducing the environmental and social impacts of sugarcane production. Its purpose is to improve the social, environmental and economic sustainability of sugarcane by promoting the use of a global metric standard, with the aim of continuously improving sugarcane production and downstream processing in order to contribute to a more sustainable future.

### The Bonsucro standard

In 2012 the Bonsucro standard<sup>6</sup> has replaced the former BSI standard, keeping up the same five principles covering legal compliance, respect for human rights and labour standards, enhancement of sustainability management, production and processing efficiencies, active management of biodiversity and ecosystem services, and continuous improvement in key areas of the business.

### Bonsucro requirements with respect to water issues

Three of the principles defined in the Bonsucro standard cover aspects of water quality and quantity. Concrete requirements are formulated in four criteria:

Criterion 3.1:	To monitor production and process efficiency; to measure the impacts of production and processing so that improvements are made over time.
Criterion 4.1:	To assess impacts of sugarcane enterprises on biodiversity and ecosystems services.
Criterion 4.2:	To implement measures to mitigate adverse impacts where identified.
Criterion 5.2:	To continuously improve the status of soil and water resources.

The indicators associated with the four water-related criteria are briefly listed below:

- Criterion 3.1 is related to sugarcane yield, with standard values depending on whether the plantation is rain-fed or irrigated.
- Criterion 4.1 includes two agriculture indicators and one mill indicator, associated with water quality. One of the agriculture indicators is the amount of “nitrogen and phosphorus fertilizer applied per hectare per year”, and the other the amount of “herbicides and pesticides applied per hectare per year”. The mill indicator is “aquatic oxygen demand per unit mass product”. For each of these indicators, a standard/maximum/benchmark value is defined.
- Criterion 4.2 under the same principle is related to both water quality and water quantity. It comprises one agriculture and mill indicator associated with a “Document plan and implementation of mitigation measures”, that is, the existence of an Environmental Plan.
- Criterion 5.2 is related specifically to water quantity, but its indicator, “net water consumed per unit mass of product”, applies to both the agricultural system and the mill. In this case, water consumed is captured water. Again, a standard/maximum/benchmark value is defined.

The number of water-related criteria gives an idea of the significance of sugarcane production with respect to the use of water.

<sup>6</sup> [http://bonsucro.com/site/wp-content/uploads/2013/03/Bonsucro\\_Production\\_Standard\\_March-2012\\_c.pdf](http://bonsucro.com/site/wp-content/uploads/2013/03/Bonsucro_Production_Standard_March-2012_c.pdf)

## **2.5 ISCC: International Sustainability and Carbon Certification**

### **Background**

The ISCC system is the outcome of a project which began in 2007 funded by the German Ministry for Agriculture (BMELV). It took up the discussions in the Netherlands (Cramer Commission) and the United Kingdom (RTFO) and the upcoming consideration by the European Commission of regulatory sustainability requirements. In 2010, the ISCC System was approved by the European Commission as the first certification system for sustainable biomass and biofuels under the RED.

The main stakeholder groups targeted by the German-based ISCC Association are agricultural, conversion, trade and logistics businesses, biomass users, NGOs, social organizations and research institutions.

### **The ISCC standard**

In terms of concrete certification requirements, the key document is ISCC 202 – Sustainability Requirements for the Production of Biomass (most recent available version: V 2.3 11-03-15) (ISCC, 2011)<sup>7</sup>. The principles and criteria listed below were taken from that document.

The first two of six general principles cover specific requirements (“Major and Minor Requirements”) that address water issues in the environmental context.

### **ISCC requirements with respect to water issues**

These requirements are closely linked with the RED requirements. Therefore, restrictions on the use of peatlands or wetlands are adopted taking carbon storage aspects into account. Basically, water-related criteria are captured in Principle 2, which states that:

Biomass shall be produced in an environmentally responsible way. This includes the protection of soil, water and air and the application of good agricultural practices.

The corresponding criteria are specified in the key document cited above. They include, for instance:

4.2.2.1 Natural vegetation areas around springs and natural watercourses are maintained or re-established.  
4.2.5.2 If groundwater is used for irrigation, the producer respects existing water rights, both formal and customary, and can justify the irrigation in light of accessibility of water for human consumption. Local legislation is followed.

Concerning water quality, the ISCC standards contain an extensive list of criteria and requirements for the prevention of contamination of surface and groundwater by fertilization, use of chemicals, tank washing, and storage as well as waste management.

Furthermore, a section is included that is indirectly related to water, e.g. through soil erosion control.

The ISCC system addresses water issues in a broad and detailed way. The requirements are highly elaborate and designed for practical application.

<sup>7</sup> [http://www.iscc-system.org/uploads/media/ISCC\\_EU\\_202\\_Sustainability\\_Requirements-Requirements\\_for\\_theProduction\\_of\\_Biomasse\\_2.3.pdf](http://www.iscc-system.org/uploads/media/ISCC_EU_202_Sustainability_Requirements-Requirements_for_theProduction_of_Biomasse_2.3.pdf)

## 2.6. SAN Rainforest Alliance

### Background

Concerned by the decline of rainforest areas due to expansion of agricultural production for exportation a number of Latin American stakeholders started to develop principles for sustainable agriculture. After about a decade of testing in practice, a revision was carried out by the Rainforest Alliance (acting as the Secretariat of the consortium) and public consultations followed. Through several further updates and consultations, following among others the ISEAL Alliance's Code of Good Practice for Setting Social and Environmental Standards (<http://www.isealalliance.org/>), the Sustainable Agriculture Network (SAN) further developed a set of requirements that must be met by farms for their products to be eligible to carry a special label (Rainforest Alliance Certified™).

### The SAN standard

The requirements mentioned above are part of the SAN's Sustainable Agriculture Standard, whose stated objective is "to encourage farms to analyze and consequently mitigate environmental and social risks caused by agriculture activities through a process that motivates continual improvement". The standard consists of ten principles addressing environmental and social topics, as well as management issues of production systems. Each principle is specified in the form of criteria, some of which are designated as "critical". The criteria relating to water issues are summarized below, based on the standard version published in July 2010.<sup>8</sup>

### SAN requirements with respect to water issues

One of the ten principles has water (as a natural resource) as its direct focus: 4. Water conservation. The specific criteria defined under it are the following, with one being classified as "critical":

- 4.1 The farm must have a water conservation program that ensures the rational use of water resources. The program activities must make use of the best available technology and resources.
- 4.2 All surface or underground water exploited by the farm for agricultural, domestic or processing purposes must have the respective concessions and permits from the corresponding legal or environmental authorities.
- 4.3 Farms that use irrigation must employ mechanisms to precisely determine and demonstrate that the volume of water applied and the duration of the application are not excessive or wasteful. The farm must demonstrate that the water quantity and the duration of the application are based on climatic information, available soil moisture, and soil properties and characteristics. The irrigation system must be well designed and maintained so that leakage is avoided.
- 4.4 The farm must have appropriate treatment systems for all wastewaters it generates. The treatment systems must comply with applicable national and local laws and have the respective operating permits. There must be operating procedures for industrial wastewater treatment systems. All packing plants must have waste traps that prevent the discharge of solids from washing and packing into canals and water bodies.

Water also plays a role in the specifications of number of further Principles such as 2. Ecosystem conservation, 6. Occupational health and safety, 7. Community relations, 9 Soil management and conservation, and 10 Integrated waste management.

<sup>8</sup> [http://sustainablefarmcert.com/?page\\_id=36#STDPOL](http://sustainablefarmcert.com/?page_id=36#STDPOL)

The SAN standard covers water use comprehensively. The requirements are ambitious and touch on a wide range of the water-oriented impacts on the agricultural production site.

## **2.7 Alliance for Water Stewardship**

### **Background**

The Alliance for Water Stewardship (AWS) provides a standard model as a guiding framework for water stewardship standards, to be developed through a global multi-stakeholder process. The model builds on work carried out since 2007 by the Water Stewardship Initiative (WSI) in Australia and the European Water Partnership (EWP). The AWS approach refers to activities by civil society organizations, public sector agencies, companies and water service providers to arrive at sustainable management practices in order to gain significant benefits at the watershed level. In 2009, AWS was formally launched as a legal entity, and by 2010 it had initiated the development of the first International Water Stewardship Standard (“AWS Standard”) via the Water Roundtable (WRT) process. In March 2013 the AWS has launched a Beta AWS Standard for a second round of public review (AWS 2013).<sup>9</sup>

### **The Beta AWS Standard**

The AWS Standard is intended to drive water stewardship, defined as the use of water that is socially equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process that involves site- and catchment-based actions. Good water stewards understand their own water use, catchment context and shared risk in terms of water governance, water balance, water quality and important water related areas, then engage in meaningful individual and collective actions that benefit people and nature.

The Standard is designed to achieve four water stewardship outcomes:(1) good water governance, (2) sustainable water balance, (3) good water quality status and (4) healthy status of important water related areas (IWRAs).

The standard is designed as a six step approach. Each step contains a number of core criteria and indicators.

- Step 1: Commit to being a responsible water steward. This step ensures that there is sufficient leadership support to enact the rest of the criteria within the Standard. This step also relates to commitments to legal/regulatory compliance and rights-related issues, which underpin water stewardship.
- Step 2: Gather data to understand water risks, impacts and opportunities. Ensures that you gather data on your site’s water use and its catchment context and that you employ this data to identify your site’s impacts and water risks. This information also informs the development of your water stewardship plan (Step 3) and guides the actions (Step 4) necessary to deliver upon the commitments (Step 1).
- Step 3: Develop a water stewardship plan. Step 3 focuses on how a site will improve its performance and the status of its catchment in terms of the AWS Water Stewardship Outcomes. Step 3 needs to explicitly link the information gathered in Step 2 to the

<sup>9</sup> [http://www.allianceforwaterstewardship.org/Beta%20AWS%20Standard%2004\\_03\\_2013.pdf](http://www.allianceforwaterstewardship.org/Beta%20AWS%20Standard%2004_03_2013.pdf)

performance noted in Step 4 by describing who will be doing what and when. The monitoring methods in Step 5 should also reflect the plan.

- Step 4: Implement your stewardship plan and improve impacts. Step 4 is intended to ensure that the site is executing the plan outlined in Step 3, mitigating risks and driving actual improvements in performance.
- Step 5: Evaluate your performance. Step 5 is intended to review performance against the actions taken in Step 4, learn from the outcomes—both intended and unintended—and inform the next iteration of your stewardship plan.
- Step 6: Communicate about water stewardship and disclose your stewardship efforts. Step 6 is intended to encourage transparency and accountability through a public presentation of performance relative to commitments, policies and plans. Disclosure allows others to make informed decisions on the risks and rewards of a site’s operations and tailor their involvement to suit.

The Standard’s structure allows for increasing levels of performance in water stewardship, which are recognized by Core, Gold and Platinum levels. At the Core level, all criteria are required. At the advanced levels, criteria have points attached to them, which reflect both the degree of effort required and the anticipated impact. The aggregation of points results in Gold or Platinum level performance. It is important to note that higher levels will require compliance with all core criteria plus a select number of points from the optional criteria.

## **2.8 Forest Stewardship Council (FSC)**

### **Background**

The Forest Stewardship Council (FSC), formed in 1993 by a number of prominent environmental NGOs, was the first group to develop a voluntary system of sustainable forest management (SFM) certification and labeling to evaluate the sustainability of forest management practices against a set of environmental, social and economic criteria.

Forest certification schemes all contain some objectives or criteria to safeguard water resources, differing in scope and detail from one scheme to another. These schemes were developed to address issues that may arise from conventional harvesting, but are also applicable to biomass harvesting for bioenergy, as they cover basic principles of sustainability.

### **The FSC International standard**

Under the FSC International Standard, water issues are largely addressed under Principle 6: Environmental impact, which states that “Forest management shall conserve biological diversity and its associated values, water resources, soils and unique and fragile ecosystems and landscapes and, by so doing, maintain the ecological functions and the integrity of the forest.” Relevant criteria call for an assessment of environmental impacts (6.1), maintenance, enhancement or restoration of ecological functions and values (6.3), written guidelines to protect water resources and other values (6.5), and criteria for chemical use (6.6).

The FSC standard states that plantations shall not occur except in exceptional circumstances (6.10) and, where exceptional circumstances do allow for certified plantations, they must adhere to criteria under Principle 10: Plantations. This principle includes provisions for water protection, including Criteria 10.6, requiring plantation management techniques that “do not result in long-term adverse impacts on water quality, quantity, or substantial deviation from stream course

drainage patterns, and 10.8, requiring monitoring of various on- and off-site impacts including impacts to water resources.

Various regional FSC standards deal with issues in greater detail, based on regional conditions and requirements. For example, the FSC standard for the State of Mississippi in the United States requires written guidelines to protect water and other values (C 6.5), including prescriptions for streamside management zones (C 6.5.v) and requirements for meeting and exceeding state best management practices (BMPs) (C 6.5.u).

## **2.9 Comparative synopsis of certification schemes**

This section presents an overview of the schemes using a tabular matrix (Table 1) for a synoptical characterization. It shows what the schemes cover, where they overlap, and where gaps can be identified.

**Table 1: Synopsis of voluntary systems (updated from UNEP, OEKO, IEA (2011))**

Certification scheme	RSB	RSPO	RTRS	Bonsucro	ISCC	SAN	AWS	FSC
Relation to bioenergy	Biofuels	Palm oil	Soybean Soybean oil	Sugarcane Ethanol from sugarcane	Biofuels	Agricultural products	Generic	Wood Fuel wood
Water is addressed by	1 dedicated principle with 4 criteria	2 criteria with 2 generic principles	1 criterion with a generic principle	Diverse indicators with 4 generic criteria	2 criteria with a generic principle	1 dedicated principle with 9 criteria		2 criteria with a generic environmental principle
Water quantity	No depletion of surface/groundwater resources beyond replenishment capacities; 7 indicators	Maintain availability of surface/groundwater ; 1 indicator	2 indicators: GAP and best irrigation practice	Report on used volumes	Minor requirement to maintain watercourse s; requirements for irrigation	Farm must have water conservation programme, permits, best irrigation practice	Water is the genuine focus of AWS	Indirectly by protection of water resources (plantations: no adverse impacts from drainage)
Water quality	Enhancement or maintenance of surface water quality of surface/groundwater resources; 6 indicators	Maintain quality of surface/groundwater. 1 indicator	2 indicators: GAP and monitoring	Monitor efficiency, assess impact on ecosystems , mitigation measures, improvement	Extensive list of criteria regarding fertilizer, chemical use, storage, etc.	Appropriate wastewater treatment, threshold values	Water is the genuine focus of AWS	Protection of water resources, avoid chemical pesticides
Water management plan (WMP)	1 dedicated criterion for efficient use and quality enhancement; 11 detailed indicators	Implemented WMP is 1 of 4 indicators within the water criterion	No	Embedded in environmental management plan	No	Embedded in environmental and social management system	Water management on focus	No (forest management plan)

Certification scheme	RSB	RSPO	RTRS	Bonsucro	ISCC	SAN	AWS	FSC
Monitoring of effects	Yes, according to management plan	Yes, consumption and effluents (BOD) of mills	Yes, effectiveness of practices, contamination	Yes, production efficiency	No	Yes, wastewater		Yes, within environmental effects
Watershed considered	Yes	No	Yes	Yes	No	Not directly addressed	Watershed is the basic unit	No
Water rights	1 dedicated criterion regarding formal, customary rights/ indigenous communities; 8 detailed indicators	No	No	No	Irrigation has to be justified	Not directly addressed	Implicit	No
Related aspects	Rural and social development, food security, buffer zones, soil erosion	Soil erosion, riparian buffer zones	Soil erosion	Soil erosion, riparian areas, wetlands	Good agricultural practice, IPM, riparian areas, waste management	Soil erosion, waste management	All consequences of water impacts	Soil erosion, maintenance or enhancement of value as watershed
Addressed to	Market operators: biofuel production chain	Market operators: palm oil production chain	Market operators: soybean oil production chain	Market operators: sugarcane ethanol production chain	Market operators: biofuel production chain	Market operators: biofuel in general	Policymakers, stakeholders, civil society, public sector, business	Forest owners, wood producers

<b>Certification scheme</b>	<b>RSB</b>	<b>RSPO</b>	<b>RTRS</b>	<b>Bonsucro</b>	<b>ISCC</b>	<b>SAN</b>	<b>AWS</b>	<b>FSC</b>
Experience	Began in 2010 in 2012 first certification issued	Began in 2009; 2013: 15% of palm oil globally RSPO certified	2012: 19 companies certified 906,000 tonnes Soybean	2013: 29 companies certified 40.1 Mio. tonnes sugarcane; 2.73 % global production	Began in 2010 2013: more than 2.500 certificates	Began certification system in 1992 long term experiences	Initiated in 2008 BETA Standard in Place since March 2013	Began in 1993; established certification system long term experiences water: minor focus

### 3. Other systems and standards

#### 3.1 Global Bioenergy Partnership (GBEP)

In June 2008, the Global Bioenergy Partnership (GBEP) established the GBEP Task Force on Sustainability to develop a relevant, practical, science-based set of measurements and indicators that can inform policy-makers and other stakeholders in countries seeking to develop their bioenergy sector to help meet national goals of sustainable development (GBEP 2011).

The GBEP indicators are unique in that they are a product of the only multilateral initiative that has built consensus on the sustainable production and use of bioenergy among a wide range of national governments and international organizations. The indicators are meant to guide analysis at the domestic level and to inform decision-making that encourages the sustainable production and use of bioenergy as a means towards meeting national goals of sustainable development. Measured over time, the indicators will show progress towards or away from a nationally-defined sustainable development path.

The indicators are value neutral, do not feature directions, thresholds or limits and do not constitute a standard. Thus they are not applicable for any type of certification at the level of farms or plants. Instead of that they are intended to inform policy-making and facilitate the sustainable development of bioenergy without any legal binding.

Within the environmental pillar two indicators directly address water issues: 5. Water use and efficiency and 6. Water quality:

5. Water use and efficiency	- Water withdrawn from nationally-determined watershed(s) for the production and processing of bioenergy feedstocks, expressed as the percentage of total actual renewable water resources (TARWR) and as the percentage of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources. - Volume of water withdrawn from nationally-determined watershed(s) used for the production and processing of bioenergy feedstocks per unit of bioenergy output, disaggregated into renewable and non-renewable water sources
6. Water quality	- Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for bioenergy feedstock cultivation, and expressed as a percentage of pollutant loadings from total agricultural production in the watershed - Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents, and expressed as a percentage of pollutant loadings from total agricultural processing effluents in the watershed

#### 3.2 The expected International Standard “Sustainability criteria for bioenergy”

In 2009 the ISO committee started a work item on “Sustainability criteria for bioenergy” under the Project Committee PC 248. The objective has been the Standardization in the field of sustainability criteria for production, supply chain and application of bioenergy. This includes terminology and aspects related to the sustainability of bioenergy and the ambition to work out where possible, science-based approaches in the development of their work which should be translated into measurable results.

The standard is still in work at the level of internal Committee Drafts. It cannot be predicted which selection of principles, criteria or indicators will constitute the final standard, once the Committee will have agreed on such a set of Principles, Criteria & Indicators. Nevertheless there is some reason to presume that the most essential sustainability criteria encompassed by relevant certifications schemes might also be covered within the future ISO standard. With regard to water the on-going discussion is about to consider water scarcity, water quality and water rights. However no decisions are taken so far.

Apart from that the Standard in work is expected not to feature directions, nor to constitute thresholds or limits. The application of the Standard, once it is agreed and published, will premise national or inter-governmental definitions of thresholds to distinguish between sustainable and non-sustainable bioenergy.

#### **4. Discussion and Conclusion**

Within this paper a number of schemes have been analyzed above, with respect to how effects on water are being addressed. Most of the analyzed schemes cover three key items: excessive water consumption, water scarcity, and protection of water quality.

Water quality, in particular, is well-covered by nearly all of the schemes. Regarding effluents from processing processes, useful water quality indicators for customary and legal threshold values are mostly in place. Certification schemes benefit from legal references.

Negative impacts of agricultural activities, such as the application of fertilizers or pesticides, are more complex. Good agricultural practice is considered to provide protection. However, impacts on surface and groundwater bodies are time-delayed, and tracing measured pollution to a specific source (the polluter) may be inconclusive in many cases. Thus, controlling and auditing agricultural practice assumes a key role in assuring protection of water quality. Almost all of the analyzed schemes address that point.

Furthermore most schemes address avoidance of excessive water consumption, since they require water management plans, efficient use and reuse, and optimization of irrigation if used. The criteria and indicators in place appear to be useful, effective and practical. On the other hand, even efficient and sparing use of water can be excessive if the consumer is large enough to absorb modest water resources. Without taking availability and the entire consumer context into account, negative impacts cannot be avoided through good management.

The final and most crucial point is how to define and encircle areas where water is scarce. Scarcity exists, but is notably difficult to standardize. Physical scarcity can be categorized easily in terms of volume of available water resources per year and capita, or a withdrawal-availability ratio. There are useful approaches, such as the Water Availability Index or Water Scarcity Index, to classify levels of availability and scarcity that can support the basic global definition of areas where water is physically scarce. For the quantification and impact assessment, the use of the Water Footprint Tool (WFN) can also be considered.

However, information concerning physical scarcity will not address the whole problem. A number of aspects have to be considered, such as the regional resolution of the data or the economic aspects of water scarcity. In some regions water is sufficiently available in a physical sense, but the population cannot afford an appropriate supply system. Such “economic water scarcity” is difficult to consider because they can promote negative as well as positive effects.

Certification of bioenergy-related water impacts will remain a challenge. Ambitious schemes are in place, such as RSB, SAN or the notable Alliance for Water Stewardship. However, in the following years there will be a need to verify the practicability of schemes and consider how to successfully avoid adverse effects. It can be assumed that successful implementation will need to be fostered through regional, national and international policy, as well as overarching stakeholder involvement at least at the watershed level.

## References

- **AWS**, 2010, Alliance for Water Stewardship, <http://www.allianceforwaterstewardship.org/>
- **AWS**, 2013, AWS International Water Stewardship Standard – Beta Version for stakeholder input and Field Testing, <http://www.allianceforwaterstewardship.org>
- **Bonsucro**, 2012, Bonsucro Production Standard; <http://bonsucro.com>
- **GBEP**, 2011, The Global Bioenergy Partnership Sustainability Indicators for Bioenergy: 1<sup>st</sup> Edition; Rome; 2011, <http://www.globalbioenergy.org>
- **ISCC**, International Sustainability and Carbon Certification, 2010, ISCC 202 Sustainability Requirements for the Production of Biomass” (V 1.15 10-04-19) <http://www.iscc-system.org>
- **RSB**, Round Table on Sustainable Biomaterials, 2010a, RSB Principles and Criteria for Sustainable Biofuels Production (Version 2.0, 2010). Ref: RSB-STD-01-001, <http://rsb.epfl.ch>
- **RSB**, Round Table on Sustainable Biomaterials 2010b, Standard on Risk Management (Version 1.0 - 2010). Ref: RSB-STD-60-001 <http://cgse.epfl.ch>
- **RSPO**, Round Table on Sustainable Palm Oil, 2007, RSPO Principles and Criteria for Sustainable Palm Oil Production’, <http://www.rspo.org>
- **RTRS**, Round Table on Responsible Soy, 2010, RTRS Standard for Responsible Soy Production”, Version 1.0, <http://www.responsiblesoy.org/>
- **SAN**, Sustainable Agriculture Network, <http://www.rainforest-alliance.org/agriculture>
- **UNEP** (United Nations Environment Programme), OEKO Institute, International Energy Agency (IEA) Bioenergy Task 43, The Bioenergy and Water Nexus; 2011; ISBN 978-92-807-3157-6
- **WFN** (Water Footprint Network), Water Footprint Tool, <http://www.waterfootprint.org>

## Abbreviations

AWS	Alliance for Water Stewardship
BMELV	German Ministry for Agriculture
BMP	Best Management Practices
BSI	Better Sugar Initiative
EPFL	Ecole Polytechnique Fédérale de Lausanne
EU	European Union
EWP	European Water Partnership
FSC	Forest Stewardship Council
GBEP	Global Bioenergy Partnership
IEA	International Energy Agency
ISCC	International Sustainability and Carbon Certification
ISEAL	International Social and Environmental Accreditation and Labelling Alliance
ISO	International Organization for Standardization
IWRA	Important Water Related Areas
NGOs	Non Governmental Organisations
PC	Project Committee
RED	Renewable Energy Directive (EU)
RSB	Round Table on Sustainable Biomaterials (ex Biofuels)
RSPO	Round Table on Sustainable Palm Oil
RTFO	Renewable Transport Fuels Obligation (UK)
RTRS	Round Table on Responsible Soy
SAN	Sustainable Agriculture Network
SFM	Sustainable Forest Management

TAWW	Total Actual Renewable Water Resources
TARWR	Total Annual Water Withdrawals
UNEP	United Nations Environment Programme
WFN	Water Footprint Network
WRT	Water RoundTable
WWF	World Wide Fund for Nature

# **Bioenergy and water: Doing the right thing ?**

## **A literature review**

**M.Banja, J.F.Dallemand**  
**Renewable Energy Unit**  
**Institute for Energy and Transport**  
**Joint Research Centre of the European Commission**  
**T.P 450**  
**21027, Ispra - Italy**

### **Abstract**

The increased attention paid to the issue of bioenergy and water is reflected by the publication of a considerable number of articles and reports addressing mainly bioenergy and water availability, water use and impact at various levels (global, national, regional, local...). In the last few years the international debate on bioenergy, especially on biofuels for transport, was mainly focused on GHG emissions savings. Presently, the issue of the impact of bioenergy on water resources is addressed more and more, often starting from the need to increase food production in the future due to a growing population. For this reason, we retained necessary to compile a bibliographic revision on bioenergy and water. This literature review includes references addressing specifically bioenergy and water but also sometimes studies indirectly linked which address for example climate change mitigation options.

The main objective of this bibliographic revision is to identify the latest studies with specific focus on water /bioenergy and to present them according to several broad categories. This review does not intend to cover in an exhaustive way all the publications related to water and bioenergy but targets articles and reports which we considered as especially important and representative of the different trends in the field. It includes as many articles as possible from refereed journals and also reports from other sources such as the United Nations (UNEP, FAO, UNESCO...), Global Water Partnership (GWP), Water Footprint Network, Water Energy Council, International Water Management Institute (IWMI), European Environment Agency (EEA)... This literature review includes studies related to bioenergy and water availability, water footprint, Life Cycle Analysis (LCA) and water, virtual water, water quality, water & bioenergy scenario modelling, water governance, water management and policy. Since most studies address various topics simultaneously, the grouping of the references is sometimes clearly artificial. The fact that biofuels for transport are addressed more than bio-heat or bioelectricity does not imply any prioritization from the authors of this review. There is no unanimous agreement on terminology in the renewable energy community; the authors of this review refer to bioenergy as the production of energy from biomass (three main categories, i.e. agriculture, forestry and waste) for uses in transport, heat & electricity. First generation biofuels are considered to be produced from agricultural crops, second generation from ligno-cellulosic material and third generation from other feedstock categories (e.g. algae). This review will hopefully be useful to identify gaps and generate opportunities for future research.

## 1. Bioenergy and water availability

In general terms, the water demand for bioenergy production risks to place an additional burden on water availability worldwide and to stimulate increased competition over water resources in an increasing number of regions. However, bioenergy demand also leads to new opportunities to develop strategies to adapt to climate change in agriculture: for example, a number of crops that are suitable for bioenergy production are drought tolerant and relatively water efficient and by adopting such crops, farmers may better cope with a change in precipitation patterns and increased rates of evapotranspiration due to higher temperature. There are also perspectives of improvement of water management or water use efficiency in agriculture.

According to UNESCO (2011), freshwater only corresponds to 3% of all the water on the earth. It is estimated that 97% of all waters is in the oceans. Nearly 69% of fresh water is locked up in glaciers, icecaps and permanent snow covers of both poles, mountainous regions and in Greenland. For the remaining part of the fresh waters:

- 30% comes from groundwater,
- only 0.3% is contained in river systems, lakes and reservoirs. This is the most accessible water source used to satisfy human needs in our daily lives.

More than 99% of all water (oceans, ice, most saline water and atmospheric water) is not available for human uses. Even of the remaining fraction of 1% (lakes 0.86%, rivers 0.02%), much is stored in the ground. Therefore, the surface waters (such as rivers and lakes) only constitute 0.0067% of the total water.

According to UNESCO (UN World Water Development Report 4, 2012), water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. Agriculture accounts for ~70% of global freshwater withdrawals (up to 90% in some fast-growing economies). Irrigation is only a modest part of agricultural water consumption but it accounts for more than 40% of the world's production on less than 20% of the cultivated land. In many countries, water availability for agriculture is already limited and uncertain, and is set to worsen. Agricultural water withdrawal accounts for 44% of total water withdrawal in OECD countries, but for more than 60% within the eight OECD countries that rely heavily on irrigated agriculture. In the BRIC countries (Brazil, Russian Federation, India and China), agriculture accounts for 74% of water withdrawals (this ranges from 20% in the Russian Federation to 87% in India). In the least developed countries (LDCs), the figure is more than 90%. Globally, irrigated crop yields are ~2.7 times those of rainfed farming, hence irrigation will continue to play an important role in food production. The area equipped for irrigation increased from 170 million ha in 1970 to 304 million ha in 2008. There is still potential for expansion, particularly in sub-Saharan Africa and South America, in places where sufficient water is available. Although there is still potential to increase the cropped area, some 5–7 million ha (0.6%) of agricultural land are lost annually because of accelerating land degradation and urbanization, which reduces the number of farms as more people move to the cities. Increasing population means that the amount of cultivated land per person is also declining sharply: from 0.4 ha in 1961 to 0.2 ha in 2005. Biofuels are an increasingly prominent component of the energy mix, as exemplified by the EU target for biofuels to constitute 10% of transport fuel by 2020. Estimates vary, but even modest projections of biofuel production suggest that if by 2030 just 5% of road transport is powered by biofuels, this could amount to at least 20% of the water used for agriculture globally.

Three scenarios are presented at the World Energy Outlook 2011 report: (i) New Policies Scenario – the central scenario - takes into account both existing government policies and declared policy intentions; (ii) Current Policies Scenario - looks at a future in which the government policies and measures enacted or adopted by mid-2011 remain unchanged and (iii) 450 Scenario - is an outcome-driven scenario, illustrating a global energy pathway with a 50% chance of limiting the increase in the average global temperature to 2°C. In the central scenario the global energy demand increases by 40% between 2009 and 2035. A rapid increase is projected by the Current Policies Scenario with an increase of 51% or the average growth 1.6% per year and the 450 Scenario projected an increase of 23% or 0.8% a year. The average rate of growth of biomass demand till 2035 is projected to be respectively 1.7% a year at New Policies Scenario; 1.3% a year at Current Policies Scenario and 2.5% a year at 450 Scenarios. The demand for biofuel in transport sector will be respectively 6% upon New Policies Scenario, 4.4% upon Current Policies Scenario and 7.9% upon 450 Scenarios from less than 3% of today. Biofuels make the biggest contribution in transport sector, as use grows from 1.3 million barrels of oil equivalent per day (Mboe/d) today to 4.4 Mboe/d in 2035, an annual rate of increase of 5%.

The World Energy Council (2010), based on UN estimates, considers that by 2050, half of the world's population will live in nations short of water. Moving water to people and controlling the water supply will become more pressing issues in the years to come. With the threat of water scarcity and water stress, exacerbated by climate change, two challenges are faced: water for energy and energy for water. An analysis of the current situation of 'water for energy' contexts is conducted about the water needs of Africa, Asia, Europe, Latin America and the Caribbean, and North America in the context of their energy production, water withdrawal, and population. This analysis explores the water needs of a range of energy processes, including crude oil, natural gas, coal, uranium and biomass. Studies of the water requirements of the respective processes for generating electricity show the water needs of different thermoelectric generating technologies and geothermal power generating plants, as well as electricity from hydro, wind and solar. It evaluates that water consumption in primary energy production accounts for 10% of the total water use from which almost 90% of freshwater is used for the production of biomass, which accounts for less than 10% of total primary energy production.

According to the International Water Management Institute(IWMI) Policy Brief (Issue 30, 2008), to a large part based on De Fraiture et al. (2008) for the quantitative part, the development of biofuels will have an impact on water, food, energy and the environment. This IWMI Policy brief considers an impact assessment as a pre-requisite and states that:

- Globally, there is enough water to produce both food and biofuel. But, in countries where water is already scarce, like India and China, growing biofuel crops will aggravate existing problems,
- Producing one litre of ethanol from sugarcane takes nearly 3,500 liters of irrigation water in India (heavy dependence on irrigation), but just 90 liters of irrigation water in Brazil (under rainfed conditions with limited irrigation). In China, it takes 2,400 liters of irrigation for maize to produce a litre of ethanol.
- Some biofuel crops, such as jatropha and sweet sorghum, are less likely to compete with food crops, use much less water, and have much less impact on food production and the environment than others.

According to Berndes (2002), water availability appears not to impose a constraint on the assumed level of bioenergy production in countries such as Canada, Brazil, Russia and

Indonesia. However, South Africa, China, and India are already facing a situation of water scarcity, which is projected to become increasingly difficult even if large-scale bioenergy production does not materialize. Finally some countries, such as the USA and Argentina, are projected to join the group of countries that withdraw more than 25% of available water for energy crop cultivation. From the studies analysed, it results that up to 700 Mha will be used for energy crop production in 2020–2030, up to 752 Mha will be used in year 2050, and up to 1350 Mha will be used in year 2100.

Hoogeveen et al. (2009) studied the future impact of the increasing demand for biofuel on global water resources. Based on biofuel production projections for 2008 and 2017, it was estimated that currently around 1% of all water withdrawn for irrigation is used for the production of bioethanol, mainly produced from irrigated sugar cane and maize. In 2017, the amount of water to be withdrawn for biofuel production would increase by 74% if agricultural practices remain the same. However, it is likely that, during the period considered, the increase will be less marked, mainly due to crop diversification in favour of rainfed crop species.

Based on the global land-use under current and future climate impacts, Berndes (2008) analyzed what opportunities and risks entail the global use of bioenergy. For the entire EU, forest extraction is equal to about half the net annual increment. Using as starting point FAO projections of global agriculture up to 2030, explorative scenarios were developed to investigate the influence of Increased livestock Productivity (IP), Ruminant meat Substitution (RS) and shifts to more Vegetarian food and less food wastage (VE). The results indicate that if the FAO projections are correct, the prospects for bioenergy will be less favourable compared to food and livestock production. The crop production increase if a future supply of 1st generation biofuels were to grow to a level corresponding to 20% of the motor fuel consumption in 2005 reveals that countries such as Germany, UK, Italy, USA, Canada, France would roughly have to double their crop production in order to support such a level of biofuels use, based on domestic feedstocks. Meanwhile for some other countries such as China, India, Brazil and Malaysia, less relative increase in harvest would be needed, but this does not necessarily mean that these countries would be able to supply all the required feedstocks domestically. There are large differences between the countries regarding how an expanding biofuel production would add to the total ET (Evaporation + Transpiration) in agriculture. The major reason is that the projected transport fuel use in 2030 varies very much. For instance, USA & Canada are together projected to use roughly 50% more transport fuels than all the other countries taken together and more than four times as much as China. Water availability appears not to impose a constraint on the assumed level of bioenergy production in countries such as Canada, Brazil, Russia and Indonesia. However, South Africa, China, and India are already facing a situation of water scarcity, which is projected to become increasingly difficult even if large-scale bioenergy production is not implemented. This report shows that bioenergy may place a great new demand for land and water. From this report, a growing bioenergy demand may be instrumental in promoting more sustainable land and water uses around the world. But, also from this report, as well as providing an option for climate change mitigation, bioenergy may be an option for adaptation to climate change.

At global level, the different impacts that biofuel production will have on water use and availability were analyzed by Meijerink et al. (2007). This study is based on 2005 data from the top five producers of biofuels (Brazil, USA, China, India and the European Union). This analysis is based on first generation biofuel technologies. It is considered that the main drivers for biofuel production include: reduced dependence on imported petroleum, climate change

and decrease of GHG emissions; concerns about trade balances, rural development and poverty reduction. From this calculation, it appeared that there are relatively minor impacts of increased biofuel production on the global food system and water use. Current biofuel production utilizes about 1% of crop water use. This will increase to about 3% in 2030. These implications can be separated in four areas: increased demand for irrigation water, increased demand for water in ethanol processing factories, pollution of groundwater through increased use of pesticides, destruction of natural forests and related disrupted water functions. The authors have analysed the different impacts that the development of biofuels will have on water use and availability. First of all, they concluded that an increased demand for irrigation water to grow biofuel crops will lead to an accelerated depletion of groundwater aquifers. Secondly an increased demand for water in ethanol processing factories will have a negative effect on water availability, which is already felt in some States of the USA. Another impact is related to the pollution of groundwater through increased use of fertilisers and pesticides. The destruction of natural areas will have various environmental impacts, including the loss of watershed protection that is provided by natural forests.

The water consumed in the production of biofuel varies by crop and location. According to this study, sugarcane in Brazil evaporates 2200 litres for every litre of ethanol, but this demand is met by abundant rainfall. In India a litre of sugarcane ethanol requires 2500 litres of water. Almost all of India's sugarcane (potentially the country's major ethanol crop) is irrigated, as is 45% of China's likely main biofuel crop (maize). Growing sugarcane to produce the 9 billion litres of bio-ethanol needed to meet 10% of India's petrol demand by 2030 will increase current demand for irrigation water by 3.4% which is equivalent to 22,000 billion litres. Growing maize to produce enough ethanol to meet 9% of China's predicted demand for gasoline by 2030 will increase current demand for irrigation water by 5% or 26,000 billion litres.

An overview on groundwater use in agriculture and on a long-term strategy to reduce the pressure on groundwater resources is presented by Shah et al. (2007). An analysis related to the global trends in groundwater irrigation is presented. According to Shah et al., even if the groundwater use in agriculture presents an exponential growth trend, the world is still using only a fraction of earth's known groundwater reserves. At less than 1,000 km<sup>3</sup>/year, global groundwater use is a quarter of total global water withdrawals but just 1.5% of the world's annually renewable freshwater supplies, 8.2% of annually renewable groundwater, and 0.0001% of global groundwater reserves (estimated to be 7–23 million km<sup>3</sup>). The socio-economic impacts of intensive groundwater use in agriculture are important to understand due to the critical links to the livelihoods and food security of some 1.2–1.5 billion rural households in some of the poorest regions of Africa and Asia.

To understand these impacts, it is retained as important to explore the dynamic of groundwater use in agriculture in different regions of the world:

- Global typology of groundwater irrigation and impacts;
- Groundwater-intensive, market-driven irrigated agriculture;
- Groundwater irrigation and rural poverty;
- Gender and equity issues in groundwater use in agriculture.

Siebert et al. (2010) presented a global inventory of the extent of areas irrigated with groundwater, surface water or non-conventional sources and determined the related consumptive water uses. An update of the Digital Global Map of Irrigation Areas for the continents of Africa and Europe as well as for selected Latin American countries (Argentina, Brazil, Mexico, Peru and Uruguay) was conducted by compiling an inventory of sub-national irrigation statistics. Above Ground Net Primary Productivity was inversely related to the Land

Marginality Index and positively related to the Soil Quality Index. As expected, the water and energy footprints increased with the Land Marginality Index and decreased with the Soil Quality Index.

The inventory contains statistics for 15 038 national or sub-national administrative units. Globally, area equipped for irrigation is about 301 Million ha of which 38% are equipped for irrigation with groundwater. Total consumptive groundwater use for irrigation is estimated at 545 km<sup>3</sup> per year (i.e. 43% of the total consumptive irrigation water use of 1277 km<sup>3</sup> per year). The countries with the largest extent of areas equipped for irrigation with groundwater, in absolute terms, are India (39 Million ha), China (19 Million ha) and the USA (17 Million ha). Groundwater use in irrigation is increasing both in absolute terms and in percentage of total irrigation, leading in places to concentrations of users exploiting groundwater storage at rates above groundwater recharge.

In the case of Europe, an analysis conducted by the European Environment Agency (EEA, 2006) tried to assess how much biomass could technically be available for energy production without increasing pressures on the environment. A set of assumptions was developed: at least 30 % of the agricultural land dedicated to environmentally-oriented farming in 2030 in every EU Member State (except for Belgium, Luxembourg, Malta and the Netherlands, where 20 % was assumed); approximately 3 % of the intensively cultivated agricultural land set aside for establishing ecological compensation areas by 2030. It was also assumed that the EU would reach future greenhouse gas emission reductions of 40 % below 1990 levels in 2030, resulting in an increasing carbon permit price. The study concluded that significant amounts of biomass can technically be available to support ambitious renewable energy targets, even if strict environmental constraints are applied. The environmentally-compatible primary biomass potential increases from around 190 million tonnes of oil equivalent (Mtoe) in 2010 to around 295 Mtoe in 2030. This compares to a use of 69 Mtoe in 2003 (of which the environmentally-compatible part is included in the 295 Mtoe). The potential was considered sufficient to reach the European renewable energy target in 2010, with an estimated requirement of 150 Mtoe of biomass use. It also allows ambitious future renewable energy targets beyond 2010. In this study, the bioenergy potential in 2030 represents around 15–16 % of the projected primary energy requirements of the EU-25 in 2030, and 17 % of the current energy consumption, compared to a 4 % share of bioenergy in 2003. It should be noted that this study did not address in detail the topics of biomass costs or biomass mobilisation constraints.

An overview of the situation of the water resources across Europe was presented by EEA in 2009. The analysis refers to:

- water availability, abstraction and supply;
- impacts of water abstraction and supply;
- water abstraction for industry and energy production,
- public water supply,
- agricultural water use and conclusions on future water resource management in Europe.

In Europe, it is estimated that the energy production accounts for 44 % of total water abstraction, primarily serving as cooling water. 24% of abstracted water is used in agriculture, 21 % for public water supply and 11 % for industrial purposes.

The Water Exploitation Index (WEI) is a tool used to highlight stressed water resources, since it represents the total water abstracted as a percentage of long-term renewable water resources. An index of over 20 % usually indicates water scarcity and an index of over 40 % is a signal of severe stress on water resources. In Europe, according to Eurostat (2010), five countries can be considered as facing water scarcity problems (i.e. with a WEI greater than 20 %): Cyprus, Belgium, Spain, Italy and Malta. For Cyprus the WEI stands at 63 %, which is by

far the highest level in Europe. In Belgium (WEI of 32 %), 60 % of the water abstracted is for cooling purposes in the production of electricity.

In the US, based on the Energy Demands on Water Resources Analysis performed by the US Department of Energy (DoE, 2006), it was estimated that in 1995, agriculture accounted for 84 percent of total freshwater consumption. Thermoelectric power accounted for 3.3 percent of total freshwater consumption (3.3 billion gallons per day) and represented over 20% of non agricultural water consumption. Consumption by the electric sector alone could equal the entire country's 1995 domestic water consumption. Consumption of water for extraction and production of transportation fuels from domestic sources also has the potential to grow substantially.

In 2007, President Bush has called for the production of 35 billion gallons of renewable and alternative fuels by 2017 (with also a reduction of gasoline use of 20% in 10 years), which, if achieved, would correspond to about 15 percent of U.S. liquid transportation fuels. According to the National Research Council (2008), in some areas of the country, water resources are already significantly stressed. For example, large portions of the Ogallala (or High Plains) aquifer, which extends from West Texas up into South Dakota and Wyoming, show water table declines of over 100 feet. Colorado River reservoirs are at their lowest levels in about 40 years and over irrigation in areas such as the San Joaquin Valley of California has led to salinisation of the soils. A deterioration in water quality may further reduce available supplies. Increased biofuels production thus adds pressure to the water management challenges the US already faces.

Smeets et al. (2006) performed a comparison of Dutch sustainability criteria and Brazilian practices as well as a quantification of the consequences for ethanol production of the implementation of sustainability criteria. Water use and water quality related to the production of sugar cane and ethanol were considered in this study. The water supply to water use ratio for Brazil as a whole was calculated at 1% in 1995. This figure is projected to increase to 3-5% in 2075, dependant on the irrigation scenario. These figures show that Brazil has one of the lowest water supplies to water use ratios in the world. The study focuses especially on the situation in the São Paulo State area, as the vast majority of ethanol (60%) is produced there, but also to some extent on the south-west and central areas, which are the most likely areas for further ethanol production. According to FAO, there is sufficient water in this area as a whole to supply all foreseeable long-term water requirements from agriculture, households and industry. However, local water shortages may occur as a result of the occurrence of various water using and water polluting sectors (agriculture, industry) and/or cities and/or in case there of unregulated use of water and unregulated dumping of wastewater. Some of these regions include sugar cane and ethanol producing regions, an example being the Piracicaba river basin in São Paulo State. Between 1990 and 2003, the demand for water from the industry increased by 22%, the demand for water from cities increased by 66%, the demand for water for irrigation decreased by 34%. These changes are partially a result of differences in definitions and also the use of water for irrigation is smaller than previously assumed. The increase in the use of water for the industry (including the sugar cane industry) is limited as a result of the implementation of new legislation that provides for billing of water use. The data also indicate that at a state level there is no water shortage. The overuse of water resources seems a limited problem in general in São Paulo, particularly because of the relatively high rainfall.

Jewitt and Kunz (2011) described the perspectives for water resources of large-scale biofuel feedstock production in sub-Saharan Africa and the approach taken by South Africa. Across

Africa, rainfall is highly variable with extremely high coefficients of variation and year-to-year anomalies are common. South Africa is a country with less than 500 mm rainfall per year or less than half of world average. Less than 10% of the country receives more than 800mm rainfall per year.

In Africa many areas are being considered by international investors as potential biofuel feedstock producers because of the large areas of land retained as suitable for feedstock production. In sub-Saharan Africa, most countries have already allowed biofuel projects using a wide range of feedstocks, many on the scale of thousands of hectares. But with some exception, this has taken place in the absence of national biofuels policy. This has provided a source of conflict in many of these countries where differences in expectations between investors and local communities have arisen. It is already difficult to meet existing water demands in many parts of sub-Saharan Africa and, in certain catchments there is fierce competition for water between domestic users, industry, agriculture, and the environment. In such areas, allocating an additional share of water for biofuel crop production may exacerbate existing problems, or create new ones.

Currently, over 95% of sub-Saharan agriculture is grown under dryland conditions, the vast majority of which is found in smallholder farming systems. A relatively small amount of land (less than 9 million ha), representing less than 5% of the total cultivated area is considered to be water managed. Africa also contains some of the most hydrologically variable of the world rivers. Furthermore, many of the areas that appear climatologically suitable for bioenergy crop production have highly leached, sandy soils with low cation exchange capacity and therefore require careful management including fertilization, in order to sustain agricultural production.

South Africa, in anticipation of a large demand for land suitable for biofuel production, has developed a national Biofuel Industrial Strategy (BIS). With its National Water Act (NWA) and other environmental policies, this provides experience for other sub-Saharan and developing countries. The medium-term (10-year) target of South Africa government related to the establishment of a renewable energy industry in order to provide a sustainable alternative to fossil fuels is as follows: 10 000 GWh (0.8 Mtoe) renewable energy contribution to final energy consumption by 2013, to be produced mainly from biomass, wind, solar and small-scale hydro. The renewable energy is to be utilised for power generation and non-electric technologies such as solar water heating and biofuels. This is approximately 4% (1667 MW) of the projected electricity demand for 2013 (41539 MW).

The South African strategy is generally considered to be conservative, tempering the international drive toward large-scale biofuel production with a pragmatic approach toward a goal of 2% biofuel penetration within five years. The focus is on the production of bioethanol from sugarcane and sugarbeet and biodiesel from sunflower, canola and soybean. The concept of Stream Flow Reduction Activity (SFRA) is contained in the 1998 National Water Act. The water use in this concept is always defined relative to a baseline and does not reflect the consumptive water use of the crop through its growth cycle. Based on this approach, the preliminary assessments of potential impacts of biofuels crops on water resources in South Africa, highlighted that only two crops (sugarcane and sweet sorghum) could be considered as potential Stream Flow Reduction Activities but only in some parts of the country.

## **2. Bioenergy and Water Footprint**

The Water Footprint (WF) term is used in different ways by different researchers. According to the Water Footprint Network, the direct water footprint of a consumer or producer (or a group of consumers or producers) refers to the freshwater consumption and pollution that is associated to the water use by the consumer or producer. This definition states that the Water

Footprint splits into three elements: the blue, green and grey water footprint. According to UNEP (2011), the blue water corresponds to water in rivers, lakes, wetlands and aquifers that can be withdrawn for irrigation and other human uses. The green water refers to the soil water held in the unsaturated zone, formed by precipitation and available to plants. The grey water refers to water that becomes contaminated during a production process.

In the Water Footprint Manual, Hoekstra et al. (2009 and 2011) explain how Water Footprints can be calculated for individual processes and products, as well as for consumers, nations and businesses. The manual includes methods for Water Footprint sustainability assessment and a library of Water Footprint response options. It also contains the global standard for Water Footprint Assessment as developed and maintained by the Water Footprint Network (WFN). A revised Water Footprint calculation method was introduced with incorporation of water stress characterization factors. For many, if not most agri-food products, the majority of the impacts from life cycle water use occur in the agricultural stage of production.

In their analysis on the Water Footprint of bioenergy and other energy carriers (UNESCO-IHE Report 29, 2008), Gerbens-Leenes et al. considered three categories of crops: trees, bioenergy crops and food crops. It was found that the Water Footprint of energy from biomass is 70 to 400 times larger than the Water Footprint of a mix of energy from non-renewable sources (excluding hydropower). Results show large differences between the average WF of non-renewable primary energy carriers on the one hand and the average WF of energy from biomass on the other. But also within the two categories large differences occur. The WF for wind energy is negligible, for solar thermal energy 0.30 m<sup>3</sup>/GJ, but for hydropower 22.3 m<sup>3</sup>/GJ. For biomass, the WF depends on crop type, agricultural production system and climate. The WF of average biomass grown in the Netherlands is 24 m<sup>3</sup>/GJ, in the US 58 m<sup>3</sup>/GJ, in Brazil 61 m<sup>3</sup>/GJ, and in Zimbabwe 143 m<sup>3</sup>/GJ. Based on the average per capita energy use in western societies (100 GJ/capita/year), a mix from coal, crude oil, natural gas and uranium requires about 35 m<sup>3</sup>/capita/year. If the same amount of energy is generated through the growth of biomass in a high productive agricultural system, as applied in the Netherlands, the WF is then 2420 m<sup>3</sup>. The trend towards a higher energy use in combination with an increasing contribution from biomass will thus correspond to a need for more water. This causes competition with other uses, such as water for food crops. The WF of non-renewable primary energy carriers increases in the following order: uranium, natural gas, coal and finally crude oil, which shows a WF of ten times the WF of uranium. Within the category of biomass for energy purposes, differences are even larger. These differences are caused by differences in crop characteristics, agricultural production situations, climatic circumstances, as well as by local factors.

The calculation of Water Footprints for bioenergy presented in the UNESCO-IHE Report 34, (2008) by Gerbens-Leenes et al. quantifies both the Water Footprint of heat and electricity from biomass and of bio-ethanol & biodiesel. This report provides an overview of crop water requirements and water footprints of the main arable crops which together contribute to 80% of the total global arable production (barley, cassava, maize, potato, rapeseed, rice, rye, sorghum, soybean, sugar beet, sugar cane, wheat and jatropha). The calculations were performed for the period 1997–2001. Results show that there are large differences in crop water requirements among countries that are caused by differences in climate.

Climatic factors in combination with agricultural practice determine differences among water footprints. For example, the crop water requirement of sugar beet grown in Iran is twice the weighted global average value. When yield levels are relatively low, Water Footprints are high and the other way round. For example, in Kazakhstan, yields of barley, potato and wheat

are relatively low. In combination with unfavourable climatic factors, this results in high values for the water footprints. Conditions in Denmark are favourable, resulting in relatively low crop water requirements for wheat.

Large differences are found among the Water Footprints. For the crops included in the study, the weighted average water footprint is up to a factor 2 smaller for electricity than for ethanol or biodiesel. The difference is caused by the fraction of the crop that can be used. For electricity, the total biomass can be used while for ethanol or biodiesel only the starch or oil fraction is used.

In 2010, Gerbens-Leenes and Hoekstra calculated the Water Footprint of transport including the use of bio-ethanol, biodiesel or bio-electricity. In the calculation for Europe it was assumed that in the transport sector, 10% of fuels would be replaced by bio-ethanol. It was found that there are differences between the transport modes depending on transport fuel. So a small car using bio-ethanol has a ten times smaller Water Footprint than a large car using biodiesel (36 versus 355 litres per passenger km). A European goal to use in 2020 10% biofuel in the transport sector would mean that the Water Footprint related to transport would grow to 62 Gm<sup>3</sup> per year assuming that the most water-efficient crops for making bio ethanol are used. This corresponds for Europe to the requirement of a water volume that is equal to about 10% of the European Water Footprint of food and cotton consumption. If the same target would be applied at all other regions of the world, the additional water consumption in China would be equivalent to 5% of the Water Footprint for food and cotton consumption, in the rest of Asia 3%, in Africa 4%, in Latin America 10%, in the former USSR 22% and both in North America and Australia 52%. The global water consumption related to biofuel-based transport in this scenario would be 9% of the current global water consumption for food and cotton. Thus, in regions where water is limited and where energy use in the transport sector is large, the trend towards biofuels is a significant factor for total water use in agriculture and increases the competition for fresh water resources.

At global level, Hoekstra (2011) studied the Water Footprint of humanity. The objective of this study was to estimate the Water Footprint of humanity by quantifying the Water Footprints of nations both from a production and consumption perspective. This study was based on the quantification and mapping of the Water Footprint (green, blue and grey) of humanity at a high spatial resolution (5x5'). Agricultural production, industrial production and domestic water supply were taken into account. The international Virtual Water flows related to trade in agricultural and industrial commodities were estimated. The Water Footprint of consumption for all countries of the world was quantified. For each country, internal and external Water Footprints of national consumption were differentiated. The analysis was performed for the 1996-2005 period. A distinction was established between:

- the green and blue Water Footprint for crop production,
- the blue and grey Water Footprint for industry production and domestic supply.

The grey Water Footprint component was included in the global assessment. The study applied a bottom-up approach in estimating the WF national consumption of agricultural products.

The global annual average Water Footprint during the period considered was 9,087 Gm<sup>3</sup>/y (74% green, 11% blue, and 15% gray), with the contribution of agriculture being 92%, industry 4.4% and domestic water supply 3.6%. About 38% of the Water Footprint of global production corresponds to China, India and the United States. India is the country with the largest blue Water Footprint in its territory (24% of the global blue water footprint). China is the country with the largest grey Water Footprint within its territory (26% of the global grey water footprint). China and the United States have the largest water footprints in their territory

related to industrial production (22% for China and 18% for the United States). About one-fifth of the global Water Footprint is related to production for export. The total volume of international virtual water flows related to trade in agricultural and industrial products was 2,320 Gm<sup>3</sup>/y (68% green, 13% blue, 19% grey). The largest net exporters of Virtual Water are located in North and South America (United States, Canada, Brazil, and Argentina), Southern Asia (India, Pakistan, Indonesia, Thailand) and Australia. The largest net Virtual Water importers are North Africa and the Middle East, Mexico, Europe, Japan and South Korea. The Water Footprint of the global average consumer was 1,385 m<sup>3</sup>/y. China is the country with the largest Water Footprint of consumption in the world, with a total footprint of 1;368 Gm<sup>3</sup>/y, followed by India and the United States with 1,145 and 821 Gm<sup>3</sup>/y, respectively.

Hoekstra et al. (2011) addressed the Global Monthly Water Scarcity and discussed Blue Water Footprints versus Blue Water Availability. This study presented an assessment of global water scarcity combining three parameters used in measuring water use and availability:

- water use measured in terms of consumptive use of ground and surface water flows (i.e., blue water footprint rather than water withdrawals),
- water availability assessed taking into account the flows needed to sustain critical ecological functions,
- water use and availability compared on a monthly rather than annual basis.

The three primary water-consuming sectors (i.e. agriculture, industry and domestic water supply) were included in this study. The blue Water Footprint of crop production was calculated using a daily soil water balance model with a 5x5' spatial resolution for the 1996-2005 period. In this assessment, 405 river basins were analyzed. They correspond to 69% of global runoff, 75% of world irrigated area and 65% of world population. The percentages of water consumed by agriculture, industry and domestic water supply vary across river basins and within the year.

While the blue Water Footprint in agriculture varies from month to month depending on the timing and intensity of irrigation, the domestic water supply and industrial production remain more constant throughout the year. For Europe and USA taken in consideration together, the maximum of blue Water Footprint appeared for the period May to September while for Australia the maximum was found for the period October to March. Such seasonal patterns in the blue Water Footprint are not clear in South America, Africa or Asia, since these continents are more heterogeneous in climatic conditions. The analysis showed that the blue Water Footprint in rivers is less than 20% of that month's natural runoff. In 223 river basins (55% of the basins studied) with 2.72 billion inhabitants (69% of the total population living in the basins included in this study), the blue Water Footprint exceeds blue water availability during at least one month of the year. For 201 of these basins, with together 2.67 billion inhabitants, there was severe water scarcity during at least one month of the year. This highlights the fact that in case of water scarcity, it is usually of a severe nature, meaning that more than 40% of natural runoff is being consumed. In 35 river basins with 483 million people, there was severe water scarcity for at least half of the year. Twelve of the river basins included in this study face severe water scarcity during all months of the year. The largest of those basins is the Eyre Lake Basin in Australia, one of the largest endorheic basins in the world (arid and inhabited by only about 86,000 people but covering around 1.2 million km<sup>2</sup>). The most heavily populated basin facing severe water scarcity all year long is the Yongding He Basin in Northern China (providing water to Beijing), with an area of 214,000 km<sup>2</sup> and a population density of 425 persons per km<sup>2</sup>. Eleven months of severe water scarcity occur in the San Antonio River Basin in Texas (USA) and the Groot-Kei River Basin in Eastern Cape (South Africa). Two heavily populated river basins face nine months of severe water scarcity:

the Penner River Basin in Southern India (dry tropical monsoon climate and 10.9 million people) and the Tarim River Basin (including the Taklamakan Desert with 9.3 million people) in China. Four basins face severe water scarcity during eight months a year: the Indus (212 million people), the Cauvery (91,000 km<sup>2</sup> and 35 million people), the Dead Sea Basin (with the Jordan River and parts of Jordan, Israel, the West Bank and minor parts of Lebanon and Egypt) and the Salinas River in California.

Ridoutt et al. (2010) presented a revised methodology of Water Footprint calculation incorporating water stress characterization factors. A detailed inventory of Life Cycle water use was conducted for a selection of case studies corresponding to products manufactured and consumed in Australia. This study does not address bioenergy and showed that for many, if not most agri-food products, the majority of the impacts from Life Cycle water use occur in the agricultural stage of production. This revised Water Footprint calculation method does not specifically account for green water consumption because it does not contribute directly to water scarcity. However, the availability of green water is one factor that determines the productive capacity of land and productive land is itself a scarce resource.

Mekonnen et al. (2011) estimated spatially the green, blue and grey Water Footprint of crops and crop products for the period 1996-2005. The Water Footprint was calculated for 146 primary crops (including crops used for biofuel production) and 200 crop derived products. The analysis of the Water Footprints of different biofuels showed that bioethanol has a lower water footprint than biodiesel. The global Water Footprint related to crop production for the period was composed by 78% of green, 12% of blue and 10% of grey water. The largest Water Footprints were found for wheat and rice that together account for 45% of the global blue Water Footprint.

For most of the crops, the contribution of the green Water Footprint toward the total consumptive Water Footprint (green and blue) is more than 80%. Among the major crops, the contribution of green water toward the total consumptive Water Footprint is lowest for date palm (43%) and cotton (64%). Globally, 86.5% of the water consumed in crop production is green water. Even in irrigated agriculture, green water often has a very significant contribution to total water consumption. The share of the blue Water Footprint is largest in arid and semi-arid regions. Regions with a large blue water proportion are located, for example, in the Western part of the USA, in a relatively narrow strip of land along the West coast of South America (Peru-Chile), in Southern Europe, North Africa, the Arabian Peninsula, Central Asia, Pakistan and Northern India, Northeast China and parts of Australia.

In the US, Bhardwa et al. (2011) calculated the Water Footprint of bioenergy crop production on marginal lands for seven sites (9–21 ha) in Southwest Michigan. Over a one year period of land conversion and soybean production, the water and energy exchange was measured in relation with land and soil quality characteristics. 2009 data were used for this study, thus from a period when all the sites except a reference no-management site were planted with no-till soybean. Sites were rated using a Land Marginality Index (LMI) based on land capability classes, slope, soil erodibility, soil hydraulic conductivity and soil tolerance factors. A Principal Components analysis based on 12 soil physical and chemical properties was used to develop a Soil Quality Index (SQI) for the study sites. The Water and energy Footprints on these sites were estimated using eddy-covariance flux techniques. Water and energy footprints increased with LMI and decreased with SQI. The Water Footprints for grain, biomass and energy production were higher on lands converted from agriculture compared with those converted from the Conservation Reserve Program land. The sites which were previously in the Conservation Reserve Program had higher SQI than those under agricultural use.

Chapagain et al. (2009) extended the existing methods for Water Footprint to more localised levels. They studied crops grown partly in open systems and partly in plastic-covered houses with multi-seasonal harvesting, such as in the case of tomato cultivation Spain. They also compared existing ecological methodologies with WF and retained that both Life Cycle Analysis (LCA) and Ecological Footprint (EF) models could benefit from WF methodologies. This study analysed EU tomato consumption and production sites in Spain. The main objective was to improve WF methods in order to account for more specific growing conditions at local level and to explore wider questions of responsibility and measurement of water resources. The methods used were Water Footprint, Ecological Footprint, Virtual Water and Life Cycle Analysis.

The results showed that the EU consumes 957,000 tons of Spanish fresh tomatoes annually, which evaporates 71 Mm<sup>3</sup>/yr of water and would require 7 Mm<sup>3</sup>/yr of water to dilute leached nitrates in Spain. In Spain, tomato production alone evaporates 297 Mm<sup>3</sup>/yr and pollutes 29 Mm<sup>3</sup>/yr of freshwater. Depending upon the local agro-climatic conditions, status of water resources, total tomato production volumes and production system, the impact of EU consumption of fresh tomatoes on Spanish freshwater is very location specific. The authors retained that the methods used were an improvement on earlier studies, with a better accounting of impacts related to covered production with extended harvesting seasons. The inclusion of local climatic information and adjusted data for covered systems, combined with yields, specific crop lengths and greenhouse efficiencies, improved the global aggregate measure towards a reflection of local impacts. Chapagain et al. suggest that the local character of a product's virtual water content must be made more transparent through the supply-chain in order to better understand the impacts of distant consumption on local water resources. This point was considered as missing in both the conceptual framework of EF models and also in the majority of WF studies. EU consumption of fresh tomatoes from Spain shows that both EF and LCA models can be enhanced by considering water as an additional indicator of resource use. Site specific data add to the usefulness of this indicator. WF models are more efficient to effectively represent major threats to the world's freshwater ecosystems, especially with regard to water abstraction and water pollution, and should be seen as complementary to EF and LCA studies.

### **3. Life Cycle Analysis**

Jeswani et al. (2011) reviewed some approaches used for the modelling and assessment of the impact of freshwater consumption. For this purpose, a case study has been developed about ethanol produced from corn grown in 12 different countries. This case study shows how the results may vary according to the methodology selected and raises the need for a standardised methodology for assessing the impacts of water use on a Life Cycle basis. The approaches reviewed address the quantification of water use and the related impacts and are proposed for use in Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA), e.g.:

- The Hoekstra approach has been used for calculating the Water Footprints of various agricultural products. The main concern for this approach is related to the fact that the Water Footprint represents just the quantity of the water used without an estimation of the related environmental impacts, such as due to water scarcity. The quantification of water use is controversial due to the inclusion of green water (rainwater as moisture in soils) which does not affect availability of blue water and therefore should not be accounted, according to Jeswani et al.

- The Milla I Canals et al. approach considers water use at the level of a river basin. According to this method, both the source of water and the type of use of freshwater should be included in the Life Cycle Inventory.

- The Pfister et al. approach considers water use on a smaller scale than the Millà i Canals et al. approach, taking watershed as the area of focus. Unlike the previous two approaches, this method considers only blue water.

Regarding the results of the case study in the areas selected, according to Hoekstra and Millà I Canals et al. approaches, Mikhaylograd (Bulgaria) has the highest water usage ( $258 \text{ m}^3/\text{GJ}$ ) and Veneto (Italy) the lowest ( $37 \text{ m}^3/\text{GJ}$ ). If only the blue water is considered, as is the case in the Pfister et al. approach, then Mikhaylograd still has the highest usage ( $163 \text{ m}^3/\text{GJ}$ ) but corn from Mexico has the lowest water consumption ( $0.54 \text{ m}^3/\text{GJ}$ ) as the cultivation relies almost entirely on green water. Similarly, the majority of water requirements for corn cultivation in Parana (Brazil), Uttar Pradesh (India), Free State (South Africa), Jilin (China) and Buenos Aires Province (Argentina) are met by green water. This is in contrast to Mikhaylograd (Bulgaria), Sohag (Egypt), Khyber Pakhtunkhwa (North West Frontier Province, Pakistan) and Castilla y León (Spain), where the corn cultivation relies heavily on the blue water. Based on the calculations for 12 countries it was found that irrigation water requirements varies from  $13 \text{ m}^3/\text{ha}$  (Mexico) to  $6667 \text{ m}^3/\text{ha}$  (Sohag, Egypt).

The case study results show that the characterisation factors based on river basin data are also not suitable as they do not differentiate between upstream and down stream water use. Therefore, impact assessment methods based on watersheds appear to be the most appropriate. However, the watershed based approaches also have some limitations; for example, although the Pfister et al. approach takes into account seasonal water variations, these are averaged across all the seasons thus obscuring the specific variations. This study stresses the fact that the impacts of water consumption are better portrayed when the scarcity factors are taken into account.

Berger et al. (2010) used a broad range of methods for assessing water use from a Life Cycle perspective. The methods were identified by literature research in cooperation with the Working Group on water assessment of the UNEP/SETAC Life Cycle Initiative. The set of methods is based on the Withdrawal-to-Availability (WTA) ratio to calculate the characterization factors for water use and/or consumption. Almost all methods include several steps such as pure water inventories, midpoint (middle of cause-effect-chain), up to damage oriented endpoint (end of cause-effect-chain) impact assessment schemes. The methods taken in consideration in this study are: LCIA (Life Cycle Impact Assessment) of Water Consumption by Means of Energy; Ecological Scarcity Method; LCIA Method for South Africa; LCI (Life Cycle Inventory) and LCIA Modelling of Water Use; Characterization Method for a New Impact Category 'Freshwater Deprivation for Human Uses'; Human Health Damage Assessment of Undernourishment Related to Agricultural Water Scarcity; Human Health Damage Assessment of Infectious Diseases Arising from Domestic Water Consumption; Characterization Factors for Assessing the Ecological Damage of Groundwater Extraction; Damage to Aquatic Ecosystems Caused by Water Use from Dams; Impact Assessment of Freshwater Consumption. Comprehensive recommendations for the development of methods to account for water use in LCA have been provided by the UNEP/SETAC Life Cycle Initiative. The recommendations are focused on off-stream freshwater consumptive use of blue water. Starting on the LCI level the framework suggests the provision of spatial information of water withdrawal and release to account for local scarcity conditions. Moreover, the inventory should distinguish the quality of water input and output fluxes (high or low) as well as the type of watercourse from which water is withdrawn and to which it is released (ground or surface water). With regard to LCIA there were

identified the following three elements of concern connected with water use: (i) Sufficiency of freshwater resource for contemporary human users; (ii) Sufficiency of freshwater resource for existing ecosystems; (iii) - Sustainable freshwater resource basis for future generations and future uses of current generations. The group reveals that there are promising methodological developments enabling sound accounting and impact assessment of water use in Life Cycle Assessment. However, most methods focus on the assessment of off-stream consumptive use of blue water while other types of water use are underrepresented. Moreover, as different watercourses fulfill different functions, more detailed inventories and impact pathways need to be considered in water use assessment. The application of the most advanced methods requires high resolution inventory data, which can hardly be satisfied, especially with regard to background processes in the production chain.

Fingerman et al. (2011) developed an adaptation of Water Footprint and Life Cycle Assessment techniques to bioenergy, describing Life Cycle Inventory approaches that account for blue and green water use as well as for pollution effects. In this paper was developed a quantitative framework for evaluating the water resource effects of biofuel increased use. A case study was prepared for the State of California (US), which has been a leader in the development of LCA-based fuel policies. The study used a coupled agro-climatic and LCA model to estimate the water resource impacts of bioenergy expansion scenarios at county level. Two types of water consumption were considered: the evapotranspiration and the industrial/biorefinery water consumption. The amount of water required to produce ethanol from purpose-grown feedstocks in California was found to range from under 500 liters of water per liter of fuel to over 3500. According to Fingerman et al., Life Cycle water consumption for ethanol production in California is up to 1000 times that of gasoline due to a cultivation phase that consumes over 99% of life cycle water use for agricultural biofuels. This consumption varies by up to 60% among different feedstocks and by over 350% across regions in California.

It appears that Water Footprint studies do not provide information on the specific location of water resources use and the impacts which are important to inform the responsible decision-making authorities. According to Fingerman et al., LCA studies can provide this information. In order to describe impacts, they also retain that Life Cycle Inventory must be comprehensive, accounting for both blue and green water use as well as for pollution effects, varying sources and the spatial heterogeneity of usage.

According to George (2011), LCA is widely used as an analysis system for measuring the environmental impacts of feedstock supply, production, use and disposal of products and services. It is used mainly for GHG emissions and for building systems, as well as in analysis that involve input-output modeling. The main aim of the use of a LCA approach for water is:

- to identify, define and understand the importance of water in the production system,
- to identify the water included in the functional unit and to understand the impact.

The use of LCA in water analysis has a limitation related to the spatial and temporal context. Considered as important are:

- Development of a standard approach based on ISO standards and WF methodology,
- Definition of how different types of water sources and water releases should be considered,
- Determination of how local environmental and socio-economic conditions should be addressed.

According to Chapagain et al. (2009), before quantifying the Water Footprint of a product, it is necessary to analyse the Virtual Water content of that product and to distinguish the kind of water used in the production process. They consider that the specific Virtual Water contents

of each region give more detailed information than aggregate water estimations as found in Life Cycle Assessment and more relevant information than equivalent Ecological Footprint results. The local character of a product's Virtual Water content must be made more transparent through the supply-chain in order to better understand the impacts of distant consumption on local water resources. They consider that this point is missing in both the conceptual framework of Ecological Footprint models and also in the majority of Water Footprint studies.

Milla I Canals et al. (2009) reported on how freshwater use can be addressed in Life Cycle Analysis (LCA). The main impact pathways resulting from freshwater use are described, with a definition of the relevant water flows that need quantification and assessment in LCA. Two main aspects of water need to be addressed: water as a resource for humans and water as a habitat. The main quantifiable impact pathways linking freshwater use to the available supply are identified, leading to the definition of the flows requiring quantification in the Life Cycle Inventory (LCI). The LCI needs to separate and quantify evaporative and non-evaporative uses of blue and green water, as well as land use changes leading to variations in the availability of freshwater. Suitable indicators are suggested to improve the representation in LCA of impacts arising from the use of freshwater resources.

The Life Cycle Inventory (LCI) modeling is based on:

- Calculation of water evaporated from irrigation,
- Calculation of water evaporated from other processes (evaporation from reservoirs and canals, cooling water, textile drying),
- Estimation of land use effects on rainwater infiltration.

Regarding the last point, it was estimated that the reference rainwater lost from forest is 67%, while in arable land this is 73%. Therefore, the extra loss due to using arable land is 6% of rainwater, or 44 l m<sup>2</sup> per year for an average precipitation of 734 mm. Several indicators are used to compare the sustainability of water supplies in different countries, such as:

- Indicator based upon Water Resources per Capita,
- Index of water sustainability based on the affordability of water supplies (Index of structural water poverty).
- Index for determining the environmental sustainability of water supply and water stress, (Water Use Per Resource),
- Water Stress Indicator.

This is considered as useful in order to assess the comparative merits/threats posed by water-intensive products such as food or feedstocks for bioenergy sourced from different regions.

An LCA-based methodology was presented by Ridoutt et al. (2009). This methodology takes into account the blue water appropriated from surface and groundwater resources, the green water appropriated from the root zone by the plants and the dilution water (being the volume of freshwater needed to assimilate emissions to freshwater). Two case studies were taken in consideration. Several points appeared:

- lack of correspondence between Water Footprints and the availability of water for alternative uses in the absence of production,
- difficulty in relating Water Footprints to potential social and environmental harm.

Regarding the last point, Ridoutt et al. retain that there is a general lack of impact assessment methodologies for water use in the field of Life Cycle Assessment. This is reinforced by the difficulty in identifying the specific locations where water is used in case of water footprinting at the product brand level. Identifying the specific locations where water is appropriated into agri-food product Life Cycles is important since water scarcity is predominantly a local and regional concern. As a consequence, they consider that there is a

need for further development of the Water Footprint concept in order to make it useful at the product brand level. This would be useful for applications involving environmental product declarations and corporate sustainability reporting. Product Water Footprints need to be calculated in order to provide a scientifically credible correspondence between water use and potential social and environmental harm.

#### **4. Virtual water**

A description of the Virtual Water (VW) concept is presented by Milla I Canals et al. (2009). This concept has evolved since the early 1990s and refers to the amount of water required to produce a given product. Virtual Water (VW) was introduced by Allan (1998, 2001) who investigated imports through the trade of water intensive crops as a partial solution to problems of local water scarcity in the Middle East. Allan suggested that such trade relieved the need for importing countries to use their own, often scarce, water resources to produce the same product. Water is termed as virtual because the amount of water physically contained in the final product is negligible compared to the amount that went into its production.

VW studies have taken on more precise and practical applications since Hoekstra and Hung (2002), Chapagain and Hoekstra (2004), Chapagain et al. (2006), Chapagain and Orr (2009) began to quantify and calculate VW flows and related WF. Originally, Hoekstra and Hung (2002) estimated the blue WF by excluding the green water use (use of effective rainfall to produce crops) from domestic production. Subsequently, Chapagain and Hoekstra (2004) included the green WF related to the consumption of domestic production, and Chapagain et al. (2006) included the grey component of VW, accounting for the water volumes needed to dilute waste flows to agreed water quality standards. Chapagain and Orr (2009) argue that a more systematic assessment to characterise the sustainability of freshwater use by production systems in Life Cycle Analysis could also be useful for VW.

Milla I Canals et al. (2009) showed that the analysis and suggestions presented for Life Cycle Assessment may also be useful for Virtual Water studies. Accounting for water stored as soil moisture (green water) is essential for VW in order to show the total water use of a crop, to calculate the amount of blue water abstracted and to show where that water came from in the hydrological cycle. However, the requirements for LCA differ from VW estimation, e. g., green water, essential in VW calculations to show the total water use of a crop, receives a characterisation factor of zero in LCA. But both methods of analysis currently lack a proper assessment of the relative scarcity and opportunity cost of water at the point of production.

Horlemann (2007) presented the Virtual Water trade concept based on the idea that water-poor developing countries are increasingly importing their food from water-rich countries in order to conserve their own water resources and use them in other, more productive areas where more value added per volume unit of water is generated. The aim of Virtual Water trade is thus to compensate for water shortages through the geographical shift of agricultural production and the sectoral shift of water consumption. The region with the largest volume of trade in agricultural products is the European Union (EU), which is both the leading exporter and the leading importer, and two thirds of that trade takes place within the EU itself. An average of 987 km<sup>3</sup> of virtual water was traded annually in the form of agricultural products between 1997 and 2001. This is equivalent to 61 % of total Virtual Water Trade; a further 17 % was traded in the form of animal products and 22 % in the form of industrial goods. Of the total global consumption of water in agriculture, 15 % was used to produce exports. As a result, since different quantities of water are consumed in different climatic zones to produce

the same quantity of agricultural products, about 8% less water was needed globally than if the same products had been grown locally.

Horlemann advocates that both the decision-makers and international development cooperation should not focus only on Virtual Water trade but much more on measures to improve water management. Virtual Water trade is considered as an interim solution which does not eliminate the cause of scarcity. Therefore, the Virtual Water trade strategy is suitable rather as a complement to other necessary steps in sustainable water management and tends to be harmful as a separate policy strategy.

## **5. Bioenergy and water quality**

Indicators to measure water quality refer to the chemical, physical and biological characteristics of the water and also to its final use. In the case of agriculture and forestry systems, indicators tend to be related to the use of agrochemicals which may pollute underground and groundwater. Relevant regulations and international standards and agreements related to water quality are for example the Stockholm Convention on Persistent Organic Pollutants, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the World Bank guidelines and the Global Reporting Initiative on water use and pollution. Water quality indicators can be determined depending on water type or use as drinking, bathing, agriculture and industrial water. The main water quality indicators are Biological Oxygen Demand (BOD) which is the main parameter for the treatment of waste water polluted with biodegradable substances, Chemical Oxygen Demand (COD), pH (acidity, alkalinity) and Total Suspended Solids (TSS). Regarding the production of biofuels in Brazil, the standard indicators used to monitor water pollution are in most of the cases different from the international ones.

Diaz-Chavez et al. (2011) performed a review related to the water quality assessment of bioenergy production: impact of bioenergy on water quality, ways to quantify the impact and options for reducing negative impacts. Bioenergy production can affect water quality through physical, chemical, biological as well as thermal pollution loading. Water quality impacts from the conversion technologies for biofuels production are well reported for some specific feedstocks such as sugarcane and palm oil. Furthermore, in addition to the identified impacts from a water quality perspective, there is also a difference due to the fact that the biomass production phase represents a diffuse and distributed source of pollution in contrast to the conversion phase that can be considered a point source of pollution. Impacts on water quality associated with the discharges from the conversion plants are caused by the potential chemical, biological, and thermal pollution loading to aquatic systems. Water pollution main indicators comprise the BOD, TSS (Total Suspended Solid) and pH. Other indicators include conductivity, Oxygen Reduction Potential (ORP). The indicators will also vary according to the goal or standard for the measurement and include physical, environmental and chemical characteristics. The standards and regulations vary between regions and countries.

The National Research Council of the USA has proposed a way to compare water quality impacts of various crops by measuring the inputs of fertilizers and pesticides per unit of the net energy gain captured in a biofuel. Out of the potential feedstocks, corn has the greatest application rates of both fertilizer and pesticides per hectare. Per unit of energy gained, biodiesel requires just 2% of the nitrogen and 8% of the phosphorous needed for corn ethanol. Pesticide use differs similarly. Low input, high-diversity prairie biomass and other native species would also compare favourably relative to corn using this method.

Because of the traditional focus on studies at the local or national level, there is a lack of understanding related to human pressures on water quality in case of large spatial extent, for example, across Europe. Only few studies have examined the relationship between various pressures and their interactions. Based on high resolution data, Schinegger et al. (2011) presented an analysis of human pressures on running waters at the European scale. The analysis included a total of 9,330 sites on approximately 3,100 rivers in 14 European countries. 15 criteria were developed to present the different pressure types:

- water quality (i.e. acidification, eutrophication, and organic pollution),
- hydrology (i.e. artificial fluctuation in flow speed induced by hydroelectric plants, removal of water for hydropower generation, irrigation and drinking water),
- morphology (i.e. altered channel form, river bed degradation, dykes for flood protection)
- connectivity (interruptions of migratory pathway for fishes by dams).

The analysis suggests that only 21% of rivers remained unaffected by human-induced pressures and that 59% of the sites are affected by water quality pressures.

An important aspect of conventional forestry is its role of protection of water quality in streams, rivers, and lakes from potential degradation from operations such as timber harvesting, site preparation, roads and trails, fertilization and herbicide applications. This applies to bioenergy and also to conventional wood products. Shepard et al. (2006) describes the US approach to the protection of water quality in the forestry sector and discusses its significance to bioenergy production.

Point source pollution was addressed by the use of Best Available Control Technology. Non-point source pollution was addressed by Best Management Practices (BMPs) defined by the the US Environmental Protection Agency (EPA) as: practice or combination of practices, that are determined by a state, or designated area-wide planning agency, after problem assessment, examination of alternative practices, and appropriate public participation, to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals. BMPs to protect water quality during forestry operations have been developed over the past several decades in the United States. These practices are being implemented routinely and have been demonstrated to be effective in protecting water quality. Thus bioenergy production from conventional forestry should also be compatible with the maintenance of high water quality. However, some special considerations may need to be considered: increased utilization may require more frequent fertilization and thus care should be taken to protect potential receiving waters. Short-rotation woody crop bioenergy production will require even more fertilization, better roads and possibly more tillage. Conventional forestry BMPs may thus need to be revised to reflect the accelerated production cycle in these systems.

Neary (IEA/Bioenergy & Water Workshop, Australia, 2011) presented a discussion paper on the BMPs concept focusing on forest bioenergy and with a LCA perspective. BMPs are defined as effective, practical, structural or non structural methods which prevent or reduce the movement of sediments, nutrient, pesticides and other pollutants from the land to surface or ground water. BMPs protect water quality from potential adverse effects of silvicultural or agricultural activities. They are developed to achieve a balance between water quality protection and the production of woody and herbaceous crops within natural and economic limitations. BMPs initially started with auxiliary pollution control in industrial wastewater, city sewage and storm water management (first mentioned in USA 1997 Clean Water Act). In 2000, the US EPA released a list of national BMPs for storm water. BMPs are codified in codes of forest practices. The bioenergy life cycle BMPs is composed by the following steps:

crop establishment, intermediate treatments, harvesting, transportation, processing and generation, energy dispersal, waste handling etc.

A study was conducted in Northwest Tasmania (Australia) in order to evaluate the water quality benefits of BMPs during tree harvesting in a streamside management zone (Neary, 2010). This case study consisted of cutting a 20-year-old *Eucalyptus nitens* in a pulpwood plantation along an intermittent stream managed according to the Tasmanian State Code of Forest Practice. A machinery exclusion zone immediately adjacent to the stream limited machinery traffic, but tracked harvesters were used to cut and extract tree stems without entering the exclusion zone. Ground cover and water quality pre- and post-harvesting were measured in order to identify the major sources of sediment in this headwater catchment and to determine the effect of tree harvesting. The study showed that post-harvesting turbidity levels in streamflow were similar to pre-harvest levels (<2.5 Nephelometric Turbidity Units-NTUs) of streamflow exiting the catchment. This study showed how BMPs can be effective in limiting adverse impacts to water quality. Forest harvesting operations for bioenergy can be conducted without increasing stream turbidity, if existing BMPs are followed.

The OECD Environmental Outlook to 2050 (The consequences of inaction, Water Chapter, 2012) summarized the key pressures on water as well as the main policy responses. It presents the current water challenges and trends and how they could affect the water outlook:

- Competing demands and over-exploitation,
- Water-related disasters,
- Poor water quality and lack of access to water supply and sanitation services.

The main analysis is based on Environmental Outlook Baseline Scenario which is a "business-as-usual" scenario. Also other scenarios as Resource Efficiency and Nutrient Recycling and Reduction are developed.

According to this report, it is estimated that globally in the last century the water demand rose twice as fast as population growth. In the OECD area, total surface water abstraction has not been changed since the 1980's. This can be explained by more efficient irrigation techniques, the decline of water intensive industries, more efficient use of water for thermoelectric power generation etc. This report estimates that the OECD agriculture water use rose by 2% between 1990 and 2003 mainly in Australia, Greece, Portugal and Turkey, where farming is a major water user – more that 60% of total freshwater abstractions and the irrigation on more that 20% of cultivated land. But the water use for agriculture has declined since that, and the water use for the irrigation in 2006 accounted for 43% of the total OECD water use.

Although at national level, for most OECD countries, water use is overall sustainable, most still face at least seasonal or local water shortages. Canada withdrew 1.2% of the country's total average water yield in 2005, while Korea abstracted more than 40% putting its water balance at risk. Some OECD European countries such as Belgium and Spain abstracted as a share of renewable water resources more than 20%.

The Baseline scenario projects that future global demands will increase from about 3500 km<sup>3</sup> in 2000 to nearly 5500 km<sup>3</sup> in 2050 or by 55%. The increase in demand will come mainly from manufacturing (+400%), electricity (+140%) and domestic use (+130%). Without new policies, the relative importance of uses which drive water demand is also projected to shift significantly in 2050. In all parts of the world the growing demand for manufacturing, electricity and domestic supply will compete with the demand for irrigation water. As a result, the share of water available for irrigation is expected to decline. Under the Baseline scenario, more river basins are projected to come under severe water stress by 2050 mainly as results of increasing of water demands. The number of people living in these areas is expected to

increase rapidly from 1.6 billion in 2000 to 3.9 billion by 2050 or more than 40% of world's population.

The Resource Efficiency scenario is based on the use of more ambitious policies which reduce the water demand and increase the water-use efficiency. This scenario assumes lower water demand for thermal electricity generation and a greater share of electricity produced through solar and wind generation. In this scenario the water demand in OECD countries would be 35% lower in 2050 than in 2000 and the rate of increase in global water demand in 2050 is expected to be 15% above the demand in 2000, but 25% below the Baseline scenario.

The pressure from agriculture on water quality in rivers, lakes, groundwater and coastal waters in most of OECD countries eased between 1990 and the mid-2000s due to a decline in nutrient surpluses and pesticide use. Despite this improvement, absolute levels of nutrients and pesticide pollution remain significant in many OECD countries and regions. In nearly half of OECD countries, nutrient and pesticide concentrations in surface and groundwater in agricultural areas exceed the limits recommended for drinking water. Other concerns are agricultural pollution of deep aquifers and micro-pollutants. The eutrophication of surface waters and coastal zones, based on Baseline scenario, is expected to increase globally in the coming two decades than stabilise in some regions (the OECD, Russia and Ukraine). In Japan and Korea, the levels of the nutrients surpluses per hectare of agricultural land have already reached the high levels. In China, India and developing countries, eutrophication is projected to increase after 2030. At the same time, according to the Baseline scenario, in China, the nutrients by wastewater surpluses in agriculture are projected to stabilise. In Brazil eutrophication is expected to increase because of growing phosphorus surpluses from agriculture, while phosphorus from wastewater effluents and nitrogen is projected to stabilise or decrease after 2030. The baseline scenario reveals that from 2000 to 2050 the levels of nitrogen effluents from wastewater are projected to increase by 180% and phosphorous effluents by over 150% due to rapid growth of population, rapid urbanisation...

The Baseline scenario projected that nitrogen surpluses in agriculture will be lower in most of OECD countries by 2050. In China, India and most of developing countries the trend goes in the opposite direction because the crop production is expected to grow by 65% between 2000 and 2030 and 10% to 20% between 2030 and 2050. The production of soybeans and other pulses in Brazil is projected to grow by over 75% between 2000 and 2030, stabilising by 2050.

In Africa the major contribution will come by North Africa which is projected to contribute 20% of Africa's total nitrogen surplus and 40% of its phosphorous surplus by 2050. Total crop production in Africa is projected to increase in the Baseline scenario by 2000 and 2050 (North Africa by 150%; West Africa 375%; East Africa 265%).

In most OECD countries, it is expected that phosphorous surpluses per hectare will increase slightly in two coming decades and will decrease thereafter. In China and India the phosphorous surpluses are expected to decrease or stabilise, while in most developing countries and Brazil to increase. Under the Baseline scenario, as a result of the increasing of nutrient loads in the surface water, the number of lakes with harmful algal blooms is projected to increase globally by some 20% in 2050 compared to 2000 mostly in Africa, Asia and Brazil.

The deterioration in water quality is estimated to have already reduced biodiversity in rivers, lakes and wetlands by about one-third globally, with the largest losses in China, Europe, Japan, South Asia and Southern Africa. According to the Baseline scenario, a further decrease in aquatic biodiversity is expected in BRIICS (Brazil, Russia, India, Indonesia, China, South Africa) and developing countries up until 2030, to be followed by a stabilisation.

The Nutrient Recycling and Reduction scenario assesses the impact measures to reuse nutrients in agriculture and reduce both the domestic and agricultural discharges of nitrogen

(N) and phosphorous (P). Under this scenario, by 2050, the global N and P surpluses in agriculture could be almost 20% less than in the Baseline scenario and the effluent of nutrients in wastewater could fall by nearly 35%. The total nutrient loads to rivers would be reduced by nearly 40% for N and 15% for P compared to Baseline scenario.

OECD (2012) published the Report on "Water Quality and Agriculture: Meeting the Policy Challenge". Agriculture is a significant source of nitrogen, phosphorus, pesticides in surface water, groundwater and marine waters for most of the OECD countries. For many countries the share of agriculture in the total pollution surface water by nitrates and phosphorus is over 40%. Evidence of the contribution of the agriculture in groundwater pollution is limited, but some information suggests it may be lower than for rivers and lakes but still increasing. Agriculture contribution of nitrogen loadings into estuarine and coastal water is also above 40% for many countries, and often reported as the main cause of eutrophication. The net agricultural production over the coming decade is projected to continue with strong growth in countries as Canada, US, Mexico, Turkey, Australia and New Zealand. In EU27 the projected production growth over the coming decade is expected to be modest and for Japan to decline. According to OECD–FAO Agricultural Outlook 2011-2020, it is projected that over the next decade there will be a sustained rise trend in crops for bioenergy. Global agricultural production is projected to grow at 1.7% annually, on average, compared to 2.6% in the previous decade. Slower growth is expected for most crops, especially oilseeds and coarse grains, which face higher production costs and slowing productivity growth. The use of agricultural output as feedstock for biofuels will continue its robust growth, largely driven by biofuel mandates and support policies. According to OECD, by 2020, an estimated 13% of global coarse grain production, 15% of vegetable oil production and 30% of sugar cane production will be used for biofuel production.

A review of more national surveys from mid 2000s to 2010 was conducted by OECD. It appears that the situation of water pollution from agriculture is either stable or deteriorating in most cases

According to the European Commission, 40% of surface water and 30% of groundwater is at risk across the European Union of failing to meet the objectives for good chemical and ecological status established under the Water Framework Directive. More specifically in most EU Member States, agriculture is responsible for over 50% of the total nitrogen discharge to surface water, although the overall trend in agricultural nitrogen discharges has been declining since the early 1990s. In the Baltic Sea area the major anthropogenic source of waterborne nitrogen is mainly agriculture which constitutes 71% of the total load into the surface waters within the catchments area. Agriculture alone contributed about 80% of the reported total diffuse load. The largest load of phosphorus originated from point sources constitutes 90% of total point source discharges in 2000, with 44% from diffuse sources. In Norway the surface water quality is more commonly degraded by acidification unrelated to farming activities. Agricultural loadings to coastal waters are significant, 60% of nitrogen and 45% of phosphorus released to coastal areas of the North Sea classified as sensitive under the North Sea Declaration, although aquaculture is important, especially with respect to phosphates.

For the US, agriculture is estimated to account for around 60% of river pollution, 30% of lake pollution and 15% of estuarine and coastal pollution. For example the agriculture is the major source of sediment, nitrogen and phosphorus loadings into the Chesapeake Bay. The Gulf of Mexico's, hypoxic zone first detected in 1970s, has increased in size substantially and it is estimated to cover 2 million ha in 2011, although the area of the zone varies annually according to climatic conditions.

Eutrophication of rivers, lakes and coastal waters is widespread across OECD countries and globally. The most severe impacts of eutrophication are on estuarine, coastal and deep sea

ecosystems. Current estimates are that hypoxia related to eutrophication annually affects at least 240 000 km<sup>2</sup> globally from which about 70 000 km<sup>2</sup> are inshore and about 170 000 km<sup>2</sup> are coastal offshore waters. In total about 4% of estuarine water and about 5% of shelf area are affected globally by hypoxia of some type. Sources of nutrients to coastal waters are diverse and vary from ecosystems to ecosystems.

## **6. Water/Bioenergy Scenarios**

A large number of water/bioenergy scenarios have been published. These scenarios differ greatly, being for example quantitative, qualitative, socio-economic related, model based, derived by scenario panels through a collective scenario-building process, or combining several of these features...

Alcamo et al. (2009) discussed the uses of qualitative and quantitative scenarios, the status of global water scenarios and their contribution to decision-making. For example, studies were identified on:

- Global scenarios of changes in water resources,
- Combined impact of climate and population scenarios on global water resources,
- Impact of scenarios on water withdrawals,
- Global scenarios of water use,
- Qualitative scenarios including economic, social, technological, environmental, demographic and governance drivers affecting future global water resources,
- Areas of particularly rapid changes in water stress due to changes in water withdrawals and climate,
- Water stress situation,
- Impact of climate change on the net irrigation water demand.

Global environmental scenarios which include future global water use and availability are presented by the Global Environmental Outlook of the United Nations (UNEP, 2008) and the Millennium Ecosystem Assessment. Some of the major shortcomings are:

- Absence of scenarios that examine the combined impact of changing climate, land use and socio-economic factors on continental or global water resources;
- Lack of quantitative scenarios dealing with ecological issues;
- Difficulty to address water governance and water pricing issues.

Kämäri et al. (2008) shows a combination of quantitative and qualitative scenarios developed under the SCENES project (Water Scenarios for Europe and Neighbouring States). This Project addresses Europe's fresh waters up to 2025. The qualitative scenarios provide an understandable way to communicate complex information and can incorporate a wide range of views about the future. The quantitative scenarios are used to check the consistency of the qualitative scenarios, to provide needed numerical information and to improve the qualitative scenarios by showing trends and dynamics not anticipated by the storylines. All together, the qualitative and quantitative scenarios provide a combination that compensates for some limitations. In addition, they are interactive/adaptive scenarios, in the sense that they can be updated to better address the requirements of decision makers and stakeholders

### **6.1 Scenarios related to water resources (Not bioenergy specific)**

The data from the 2007 Scenario of the World Energy Council (WEC, Updated 2009, see Water for Energy Report 2010) provide a basis for identifying the future requirements of

“water for energy” for different regions, for the years 2020, 2035, and 2050. The scenarios identify:

- Regions that suffer from water stress and/or water scarcity, or will be affected soon,
- Regions where total internal renewable water resources seem to be sufficient to meet requirements of water for energy, without competing with other basic water uses.

The main highlights of the scenarios are related to the impact on water savings of:

- New technologies in processing primary energy, especially in thermal electricity generation,
- Increased use of renewable energy and improved energy efficiency.

The main findings of this study are:

- Water consumption in primary energy production accounts for only 10% at the date of the study but in 2050 is expected to rise to 18% mainly due to the increasing share of nonconventional oil in total oil production, from 1% now to 12% in 2050 (higher water consumption).
- Natural gas production worldwide will almost double, with the biggest increases in Asia, mainly in the Middle East, where it will almost triple and North America, where it will double.
- Energy from coal production is presently below oil but will likely become higher over the next 30-40 years.
- Mining and refining coal requires water at various stages as well. Estimates show that approximately 0.164 m<sup>3</sup> of water is needed per GJ. Overall the production of coal accounts for about 1% of total water consumption in energy production.
- Almost 90% of freshwater presently used to produce primary energy is for the production of biomass, which accounts for less 10% of total primary energy production. But in 40 years, the share of freshwater used to produce biomass should decrease to less than 80%, while at the same time the share of biomass in the total primary energy production should diminish to less than 5%.
- Water consumption to generate electricity will more than double over the next 40 years. The highest increases will occur in Latin America, where electricity generation per capita will be four times higher than today, followed by Africa and Asia, where it will almost triple. In Europe electricity generation per capita will presumably double, whereas in North America it will increase by only 50%.

Cai X. et al. (2002) developed scenarios to analyse sustainability in irrigation dominated river basins. The set of scenarios considered included:

- Baseline scenario which assumes that the current crop pattern, irrigated area, and infrastructure are maintained over the 30-year modelling horizon,
- Master scenario that assumes a 5% increase in the irrigated area and a 25% increase of municipal and industrial water demand over the modelling horizon with equal yearly changes,
- Low-irrigation scenario that assumes a 5% increase in the irrigated area and a 25% increase of municipal and industrial water demand over the modelling horizon with equal yearly changes,
- High-irrigation scenario that is the master scenario with irrigated area increasing 10% from the baseline scenario in the next 30 years, with equal yearly changes.

The results show that the high-irrigation scenario has higher irrigation profit than the low-irrigation scenario in almost every year. However, in drought periods, the differences are small, since irrigated area must be reduced because of water deficits in those years. Results show also that both long-term soil and water salinity are very sensitive to changes in irrigated area. Even small increases in the irrigated area without accompanying investments in infrastructure improvements places the environment at risk, especially in downstream demand sites.

According to Rosegrant et al. (2002), it will be difficult to meet the world's food needs if current water policies remain unchanged. In addition to the weather parameters, other critical factors include income and population growth, investment in water infrastructure, allocation of water to various uses, reform in water management and technological changes in agriculture.

Three alternative futures for global water and food were defined and followed by an assessment of specific policy options:

- Business As Usual Scenario (BAU);
- Water Crisis Scenario (WC),
- Sustainable Water Scenario.

Under the BAU scenario, total global water withdrawals in 2025 are projected to increase by 22% above 1995 withdrawals. Projected withdrawals in developing countries will increase 27 % over the 30-year period, while developed countries withdrawals will increase by 11 %. Potential irrigation demand will grow by 12 % in developing countries, while it will actually decline in developed countries by 1.5 %. The fastest growth in potential demand for irrigation water will occur in Sub-Saharan Africa, with an increase of 27 % and in Latin America with an increase of 21%.

Under the WC scenario total worldwide water consumption in 2025 will be 13% higher than under the BAU scenario but much of this water will be wasted. Under the Sustainable Water scenario, in 2025, total worldwide water consumption will be 20 % lower than under the BAU scenario. The scenarios were analyzed in case water policies remain unchanged, but also if certain key factors change e.g. increased water prices, shift to sustainable groundwater use and better exploitation of the potential of rain fed agriculture. Under both scenarios (Water Crisis and Sustainable Water), water prices for agriculture, industry, and connected households are assumed to increase gradually over the period from 2000 to 2025. By 2025 water prices for industrial water would be 1.75 times higher than prices under the BAU in developed countries and 2.25 times higher in developing countries. For domestic water uses, water prices would be 1.5 times higher in developed countries and double in developing countries. For agricultural water uses, prices double by 2025 in developed countries and triple in developing countries compared with the BAU prices.

The analysis shows that according to the WC scenario, major cereal crop prices would more than double compared with the projections under the BAU scenario. At the same time, food demand may be significantly reduced, especially in developing countries. Moreover, price increases can have an even larger impact on low income consumers. The analysis also shows that in the absence of policy and investment reform, competition over water between households and industries and between farmers and environmental uses will increase in many parts of the world. The scenarios explored in this report point to three broad strategies that can address the challenge posed by water scarcity for food production:

- Invest in infrastructure to increase the supply of water for irrigation, domestic and industrial purposes,
- Conserve water and improve the efficiency of water use in existing systems through reforms in water management and policy,
- Improve crop productivity per unit of water and land through integrated water management, agricultural research and policy efforts, including crop breeding and water management for rain fed agriculture.

By 2025 water withdrawal for most uses (domestic, industrial and livestock) is projected to increase by at least 50%. This will severely limit irrigation water withdrawal, which will increase by only 4% and will constrain food production.

Fischer et al. (2007) analyzed the impact of climate change and mitigation on irrigation water requirements. A methodology was developed with the aim to improve, within a coherent Agro Ecological Zone (AEZ) framework, estimates of irrigation water requirements (for current and future decades due to changes in both climate and socio-economic conditions). The study focused on agricultural development within a IIASA socio-economic scenario, in order to quantify global and regional trends from 1990 to 2080, as well as impacts of associated climate change, with and without mitigation options. The study findings indicate that:

- Globally the impacts of climate change on increasing irrigation water requirements could be nearly as large as the changes projected from socio-economic development in this century,
- Effects of mitigation on irrigation water requirements can be significant in the coming decades, with large overall water savings, both globally and regionally,
- Some regions may however be negatively affected by mitigation actions (i.e., become worse-off than under non-mitigated climate change) in the early decades, depending on specific combinations of CO<sub>2</sub> changes that affect crop water requirements and predicted precipitation and temperature changes.

The analysis indicates that mitigation can play an important role in reducing the impacts of climate change on agricultural water resources, globally and regionally. Countries which implement regional and global mitigation actions should also create additional resources to help those regions where the intended benefits do not materialize by enabling a range of adaptation options—particularly in those developing countries where food security is fragile and water resources are already vulnerable today.

Alcamo and Henrichs (2002) presented a top-down approach for identifying regions whose water resources have a high sensitivity to global change. An increase in water stress is used as a measure of the increasing sensitivity of watersheds to global change. This stress is computed with the WaterGAP global water model. Stress increases when either water withdrawals increase or water availability decreases. Despite uncertainty, sets of criteria were prepared for determining critical regions and four different socio-economic and climate scenarios were built and compared. Under the scenario corresponding to the largest increase in water stress, the estimated area of critical regions (in 2032) ranges from 7.4 to 13.0 percent of total land area, depending on the criteria used for identifying critical regions. As expected, the estimate of critical regions is very scenario-dependent. However, some regions always appear as critical regions regardless of the scenario. These include parts of Central Mexico, the Middle East, large parts of the Indian sub-continent and stretches of the North African coast.

Alcamo et al. (2003) analyzed the impact on withdrawals of a business-as-usual scenario driven by changes in socio-economic variables for 2025 under the assumption that current trends in population, economy and technology continue. Withdrawals in 2025 are then compared with estimates of current water availability. In this analysis the possible effects of climate change on water availability or use are not taken into account. It was found that 41% of world river basin area falls into the category with a stabilization or decrease in water withdrawals between 1995 and 2025 (i.e. increase of no more than 5% compared to the 1995 situation); more than 16% of world river basins falls into the category with an increase of water withdrawals and the river basins as Amazon, Congo, Volga and Yangtze belongs to the category with a decrease of water withdrawals.

The combined impact of climate, population and other economic factors scenarios on global water resources has been analyzed by Alcamo et al. (2007). According to this study, about

two-thirds to three-quarters of future river basin area will have increasing water stress up to the 2050s (compared to current conditions), depending on the scenario and climate model selected. The methodology of the study is based on:

- Climate scenarios,
- Global Hydrology Model of WaterGAP used together with the climate scenarios and other data to compute monthly river discharge on a grid level and at river basin scale,
- socioeconomic data from two IPCC scenarios.

The total area with severe water stress is similar for both scenarios but the direction of change of water stress is different between scenarios. Increasing water stress is caused mainly (on an area basis) by increasing water withdrawals. The most important factor for this increase is the growth of domestic water use, followed by increasing water use for industry and agriculture. Although population growth has an important direct role in increasing the number of water consumers in the domestic sector (and an indirect role in stimulating future electricity water use), a more important factor was found to be an increasing income, which will stimulate higher per capita water use in the domestic sector.

In relation to aquatic biodiversity, global scenarios were prepared by Xenopoulos et al.(2005). Two scenarios from IPCC were combined with a global hydrological model to build global scenarios of future losses in river discharge due to climate change and increased water withdrawal. Both scenarios produced similar results with respect to river discharge despite incorporating different climate, economic and social assumptions. In both scenarios, decreases in discharge occurred for about 30–35% of the world's river basins, affected mainly by climate change. So the risk for the global extinctions in these rivers is high. Although climate change is largely beyond the control of individual nations and regions, regional changes in the management of water and other factors of stress on freshwater ecosystems could help prevent these scenarios from being realized.

## **6.2 Water related scenarios addressing bioenergy**

Based on IIASA/WEC (World Energy Council) scenarios and other studies, Berndes (2002) calculated the global water consumption for the energy sector (1998). On this basis, 6 scenarios were analysed for 2025:

- Values and lifestyle (VAL),
- Technology, economics and private sector (TEC),
- Business as usual (BAU),
- Conventional development (CDS) and 2 forecast scenarios.

The BAU, CDS and the two forecasts scenarios project future water withdrawal and consumption. The VAL and TEC scenarios explore possibilities for water conservation and deep reductions in the intensity of water use. The scenarios analysis showed that the irrigated land expansion up to 2025 ranges from 1.5% to 35%. The analysis based on four scenarios (BAU, CDS and two forecast scenarios) showed that per-capita withdrawals in agriculture (mainly irrigation) almost tripled from 1900 to 1960, but came to a turning point between 1960 and 1970 and have decreased since. Total agricultural withdrawals have increased about 60% since 1960, but this growth is smaller than the population growth. All studies expect that per-capita agricultural withdrawals will continue to decrease up to 2025, but the total agricultural withdrawals increase in four scenarios (BAU, CDS and two forecast scenarios) and decrease in two scenarios (Val and TEC). One main conclusion was that no study includes large-scale energy crops production as a new source of water demand in the future.

At the same time the IIASA/WEC scenarios were used as examples of how the future biomass supply for energy could develop. A scenario of future global water use and availability is

constructed based on IIASA/WEC A3 scenario, which is the most biomass-intensive scenario in the IIASA/WEC study, reaching a biomass supply of 304 EJ yr<sup>-1</sup> in the year 2100. The IIASA/WEC scenarios are developed on a regional level. The regional scenarios have been scaled down to a country by country basis, e.g., Argentina is assumed to produce as much bioenergy as Latin America as a whole on a per capita basis. The main conclusions from the analysis can be summarized as follows:

- Water availability appears not to impose a constraint on the assumed level of bioenergy production in countries such as Canada, Brazil, Russia, Indonesia and in several countries in sub-Saharan Africa.
- Several countries (e.g., South Africa, Poland, Turkey, China and India) are already facing a scarce water situation, which is projected to become increasingly difficult even if large-scale bioenergy feedstock production would not materialize.
- Other countries, such as USA and Argentina, are projected to join the group of countries that withdraw more than 25% of available water. The reason is large per-capita withdrawals rather than scarce availability.

Flörke and Alcamo (2004) presented quantitative scenarios of future water use up to 2030 in 30 European countries. A baseline scenario and a climate policy scenario were developed using as basis the year 2000. The scenarios account for a wide range of driving forces of water use including changing population, economic growth, technological changes, changes in electricity production, transition to new types of power station cooling, structural changes in domestic water use, extent and exploitation of irrigated areas and climate change. A modelling approach (WaterGap model) was then applied to quantify the current and future European water use in a consistent way.

The sectors taken under the consideration were: domestic, manufacturing, electricity power production and agriculture. The main findings of the analysis of these scenarios were:

- Downward trend of total European water withdrawals; with a change in the profile of the water use,
- Need of a multi-sector and river basin approach,
- Major uncertainty in the future domestic water use in the new EU Member States,
- Water use in the electricity production sector expected (with medium certainty) to significantly decrease during the scenario period (Technological development lowering water use),
- Irrigation water withdrawals may increase in the South; Increase in irrigated areas and/or irrigation water withdrawals may deteriorate the ecological and chemical status of freshwater bodies,
- Climate policies will lead to lower water use in the electricity production sector (medium to high certainty).

A quantitative scenario initially proposed by IIASA was used by Varis (2007). This scenario addresses agricultural development (socio-economic scenario) in order to quantify global and regional trends from 1990 to 2080, as well as impacts of associated climate change (with and without mitigation options). IIASA/WEC proposed the following scenarios:

- A1-High growth, ample oil and gas,
- A2-High growth, return to coal; A3-High growth, fossil phase out,
- B-Middle Course,
- C1-Ecologically driven, new renewables with nuclear phase out,
- C2-Ecologically driven, renewables and new nuclear.

Upon B scenario, between the years 2000 and 2050, bioenergy production is expected to grow by 70%. The calculations show that by 2030, the global water consumption (evaporation) due

to commercial bioenergy production will be around 500–600 km<sup>3</sup> in the case of all other scenarios except A2 and A3. Those scenarios will mean far higher water consumption, namely 1200 and 2300 km<sup>3</sup>, respectively. Between 2030 and 2050, water consumption is projected to accelerate due to the phasing out of fossil energy production. The water consumption of non-commercial bioenergy production would not be very different from the present level of 800–1000 km<sup>3</sup> per year in any scenario. By 2050, non-commercial bioenergy production is projected to decrease by some 10 to 20% from that amount. So the total water consumption of bioenergy production would be 1400–2000 km<sup>3</sup> in 2030, if scenarios A2 and A3 were omitted.

Using the WATERSIM scenario, De Fraiture et al. (2007) studied the land and water implications of increased biofuel production at global level and also with a special focus on China and India.

The total volume of water resources in China ranks sixth worldwide, but per capita supplies are only 2200m<sup>3</sup> in 2000, about one-quarter of the world average and in the northern part the volume can reach 290 m<sup>3</sup> per capita. China withdraws on average 2,400 l of irrigation water to produce the amount of maize needed for one liter of ethanol therefore around 2% of total irrigation withdrawals in China are for biofuel crop production. According to WATERSIM scenario the percentage increase on maize, sugarcane and rapeseed in order to meet biofuel demand will be respectively 20, 25 and 80.

In India, total renewable water resources are estimated at 1,887 km<sup>3</sup>, but only half (or 975 km<sup>3</sup>) are potentially utilizable. Total water resources amount to 2,025m<sup>3</sup> per capita (for the year 2000), or only around 1,100m<sup>3</sup> of potentially utilizable per capita supplies. In India, the water withdrawals for every liter of ethanol are nearly 3,500 l. Oil demand in India is expected to grow by a factor 2.2 by 2030, increasing the oil import dependency from 69% now to 91%. Water withdrawals in India were estimated at 630 km<sup>3</sup> in the year 2000, of which more than 90% was for irrigation. Close to 85% of the area under sugarcane is irrigated. The biofuel scenario implies that in India an additional 100 million tonnes of sugarcane is needed for the production of bioethanol, for which 30 km<sup>3</sup> additional irrigation water needs to be withdrawn.

A set of policy scenarios was presented by Bärlund et al.(2008) in order to provide a vision for Europe's water for the next twenty to forty years. Four types of scenarios were prepared and the quantification of water availability and stress is performed using the WaterGap model. Under the climate change assumptions of the GEO-4 scenarios, only a small change is computed in water availability in Central Europe up to 2030. Although they showed a similar impact of climate change, the scenarios used differ greatly in their estimates of future water withdrawals in Europe. According to the scenario "Sustainability First" where a reinforcement of water-saving actions is assumed, total water withdrawals may decline by more than 50% in Central and Northern Europe. Under the scenario "Security First" without major water-saving actions, water withdrawals decrease by 25 to 50% in Western Europe, parts of the Baltic countries and Scandinavia. This is because of the saturation of water demand in the household sector, and because of expected improvements in the efficiency of water use in all economic sectors. So it is proposed to focus scenario studies on changes expected in seasonal indicators, for example, on the availability of water during the summer versus winter season.

Bonnet et al. (2009) performed a prospective assessment of the potential water impacts of different biofuel production scenarios in France. The study was performed for the 2030 horizon through elaboration of a scenario set and evaluation of water resource consumption and nitrate and pesticide pollution. The set of scenarios included:

- S1A - 5 Mtoe of first-generation liquid biofuels,
- S1B - 5 Mtoe of first-generation liquid and gaseous biofuels;
- S2 - 20 Mtoe of second-generation biofuels,
- S3 - 14 Mtoe of second-generation biofuels, with water resource protection.

Each scenario was defined by the crop needs and agricultural area dedicated to attaining the required levels of biofuel production. The change in land use was first defined at a national level and then at the level of two main hydrographic basins, Adour-Garonne and Seine-Normandy. The water stress assessments measured the effects of land conversion in 2030, compared to a 2006 baseline. The assessments involved quantitative aspects (water consumption, impacts on water balance in the Basins) as well as the qualitative aspects (nitrate and pesticide pollution) related to the mobilisation of water resources. Each scenario was based on biofuel production from agricultural products or by-products produced on current useable farmland. Three main groups of results were prepared:

- Quantitative stresses based on crop water balance. For each scenario, the different terms of the balance (e.g., evapotranspiration, consumption, water deficit, and drainage) determine the pressure indicators (evaluated at the level of the basins using the assessments of land conversion between 2006 and 2030).
- Qualitative nitrate stress based on the evaluation of nitrogen leaks and nitrate concentrations in sub-root draining.
- Qualitative phytosanitary stress based on the study and on the adjustment of existing indicators such as Treatment Frequency Index (TFI) and contamination of surface and subsurface water (SIRIS-Pesticides ranking).

Scenario 1A, based on conventional food agriculture and first-generation technologies deployed on available area, leads to a clear intensification of stress on the converted areas. Scenario 1B, with the same agricultural structure, reduces stress by using biogas production, whether it is through dedicated crops (SN) or through using crop residue (AG). This leads to a dampened increase of the stresses typical of S1A, although it does not reverse completely the trends.

Scenario 2, which describes a strong development of energy crop production for 2<sup>nd</sup>-generation technologies, leads to the intensification of certain quantitative stresses, and to a reduction of other stresses (nitrogen stress) and Scenario 3, whose objective is to improve the water resource situation on the same surface area as Scenario 2, is effective in hydric balance; nitrogen stress and phytosanitary stress.

At global level, Hoogeveen et al. (2009) performed a quantitative estimation of water withdrawal for biofuels production. Based on biofuels production projections for 2008 and 2017, it was estimated that currently around 1% of all water withdrawn for irrigation is used for the production of bio-ethanol, mainly produced from irrigated sugar cane and maize. In 2017 the amount of water to be withdrawn for biofuel production would increase by 74% if agricultural practices remain the same. It is, however, likely that in 10 years the increase will be lower, mainly due to crop diversification in favour of rainfed crop species.

Van Lienden (2009) analysed a set of energy scenarios focusing on water. The goal was:

- to study the consequences of the transition to a larger share of bioenergy in total energy consumption on the water footprint of energy sectors across the globe,
- to subsequently assess the water stress caused by existing energy scenarios for 2030.

The research focused specially on the Water Footprint of scenarios in which bio-energy plays a substantial role. The analysis included the consumption of first generation bioethanol, biodiesel and bio-electricity and heat in nearly all countries of the world. With existing energy scenarios all projecting an absolute increase in bio-energy consumption in the future, the

transition to bioenergy will lead to a larger water use for the global energy sector. The competition for available runoff between blue water users will likely cause blue water stress in many countries, especially in Europe, Developing Asia and the Middle East. It is expected that the green bioenergy Water Footprint will cause green water stress in even more countries all over the world. The primary reason is the enormous projected increase in consumption of bio-electricity from rain fed plantation wood. At global level, the green bioenergy Water Footprint will comprise almost 40 percent of the total green water supply, whilst the blue bio-energy water footprint is expected to be about 4 percent of total available runoff for humans in 2030.

## **7. Modelling studies related to bioenergy and water**

For Europe, Bouraoui et al. (2008) analysed the environmental efficiencies and impacts, in particular on water and nitrogen, of biofuel production from rapeseed. This analysis was based on using regional yield data for the period from 1995 to 2003. Pan-European modelling was performed with Environmental Policy Integrated Climate (EPIC) model at a 10x10km scale covering EU-27 plus Switzerland. Rapeseed is now the fourth most important crop by area in the EU, after wheat, maize and barley. Rapeseed is the EU's dominant biofuel crop with a share of about 80% of the feedstock. The main rapeseed producing countries are France, Germany, Poland and the Czech Republic. France and Germany have a median production of about  $5 \times 10^6$  ton yr<sup>-1</sup>. The target set by the Biofuel Directive (5,75% of biofuels in the transport sector) would demand an enormous increase in biofuel production (and import) and has led to a 14% increase in the area of rapeseed compared with 2006 (and 31.5% relative to the 2002–2006 average). This might be an indication for less productive land now being used for growing rapeseed. The EPIC model is a continuous simulation model in order to determine the effects of management strategies on agricultural production and soil and water resources. The model has been used before in a global assessment to model crop yields at national level and also for irrigation scheduling, climate change studies and soil organic carbon assessments. A specific data framework was designed in order to structure all the relevant geographic information necessary to perform EPIC modelling at a European scale. The database includes European meteorological, topographic, soil, land use and farm management practices. Rapeseed was modelled as a winter crop. Highest modelled and reported rapeseed yields generally occur in the North-western and North central regions, while lowest yields occurred in the South-western and Southern regions of the European Union. The evaluation of the model against regional yield data at pan-European scale, showed the regional differences in the efficiency of the use of water and nitrogen. It was retained that the environment will be affected across Europe, depending on the inherent environmental, climatic and soil characteristics.

Wriedt et al. (2008) used the same model to estimate irrigation water requirements and regional irrigation water demands in the EU at high spatial resolution. The total area equipped for irrigation (total irrigable area) in EU-27 in the year 2003 accounts for 16 million ha on a total of 182 million ha of agricultural land. The majority of irrigated areas are concentrated in the Mediterranean region. France, Greece, Italy, Portugal and Spain accounted for 12 million ha corresponding to 75 % of the total area equipped for irrigation in EU-27. In Central and Northern European countries, agricultural water abstractions account for less than 1 % of total abstractions (e.g. Belgium 0.1%, Germany 0.5%, Netherlands 0.8%). In these regions, temporary irrigation is generally used to improve production in dry summers, especially when the dry period occurs at a sensitive crop growth stage. In Southern Europe, however,

irrigation is an essential element of agricultural production and agricultural abstractions account for more than 60% of total abstractions (e.g. Spain 64%, Greece 88%, Portugal 80%). The modelling approach was applied for a first assessment of irrigation water requirements. A prerequisite of the analysis was the compilation of a European Irrigation Map (EIM), providing information on the distribution of irrigated areas in EU27 plus Switzerland for modelling studies. The map was used to derive irrigated areas (as total and per crop) for spatial modelling units. The calculation was done based on the most efficient irrigation strategy (maintaining optimum yield with lowest irrigation). The analysis showed that allowing higher soil water deficit does not automatically lead to non-tolerable reduction of crop yields and soil moisture. Water demands (volume for defined spatial units) were calculated based on the irrigated area within each cell, where the irrigation requirements for Europe range up to 2368 mm/yr in average per cell. A comparison with reported national statistics on water abstraction data showed considerable discrepancies for many countries, indicating not only model uncertainties, but also illustrating shortcomings of national statistics. It was found that the irrigation requirements varied considerably reflecting inter-annual variability of climatic conditions. The highest ranges (exceeding 600 mm) were observed in Southern Portugal, Southwest Spain, Southern Italy and Greece. In Central and Northern Europe (United Kingdom, Belgium, Netherlands, Luxemburg, Germany, Denmark and Sweden) the range was below 250 mm.

In the United States, environmental impacts of large scale bioenergy crops were analyzed by Bradley et al. (2011). This study used the Soil and Water Assessment Tool (SWAT) model to predict the effects of 14 future landuse/bioenergy crop rotations scenarios in four large watersheds in agricultural regions of Michigan over six years (2000 to 2005). The results suggest that traditional intensive row crops such as canola, corn and sorghum may negatively impact aquatic life and in most cases affect the safe drinking water availability;

The results of the study addressed:

- Basin-wide concentration fluctuation analysis,
- Basin-wide impact of land use conversion on stream impairment (classification of poor water quality for a surface water body under the US Clean Water Act),
- Basin-wide temporal variation of stream impairment,
- Basin-wide spatial variation of stream impairment.

The continuous corn rotation, the most representative rotation for current agricultural practices for a starch-based ethanol economy, delivers the highest concentrations of glyphosate to the stream. In addition, continuous canola contributed to a concentration of 1.11 ppm of trifluralin, a highly toxic herbicide, which is 8.7 times greater than the 96-hour-ecotoxicity threshold for bluegills and 21 times greater than the threshold for safe drinking water level. Also during the period of study, continuous corn rotation caused waterbody impairment (exceeding the human consumption threshold) from 181,630 km (under current landuse scenario) to 541,152 km. In addition, this rotation also degraded water quality for aquatic ecosystems in 3970 km of stream in which atrazine, glyphosate, and metolachlor concentration exceeded the bluegill threshold of LC50. However, second-generation lignocellulosic bioenergy crops such as switchgrass appear positively since they resulted in a 171,667 km reduction in total stream length that exceeds the human threshold criteria.

Pfister et al. (2011) studied the modelling of global water consumption and land use in the cultivation phase of 160 crops. The evaluation took into account the economic value of the crops and was performed at high spatial resolution and with a global coverage. The analysis showed that wheat, rice, cotton, maize (excluding forage) and sugar cane, account for 49% of the RED (Relevant for Environmental Deficiency) water, which represent the water use

related to environmental impacts, and 42% of land resource stress caused by worldwide crop production. Three of these crops, namely wheat, rice, and maize, provide about 60% of the current global food calorific content and contribute in total between 37% and 38% to global RED water and land stress. In addition to their use as food, maize and sugar cane are also major sources of biofuel feedstock, whereas cotton supplies about 40% of global textile fibers. The result is that no significant difference in yield and irrigation requirements is observed between maize and wheat. The current differences in land and water use between crops may thus be due to additional properties of the crops (e.g., drought resistance) or economic profitability, resulting in cash crops to be grown with priority at suitable production sites. This study is not bioenergy specific but it addresses crops which are grown for food or non food purposes.

Chiu et al. (2009) estimated the state-level field-to-pump water requirement of bioethanol in the United States. This was based on the analysis of irrigation rate and volume, state corn production, ethanol requirements, facility operations and fractionation process. The results indicate that there are wide variations of bioethanol's water requirements from 5 to 2138 l per liter of ethanol depending on regional irrigation practices. As a general trend, the water requirements increase from the East to the West and from the Midwest to the Southwest regions of the United States. The results also show that as the ethanol industry expands to areas that use more irrigated water than others. Consumptive water appropriation by bioethanol in the US has increased 246% from 1.9 to 6.1 trillion liters between 2005 and 2008, whereas US bioethanol production has increased 133% from 15 to 34 billion liters during the same period.

Mubako et al. (2008) also studied the water resource requirements and water quality impacts of corn-based ethanol production in the USA. In assessing the forms of water use and water quality impacts, the study focused on the two States with the greatest corn production (Illinois and Iowa) as well as the leading State in irrigated corn production (Nebraska). This study used climatic and agricultural data from the 25-year period 1982–2006. Based on these calculations it results that the virtual water content of corn ranges from 276 m<sup>3</sup> in Nebraska to 351 m<sup>3</sup> in Iowa.

Also in the US, Bradley et al. (2011) used the Soil and Water Assessment Tool (SWAT) to predict the possible long-term environmental implications, specifically water quality, due to large-scale bioenergy cropping system expansion. This study was based on four land use scenarios and 15 bioenergy crop rotations for four watersheds, totalling 244 model simulations. The study area consisted of four watersheds totalling 53,358 km<sup>2</sup> located in Michigan. The results suggest that perennial grass species are the most suitable for large-scale implementation, whereas traditional intensive row crops should be implemented with caution on such a broad scale. Row crops also had the highest increases of high priority areas for sediment, nitrogen and phosphorus. Based on the data from this study, it is not recommended to convert marginal land to any bioenergy rotation in areas with pre-existing high nitrogen levels. Statistical analyses showed that perennial grass species significantly reduce sediment on all lands except marginal lands. With the exception of row crops cultivated on marginal lands and all agricultural land, the majority of bioenergy crops significantly reduce total phosphorus loads.

Green and blue water simulations from a wide range of global models with different origins, ranging from hydrological, vegetation and crop models, to partial and general equilibrium economic models were presented by Rockstrom et al. (2009). Biophysical models were used

in this study to compute the water fluxes and related processes on a grid cell basis, at 0.5° resolution. They calculated soil water balances based on climate, land cover (cropland, pasture, natural vegetation) and soil information. From the initial inter-comparison of a range of different (hydrological, vegetation, crop, water resources and economic) models, green water use in global crop production is about 4–5 times greater than consumptive blue water use.

## **8. Water Management**

Wu et al. (2009) evaluated the water consumption of liquid fuel production. Five fuel pathways were studied: bioethanol from corn, bioethanol from cellulosic feedstocks, gasoline from U.S. conventional crude obtained from onshore wells, gasoline from Saudi Arabian crude and gasoline from Canadian oil sands. The analysis showed that the amount of irrigation water used to grow biofuel feedstocks varies significantly from one region to another and that water consumption for biofuel production varies with processing technology. Results indicated that crop irrigation is the most important factor determining water consumption in the production of corn ethanol. Nearly 70% of US corn used for ethanol is produced in regions where 10–17 liters of water are consumed to produce one liter of ethanol. It is found that water is consumed at a rate of 2.8–6.6 liters for each liter of gasoline produced for more than 90% of crude oil obtained from conventional onshore sources in the U.S. and more than half of crude oil imported from Saudi Arabia. For more than 55% of crude oil from Canadian oil sands, about 5.2 liters of water are consumed for each liter of gasoline produced.

According to Ongley (1996), the need for integrated water resources management has been widely accepted as a necessary national policy goal. The assessment methodology can be used at farm and river basin level. The river basin-scale assessment (small and large scale) is essential for the development of rational and cost effective remediation and control programmes. These programmes are usually driven by national policies on water pollution with management alternatives both for point and non-point sources. Since the management of water quality in agriculture is a complex and multi-sectorial problem, this report recommends to:

- develop expertise to predict environmental consequences,
- analyse remedial options both at the farm level and at the basin level,
- carry out cost-benefit analysis of other sectors needs and impacts on water quality,
- identify policy options at basin, regional or national levels,
- determine the effectiveness of the implemented measures.

Hoekstra (2011) considered that the river basin level is not always sufficient. A substantial part of today's water issues carries an intrinsically (sub)continental or even global dimension, which urges for a governance approach that comprises coordination and thus some form of institutional arrangements at a level above that of the river basin. Water management and governance yet have to catch up with the scientific advances in understanding the interdependencies and dynamics of the global water system.

According to Hoff (2009), water resources and their management have so far mostly been addressed at a local to basin scale. It has only recently been recognized that water resources are both subject to and an integral part of global change and globalization. Modifications of the global water system are, for example, driven by land use, water withdrawals, pollution, eutrophication and climate change. An example of the global dimension of anthropogenic modifications is the total consumptive water use in rainfed and irrigated crop production,

which cumulatively amounts to some 7000 km<sup>3</sup> per year. Conventional water management strategies alone cannot cope with these complex interdependencies and connections. A paradigm shift is thus required in water management itself. Inclusion of the full water resource instead of only blue water is urgently needed. Climate change mitigation measures, such as carbon sequestration and biofuel plantations, can limit some of the negative impacts. A more sustainable trade strategy must be developed and implemented to reduce its negative impacts on water systems. Integrated approaches, institutional changes and interventions across sectors and scales (i.e. horizontal and vertical integration) are required. The management of water resources needs to be supported by integrated assessments across scales, for example, in terms of future water limitations, combined effects and by linking interventions, such as deforestation, afforestation or irrigation.

According to the UNEP Global Environment Outlook (Issue 4, 2008) states that the implementation of Integrated Water Resource Management (IWRM) at the basin scale (including consideration of conjunctive groundwater aquifers and downstream coastal areas) is a key response to freshwater scarcity. Since agriculture accounts for more than 70% of global water use, it is a logical target for water savings and demand management efforts. Stakeholders should pay attention to increasing the productivity of rainfed agriculture and aquaculture, since this can contribute to an improved food security.

Rockstrom et al. (2007) retained that in order to assess the impact of land/water use and management, an integrated basin analysis is required. The water requirements in terms of vapour flows were quantified, potential water sources identified and impacts on agricultural land expansion and water tradeoffs with ecosystems analysed. This study quantified the relative contribution from infiltrated rainwater/green water in rainfed agriculture, the liquid water/blue water from irrigation and how far Water Productivity (WP) gains can contribute to the reduction of the pressure on freshwater resources. A nonlinear relationship between vapour flow and yield growth (particularly in low yielding savannah agro-ecosystems) indicated a high potential for Water Productivity increase. Such Water Productivity gains may reduce additional water needs in agriculture by 16% in 2015 and 45% by 2050. Yield growth, increasing consumptive use on existing rain-fed cropland, and fodder from grazing lands may reduce the additional rain-fed water use further by 43–47% until 2030. To meet remaining water needs, a cropland expansion of 0.8% per year, i.e., a similar rate as over the past 50 years (0.65% per year), seems unavoidable if food production is to occur in proximity to local markets. In this context, it is recommended to adopt a water balance approach linked with water consumed for food production, cropland expansion and subsequent tradeoffs.

According to the Global Water Partnership (TEC Report 14, 2009), water resources management should be a focus for climate change adaptation and Integrated Water Resource Management (IWRM) is the most suitable approach to an adaptation action. Considering the likely social, economic and environmental impacts of climate change and the challenges climate change poses for water resources management; the proposed actions needed to address those challenges are investments in infrastructure, institutions and information as well as approaches to financing IWRM for adaptation. Since water resources do not follow administrative boundaries, special arrangements should be made to fund water management activities across boundaries whether at local, state or national level.

McGrath et al. (2011) presented an Australian experience related to water use management. In the dry Mediterranean climate of Southern Australia, biomass productivity is strongly linked to water availability. Although biomass production is primarily driven by rainfall and

evaporation, site conditions and management influence the degree to which the potential is met. Soil water storage capacity is important in determining both overall productivity and in providing a buffer against droughts. Topography and aspect can influence growth by controlling the availability and demand for moisture. Due to water limitations there is an impact of seasonal and episodic droughts. The main challenges faced by biomass in such conditions are related to: dry climate, infertile and shallow soils, low water storage, climate change and variability, altered hydrology, planting in dry areas and water allocation. Some of Australia soils have low water holding capacity, low fertility, saline, acid and with erosion problems. Maximizing water use and efficiency will improve the productivity and minimize the water cost at the large scales. Optimizing water use will increase drought risk in dry years. Risk assessment based on climate parameters is thus needed. Options for managing the water limitations were developed. These options comprise for example selection of species, sites assessment prior to establishment, arrangement of plantings in landscapes, manipulating water demand through plant density, thinning and nutrient management and management.

## **9. Water Governance**

According to the Global Water Partnership (GWP, 2003), water governance refers to the range of political, social, economic and administrative systems that are in place to develop and manage water resources as well as to deliver water services at different levels of society. At the 2000 World Water Forum in The Hague, the GWP Framework for Action stated that the water crisis is often a crisis of governance and identified making water governance effective as one of the highest priorities for action.

Hoekstra (2011) showed that the relevance of external coordination for effective water governance is associated to the necessity of including coordination at higher spatial levels than that of the river basin. He retained that neglecting the global dimension of water governance would carry the risk that developments outside the domain of water governance could overrule and possibly even nullify the good intentions in the domain of water governance. The increasing demand for freshwater and the limited possibilities of raising supply urge for a greater efficiency in water use which can be achieved at three different levels: local, basin and global levels. So it is necessary to make global arrangements to mitigate climate change, some steps being already taken within IPCC and the Kyoto Protocol. He also stressed the need for an international business code for multinationals in the water sector. This would guarantee that in cases where governmental control is ineffective, this is compensated by international regulations.

As an example of tools to be used, the Bioenergy Impact Assessment (BIAS) framework (Oeko-Institut/IFEU/Copernicus Institute, 2010) proposes environmental assessment methods and tools suitable for bioenergy production chains, mainly on a national scale. It is part of an effort of FAO to facilitate decisions at various levels that take their wider impact into consideration, above all their impact on food security and the environment. It aims to provide an integrated yet simple approach for the comprehensive analysis of environmental impacts associated with production and use of biomass for bioenergy.

A holistic approach was presented by OECD (2011) in the study on Water Governance in OECD Countries (A Multi-level Approach). This report explored the co-ordination gaps in water policy. It was based on a methodological framework designed to diagnose multi-level governance challenges in decentralized public policy and to identify relevant policy

responses. The analysis was based on a 2010 survey on water governance to which 17 OECD countries contributed. The report focused on three points:

- role and responsibilities of public actors in water policy at central and sub-national levels,
- challenges related to their interaction in horizontal and vertical levels,
- tools and strategies currently in use to enhance governance in water sector.

This report stressed the fact that vertical and horizontal coordination challenges are interrelated and can potentially exacerbate each other. In similar way the instruments for co-ordination at central and vertical levels need to be assessed according to a broader perspective that consider a possible synergies and spill-over effects. A large number of tools does not show the existence of "good governance" since that they may overlap and their effect may be neutralized.

This report defined three non-normative models which raise different water governance challenges:

- Implementation of an integrated and placed –based approach at the territorial level;
- Integration of different actors at central and sub-national levels;
- Integration of multi-sectoral and territorial specificities in strategic planning and design at central level.

This report suggested a number of tentative guidelines in order to serve as a tool for policy makers to diagnose and overcome multi-level governance challenges in the design of water policy:

- Diagnose multi-level governance gaps in water policy making across ministries and public agencies, between levels of government and across sub-national actors,
- Involve sub-national governments in designing water policy, beyond their roles in implementation and allocate human and financial resources,
- Adopt horizontal governance tools to foster coherence across water-related policy areas and enhance inter-institutional co-operation across ministries and public agencies,
- Create, update and harmonise water information systems and databases for sharing water policy needs at basin, country and international levels,
- Encourage performance measurement to evaluate and monitor the outcomes of water policies at all levels of government and provide incentives for capacity building,
- Respond to the fragmentation of water policy at the sub-national level by encouraging co-ordination across sub-national actors,
- Foster capacity-building at all levels of government.
- Encourage a more open and inclusive approach to water policy making through public participation in water policy design and implementation;
- Assess the adequacy of existing governance instruments for addressing identified challenges and fostering co-ordination of water policy at horizontal and vertical levels.

## **10. Bioenergy and Water, Policy issues**

Bioenergy is one component of the present global energy supply and is expected to grow. The International Chamber of Commerce (2009) has prepared a discussion paper on international bioenergy policy. Considering that bioenergy represents 10% of primary energy consumption but largely in conventional form for heating and cooking, with 18% of bioenergy use for modern heat and electricity production and 4% for biofuel production, the main recommendations of this discussion paper are to:

- Support market-oriented bioenergy approaches based on integrated and balanced policy objectives;

- Engage business experts across sectors to better understand economic, technological, energy, land use, water use, environmental, labour and market realities of bioenergy development and deployment;
- Pursue public-private partnerships and international cooperation to support a responsible use, technological progress and commercialization of bioenergy, avoiding mandates and subsidies;
- Establish voluntary technical standards to ensure appropriate and effective use of bioenergy with associated criteria for sustainable land and water use and emissions, and provide for mutual recognition of compatible products;
- Support enhanced R&D and information sharing that can respond to emerging innovations or new findings relating to bioenergy, within a framework of intellectual property right protection;
- Emphasize performance-based and technology-neutral policies in connection with bioenergy.

The IWMI Water Policy Brief (Issue 30, 2008) stressed that policymakers need to consider that growing crops as raw materials for biofuel will have a major impact on water resources, agricultural production and food prices as well as on jobs and incomes in rural areas and environment. Biofuel crops in rainfed regions have little direct effect on existing water allocations. But, ambitious plans in China and India to boost domestic production of biofuels raise serious concerns for future water supplies if traditional food crops (maize in China and sugarcane in India) are used. Because of this, both countries are already looking at biofuel crops that use less water and do not compete directly with food crops. The water sector already faces conflicts between environmental goals on the one hand and food and livelihood goals on the other. The issue of how to resolve these conflicts with acceptable tradeoffs is going to be a major concern for policymakers in developing regions, particularly in Asia and Africa.

The European Environment Agency State of the Environment Report (SOER, 2010) seeks to shed light from various viewpoints on key characteristics of the links between environmental issues. It does so by providing an analysis of the links between different environmental challenges, as well as between environmental and sectoral trends and their respective policies. This report presents a set of thematic assessments that describe the state of environment, the trends in key issues. It reviews related socio-economic driving forces and contributes to an evaluation of policy objectives with a set of country assessments and an exploratory assessment of global megatrends relevant for the European environment. The 2010 SOER Report estimates that in 20 years, global demand for water could be 40 % higher than presently and more than 50 % higher in the most rapidly developing countries.

## **11. Bioenergy and water, Understanding the nexus**

According to the Bioenergy and Water Nexus Report (UNEP-IEA Bioenergy-Oeko Institute, 2011), bioenergy development needs to be carefully planned in order to avoid adding additional pressures to the existing ones, in a world where more than 70% of global freshwater is used for agriculture. This planning needs to reflect the increasing and competing needs for the same raw materials for uses such as food, animal fodder and fibre as the world's population climbs to an expected nine billion by mid-century. In some cases, these considerations may argue against bioenergy development. This UNEP report also outlines circumstances in which well-planned bioenergy development can improve agricultural

practices, including promoting water efficiency and sustainable fertilizer use and recommends to:

- Take a holistic approach and a long-term perspective,
- Consider the context to identify the best use for water, to apply a life-cycle approach, consider inter-relationships with other resource needs and take into account the whole watershed,
- Base decisions on impact assessments to ensure sustainable water management
- Analyse bioenergy systems from a comprehensive socio-ecological perspective and to promote sustainable land and water use,
- Design and implement effective water-related policies. These should cover feedstock production and energy conversion and monitor competition between sectorial uses of water,
- Promote technology development. New technologies may help relieve pressure on water resources, but they will need a due diligence check before deployment,
- Conduct further research, fill data gaps, and develop regionalized tools,
- Support international cooperation in research on bioenergy-related water impacts; address emerging and largely unexplored issues such as the potential and risks of coastal zones/microalgae, land-based microalgae and genetically modified organisms.

This UNEP Report presents environmental policy instruments (description, examples of application, advantages and disadvantages) such as command and control approaches (level-based water standards, technology-based water standards, ambient-based water standards...) and market-based instruments (charges, subsidies, payment system per land reservation, water markets...)

A nexus approach has been presented by the Stockholm Environment Institute (SEI, 2011). Biomass is a central resource for energy and food security in a Green Economy. Water is required for the extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing biofuels and for generating electricity. Biofuels are substantially more water intensive than fossil fuels, requiring about 10,000–100,000 litres per GJ of energy (almost all of their water demand being for growing feedstock, very little of which being for further processing). These numbers indicate that water-use efficiency can decrease when replacing conventional with non-conventional resources, in particular with biofuels as a renewable resource. Biofuel production in some locations, (such as India), relies mostly on blue water/irrigation, while in others (such as Brazil), it is mostly green-water/rainfall dependent. In addition, some of the water uses in the energy sector are consumptive, while others are not.

The SEI nexus approach is proposed as a tool to enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors. The water for energy currently amounts to about 8% of global water withdrawals (this proportion reaches 45% in industrialized countries, e.g. in Europe). Agricultural production will have to increase by about 70% by 2050 and about 50% more primary energy has to be made available by 2035. Climate change is also likely to aggravate pressure on resources and so add to the vulnerability of people and ecosystems, particularly in water scarce and marginal regions. A nexus approach is therefore needed to:

- Help climate mitigation measures and be more water smart with less energy intensive adaptation measures,
- Avoid damaging consequences for food production and other vital ecosystem services.

A number of knowledge gaps are presented in this report:

- More data needed on sustainably available water resources, in particular on safe aquifer yields and for economically water scarce regions, such as sub-Saharan Africa.

- Scarce data on consumptive water use in the energy sector, compared to withdrawal data. Existing data are scattered and not consistently traced throughout the full Life Cycle (Well to Wheel).
- Full Life Cycle assessments in terms of water and energy use are generally insufficient and do not address the full nexus.
- Energy productivity in agriculture requires further research.
- Uniformly applicable Water Footprint frameworks do not yet exist. They would allow comparison of water use efficiency for different forms of energy or food production. Such Water Footprint frameworks would have to consistently integrate water productivity with water scarcity and opportunity costs in any particular location.
- Lack of consistent and agreed upon water quality standards for different crops and production systems. Such standards would promote wastewater reuse and hence increase water use efficiency.
- It is not clear how policy frameworks, such as the EU Common Agricultural Policy, affect water and energy use and resource use efficiency in food production, both in Europe and outside Europe.
- No harmonized 'nexus database' or analytical framework that could be used for monitoring purposes or trade-off analyses.
- No blueprint for overcoming institutional disconnection and power imbalances between sectors.

Hardy et al. (2012) studied the water-energy nexus in the case of Spain. Energy production uses large quantities of water and, in turn, water provision requires considerable amounts of energy. This study has investigated this interconnection in Spain and found that 5.8% of total electricity consumption is for water-use and 25% of water withdrawals are for energy generation. This study evaluated the electricity consumption associated with all stages of water use, from water extraction to wastewater treatment, in addition to the water withdrawn and consumed to generate energy in Spain. It was found that, in 2008, total electricity used to manage the 35,000 Mm<sup>3</sup> (million cubic metres) of water in the entire water use cycle was 16,323 GWh (gigawatt hours). This represented 5.8% of demand for electricity in Spain in that year.

The most energy consuming stage of the water use cycle was extraction and treatment prior to distribution, which, across all sectors, accounted for 64% of the total water-related electricity demand. For the other two stages of the water use cycle, distribution accounted for 21% of the water-related electricity demand in 2008 and wastewater treatment accounted for 16%.

Water use in agriculture accounted for about 58% of the water withdrawn in Spain in 2008 and, as a sector, irrigated agriculture accounts for 40% of total water-related electricity demand. Irrigation practices were modernised during the last decade and about 40% of the irrigated area changed from conventional flood and gravity irrigation to drip irrigation systems. Drip irrigation uses less water, but has increased energy use in the agricultural sector. However, alternative, less energy intensive water sources may become more preferable as the cost of generating energy rises.

In 2007, 25% of the total water withdrawals were used in the energy sector, although 96% of this amount of water was returned after use (i.e. it was not consumed). Nuclear power accounted for 50% of these energy-related water withdrawals and solar thermal power accounted for 0.03%.

Although renewable energy technologies typically require less water than fossil fuel technologies, some renewables, such as biomass, still require relatively high volumes of water - 31 litres per kWh (L/kWh), compared to three L/kWh for solar thermal. The study estimated the water footprint for biofuels in Spain, focusing on first-generation biofuels used in the transport sector. Growing biomass on dry land would increase agricultural demand for water by 10%, and by 26% if irrigated agricultural land was used.

The researchers recommend that water is used more efficiently to reduce energy costs in absolute terms, and must be considered in energy plans. In addition, measures are needed to ensure that a switch to renewable sources of energy is not compromised by future water shortages. This study focused on water-related electricity consumption before distributed water is actually used, and so excluded the energy needed to heat household water. However, the researchers note that significant amounts of energy are needed for this purpose: 21% of primary energy consumed in Spanish households is estimated to be associated with domestic hot water.

## 12. Conclusion

It appears from this literature review that the issue of bioenergy & water is addressed at various levels (global, national, regional, local...) by different groups in very different ways. As expected in any scientific field, there are differences in terminology used, methodologies followed, as well as in data quality and availability. A large part of the references found are rather recent. Considering future bioenergy development, if an uncontrolled increase of water withdrawals for bioenergy is generally considered as a risk, some experts also point out the possibility to improve farming practices, to improve the efficiency of water use in agriculture and to implement Best Management Practices. In general terms but also in relation to water issues, biofuels for transport have so far received more attention than bioenergy for heat & electricity. There are only few studies addressing water & bioenergy scenarios at national level. There are also very few studies comparing water implications of bioenergy development (both in terms of water quantity and quality) and other categories of renewables, or comparing bioenergy and other categories of energy production (e.g. fossil fuel, nuclear...) with integration of external environmental costs. New topics are for example the comparison between water use for bioenergy between agriculture, Short Rotation Coppice/Short Rotation Forestry and algae. There are also very few research or operational references about the combination of biomass production and wastewater treatment.

The Water Footprint or Virtual Water approaches and methodologies are useful in order to allow indicator based comparisons but for in depth analysis of complex hydrological interactions or mechanisms, they must be combined with other assessment tools. If it is generally agreed that biomass feedstock production has strong implications related to water, especially for agricultural resources, the papers reviewed seem to indicate that the future impact on water resources will depend from the practices selected, which will be affected both by regulatory and market mechanisms.

## References

- **Alcamo J., Henrichs T.**, (2002) - Critical regions: A model-based estimation of world water resources sensitive to global changes. *Aquatic Sciences* 64, pp.352–362
- **Alcamo J., et al.**, (2007), Future long-term changes in global water resources driven by socio-economic and climatic changes, *Hydrological Sciences. Journal*, 52(2), pp. 247-275.

- **Alcamo J., et al.**, (2009) - Building a 2<sup>nd</sup> generation of world water scenarios. UN World Water Assessment Programme
- **Allan, J.A.**, (1998), Virtual water: a strategic resource, Global solutions to regional deficits. *Groundwater*, 36(4):545-546.
- **Allan J.A.**, (2001) Virtual Water - economically invisible and politically silent - a way to solve strategic water problems, *International Water and Irrigation*, 21(4): 39-41.
- **Bärlund I., et al.**, (2008) - The future of Europe's freshwaters, perspective up to 2030, 13<sup>th</sup> IWRA World Water Congress, Montpellier/France
- **Berger M., Finkbeiner M.**, (2010). Water footprinting: How to address water use in Life Cycle Assessment? *Sustainability* 2 (4), pp. 919-944
- **Berndes G.**, (2008), Water demand for global bioenergy production: trends, risks and opportunities, German Advisory Council on Global Change, WGBU, Berlin.
- **Berndes G.**, (2002), Bioenergy and water, the implications of large-scale bioenergy production for water use and supply, *Global Environmental Change* 12, pp. 253–271
- **Bhardwa J.A.K., et al.** (2011), Water and energy footprints of bioenergy crop production on marginal lands, *GCB (Global Change Biology) Bioenergy* 3, pp. 208–222
- **Bonnet J.F., Lorne D.**, (2009), Water and biofuels in 2030, Water impact on French biofuel development at 2030 time horizon, *Les Cahiers du CLIP No.19*, IDDRI-Sciences Po, Paris.
- **Bouraoui F., et al.**, (2008), Pan-European regional-scale modelling of water and N efficiencies of rapeseed cultivation for biodiesel Production, *Global Change Biology* 14, pp. 1–14
- **Bradley J. L., et al.**, (2011), Effects on aquatic and human health due to large scale bioenergy crop expansion, *Science of the Total Environment* 409, pp. 3215–3229
- **Bradley J., et al.**, (2011). Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. *Biomass and Bioenergy* 35, pp. 2200 – 2216
- **Cai X.**, (2002). A framework for sustainability analysis in water resources management and application to the Syr Darya Basin. *Water Resources* 38(10), pp. 1029
- **Chapagain AK, Hoekstra AY**, (2004), Water footprints of nations. Value of Water Research Report Series No 16. UNESCO-IHE, Delft, the Netherlands
- **Chapagain A.K.**, (2006), Globalisation of water. Opportunities and threats of virtual water trade. Balkema, Taylor & Francis Group, the Netherlands
- **Chapagain A.K., Orr S.**, (2009), An improved water footprint methodology linking global consumption to local water resources. A case of Spanish tomatoes. *Journal of Environmental Management* 90. 1219-1228
- **Chiu, Y-W., et al.**, (2009). Water embodied in bioethanol in the United States. *Environmental Science & Technology* 43 (8), pp. 2688-2692
- **De Fraiture C., et al.**, (2008), Water implications of biofuel crops: understanding tradeoffs and identifying options, *Water Policy Brief*, Issue 30
- **De Fraiture C., et al.**, (2007), Biofuels and the implications for agricultural water use: blue impacts of green energy, *Water Policy* 10 Supplement 1 (2008) 67.
- **De Fraiture C., Berndes G.**, (2009), Biofuels and water. R.W. Howarth & S. Bringezu (Editors), Chapter 8 In: *Biofuels: Environmental Consequences and Interactions with Changing Land Use*, pp. 139-153
- **Diaz-Chavez R. et al.**, (2011), Review: Water quality assessment of bioenergy production. *Biofuels, Bioproduction & Biorefining*. 5, pp. 445–463
- **DoE**, Department of Energy, (2006), Energy Demands On Water Resources, Report To Congress On The Interdependency Of Energy And Water, U.S. Department of Energy.
- **EcoLogic** (42009), Assessment of inter-linkages between bioenergy development and water availability, Report ENV.D.2/SER/2008/0003r

- **EEA** (2009), Water resources across Europe, confronting water scarcity and drought, Report No.2/2009, European Environment Agency, Copenhagen
- **EEA** (2006), How much bioenergy can Europe produce without harming the environment, Report No 7/2006, European Environment Agency, Copenhagen.
- **EEA** (2010), The European Environment–State and outlook 2010, European Environment Agency, Copenhagen.
- **EREC** (European Renewable Energy Council) (2007), Renewable Energy Scenarios to 2040, Brussels.
- **Feng K., et al.**, (2011) - Spatially Explicit Analysis of Water Footprints in the UK, Water 2011, 3, pp. 47-63.
- **Fingerman K., Kammen D.M., O'Hare M.**, (2008), Integrating Water Sustainability into the Low Carbon Fuel Standard, Renewable & Appropriate Energy Laboratory, University of California, Berkeley.
- **Fingerman K., et al.**, (2010). Accounting for the water impacts of ethanol production. Environmental Research Letters 5(1). 014020
- **Fingerman K., et al.**, (2011), Impact assessment at the bioenergy-water nexus, Biofuel, Bioproducts & Biorefining 5: 375-386
- **Fischer G. et al.**, (2007), Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080, Technological Forecasting and Social Change, 74 (7), pp. 1083-1107
- **Flörke M., Alcamo J.** (2004), European Outlook on Water Use, Center for Environmental Systems Research, University of Kassel, Final Report, EEA/RNC/03/007.
- **George B.**, (2011). Conceptual and analytical frameworks for evaluation and reporting of the bioenergy impacts – The challenge for applying LCA for water. Bioenergy-Water Workshop, IEA Bioenergy Tasks 43. <http://142.150.176.36/task43/library/workshops.html>
- **Gerbens-Leenes P.W., Hoekstra A.Y.**, (June 2010) - The water footprint of biofuel – based transport
- **Gerbens-Leenes P.W., et al.**, (2009) - The water footprint of bioenergy – PNAS Early Edition. DOI: 10.1073/pnas.0812619106.
- **Gerbens-Leenes P.W., et al.**, (2010) - The Water Footprint of Energy Scenarios - ISEE Conference, Oldenburg-Bremen
- **Gerbens-Leenes P.W., et al.**, ( 2009) - The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply -, Ecological Economics 68, pp.1052-1060
- **Global Water Partnership**, (2003) - Effective water governance. TEC Background Papers No.7
- **Global Water Partnership**, (2009) - Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses. TEC Background Papers No.14
- **Hardy L., Garrido, A. & Juana, L.** (2012) Evaluation of Spain's Water-Energy Nexus. International Journal of Water Resources Development. 28: 151-170.
- **Kumar H.J. et al.**, (2011), Water footprint: methodologies and a case study for assessing the impacts of water use, Journal of Cleaner Production 19, pp. 1288 – 1299.
- **Hoekstra A.Y., Hung P.Q.**, (2002), Water flows between nations in relation to international crop trade. Value of Water Research, Report Series No. 11, IHE-Delft, the Netherlands
- **Hoekstra A.Y., et al.**, (2009), Water Footprint Manual, State of the art ,Water Footprint Network.
- **Hoekstra A.Y., et al.**, (2011), Water Footprint Assessment Manual, Setting the Global Standard. – Printed by Earthscan.

- **Hoekstra A.Y.**, (2011), The Global Dimension of Water Governance: Why the River Basin Approach Is No Longer Sufficient and Why Cooperative Action at Global Level is Needed. *Water* No.3: 21-46.
- **Hoekstra A.Y.**, (2011), The water footprint of humanity. *PNAS Early Edition* [www.pnas.org/cgi/doi/10.1073/pnas.1109936109](http://www.pnas.org/cgi/doi/10.1073/pnas.1109936109)
- **Hoekstra A.Y. et al**, (2011). Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. *PLoS ONE*, Vol.7, Issue 2.
- **Hoff H.**, (2009), Global water resources and their management. *Current Opinion in Environmental Sustainability* 1, pp. 141–147.
- **Hoogeveen J., et al**, (2009). Increased biofuel production in the coming decade: to what extent will it affect global freshwater resources? *Irrigation and Drainage* 58, pp.148-160.
- **Holermann L., Neubert S.**, (2007), Virtual Water Trade, *Studies / Deutsches Institut für Entwicklungspolitik*; 25
- **Hong Y., et al.**, (2009), Land and water requirements of biofuel and implications for food supply and the environment in China, *Energy Policy* 37, pp.1876–1885.
- **IEA**, (2011), *World Energy Outlook*, International Energy Agency, Paris.
- **IEA**, (2012), *Bioenergy Tasks, Country Reports*, International Energy Agency, Paris.
- **ICC**, International Chamber of Commerce, (2009), *Commission on Environment and Energy, Discussion Paper on International Bioenergy Policy–*, Doc. 213/69.
- **IWMI**, (2008), Water implications of biofuel crops: understanding tradeoffs and identifying options. *Water Policy Brief*, Issue 30
- **Jewitt G., Kunz R.**, (2011), The impact of biofuel feedstock production on water resources: a developing country perspective. *Biofuels, Bioproducts and Biorefining* 5, pp.387–398
- **Kämäri J., et al.**, (2008), Envisioning the future of water in Europe, the SCENES (Water Scenarios for Europe and for Neighbouring States) Project, Official Publication of the European Water Association (EWA), ISSN 1994-8549
- **McGrath J., et al.**, (2011). Optimising water use and minimising drought risk in biomass production – An Australian experience. *Bioenergy-Water Workshop, IEA Bioenergy Tasks 43*. <http://142.150.176.36/task43/library/workshops.html>
- **McIsaac G.F., et al.**, (2010). Miscanthus and Switchgrass Production in Central Illinois: Impacts on Hydrology and Inorganic Nitrogen Leaching. *Journal of Environmental Quality* 39(5), pp 1790-1799.
- **Meijerink G., et al.**, (2007). *Biofuels and Water: an exploration*, Wageningen UR For quality of Life.
- **Mekonnen M.M. and A. Y. Hoekstra A.Y.**, (2011)- The green, blue and grey water footprint of crops and derived crop products, Twente Water Centre, University of Twente, The Netherlands, *Hydrol. Earth Syst. Sci.*, 15, pp. 1577–1600
- **Mila I Canals, L., et al.**, (2009), Assessing freshwater use impacts in LCA: Part 1- Inventory modelling and characterisation factors for the main impact pathways. *International Journal of Life Cycle Assessment* 14(1), pp. 28-42
- **Mubako, S., Lant, C.**, (2008). Water resource requirements of corn-based ethanol. *Water Resources Research* 44(7):W00A02
- **National Research Council**, (2008). *Water Implications of Biofuels Production in the United States*. Committee on Water Implications of Biofuels Production in the United States. Washington, D.C.: National Research Council.
- **Neary D.G.**, (2011). *Best Management Practices, A Tool for Responsible Management*. *Bioenergy-Water Workshop, IEA Bioenergy Tasks 43*, Sunshine Coast, Queensland, Australia. <http://142.150.176.36/task43/library/workshops.html>
- **OECD**, (2011), *Water Governance in OECD Countries: A Multi-level Approach*, OECD Studies on Water, OECD Publishing, Paris.

- **OECD**, (2012), Environmental Outlook to 2050: The Consequences of Inaction, OECD Publishing, Paris.
- **OECD**, (2012), "Water Quality and Agriculture: Meeting the Policy Challenge", OECD Studies on Water, Paris.
- **Oeko-Institut, IFEU , Copernicus Institute** (2010), Bioenergy Environmental Impact Analysis , Environment and Natural Resources Management Series 46, Darmstadt, Germany.
- **Ongley E.**, (1996). Control of Water Pollution from Agriculture. FAO Irrigation and Drainage Paper 55. GEMS/Water Collaborating Centre, Canada Centre for Inlands Waters Burlington, Canada. Rome: Food and Agriculture Organization of the United Nations.
- **Pate R., et al.**, (2007), Overview of energy-water interdependencies and the emerging energy demands on water resources, SAND 2007-1349C
- **Perry C., et al.**, (2009), Increasing productivity in the irrigated agriculture: Agronomic constrains and hydrological realities. Agricultural Water Management 96(11), pp. 1517-1524
- **Pfister S., et al.**, (2011), Environmental Impacts of water use in global crop production. Hotspots and trade off with land use. Environmental Science and Technology 45, pp.5761-5768
- **Pfister S., et al.**, (2009), Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science Technology 43, pp.4098-4104
- **Ridoutt B.G. et al.**, (2009), Water footprinting at the product brand level: case study and future challenges. Journal of Cleaner Production 17, pp. 1228–1235
- **Ridoutt B.G., Pfister S.**, (2010), A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Global Environmental Change 20(1), pp 113-120.
- **Rockstrom et al.** (2007), Assessing the water challenge of a new green revolution in developing countries - Assessing the water challenge of a new green revolution in developing countries. PNAS Vol.105, No.15, pp.6253-6260
- **Rockstrom, J., et al.**, (2009), Greening the global water system. Journal of Hydrology, 384, pp. 177-186
- **Rosegrant M. W., et al.**, (2002), Global Water Outlook 2025- Averting an Impending Crisis
- **Roth E., Horst F. H.** (2009), Working paper "Focus Topic Water", IFEU/Öko-Institut and UBA/Bio-global, Heidleberg, Germany.
- **Schinegger et al.**, (2011), Multiple human pressures and their spatial patterns in European running waters. Water and Environment Journal, CIWEM
- **Shah T., et al.**, (2007). Groundwater: A global assessment of scale and significance, Chapter 10: Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. IWMI
- **Shepard J.P.**, (2006), Water quality protection in bioenergy production: the US system of forestry Best Management Practices. Biomass and Bioenergy 30, pp. 378–384
- **Siebert S., et al.**,(2006), Irrigation in Africa, Europe and Latin America-Update of the Digital Global Map of Irrigation Areas to version 4, Frankfurt Hydrology Paper
- **Siebert S., et al.** (2010), Groundwater used for irrigation- a global inventory, Hydrol. Earth Syst. Sci., 14, pp. 1863–1880
- **Smeets E., et al.**, (2006), The sustainability of Brazilian bio-ethanol. Report NWS-E-2006-110. UNICAMP, University of Utrecht, the Netherlands.
- **Stockholm Environmental Institute**, (2011), Understanding the Nexus , Background paper for the Bonn 2011 Nexus Conference
- **Stone K.C., et al.**, (2010), The potential impacts of biomass feedstock production on water resource availability, Bioresource Technology 101, pp. 2014–2025

- **UBA**, Federal Environment Agency, (2010), Development of strategies and sustainability standards for the certification of biomass for international trade, Report 49, Germany.
- **UNEP**, United Nations Environment Programme, Water and Bioenergy, Issue Paper No.2
- **UNEP, Oeko Institut and IEA BioenergyTask 43**, (2011), The Bioenergy and Water Nexus, Nairobi.
- **UNEP** (2008), Global Environment Outlook 4: Chapter 4–Water. United Nations Environment Programme
- **UNESCO**, (2007), UNESCO Water Portal Weekly Update No. 177: Polar Regions, Paris.
- **UNESCO–IHE**, (2008), Water Footprint of Bioenergy and other primary energy carriers, Report 29, Paris.
- **UNESCO–IHE**, (2008), The Water Footprint of Bio-energy: global water use for bio-ethanol, biodiesel, heat and electricity, Value of Water Research Report Series No.34, Paris.
- **UNESCO** (2012), The United Nations World Water Development Report 4, WWDR, Paris.
- **UNESCO** (2011), Water Ethics and Water Resource Management. ECCAP (Ethics and Climate Change in Asia and the Pacific) Project, Paris.
- **Van Lienden A.R., et al.**, (2010), Biofuel Scenarios in a water perspective–The total blue and green water footprint of road transport in 2030–Report 43, UNESCO –IHE (Institute for Water Education), Paris.
- **Van Lienden A.R.**, (2009), Energy Scenarios in a water perspective. Master Thesis, University of Twente, Netherlands.
- **Varis O.** (2007), Water Demands of Bioenergy Production, International Journal of Water Resources Development 23(3), September 2007. pp. 519–535.
- **World Energy Council** (2010), Water for Energy.
- **Wriedt G., et al.**, (2008), Water requirements for irrigations in European Union. European Commission Joint Research Centre Scientific and Technical Reports, EC JRC, EUR 23453 EN.
- **Wu.M., et al.**,(2009), Water consumption in the production of ethanol and petroleum gasoline. Environmental Management 44(5), pp. 981-997
- **Xenopoulos M.A.,et al.**,(2005), Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biology No.11, pp. 1557–1564

## Abbreviations

AEZ	Agro Ecological Zone
BAU	Business as Usual Scenario
BIAS	Bioenergy Impact Assessment
BOD	Biological Oxygen Demand
BMPs	Best Management Practices
BRIICS	Brazil, Russia, India, Indonesia, China, South Africa
COD	Chemical Oxygen Demand
CDS	Conventional Development Scenario
EU	European Union
EEA	European Environment Agency
ET	Evaporation and Transpiration
EF	Ecological Footprint
EPIC	Environmental Policy Integrated Climate
FAO	Food and Agriculture Organization
GEO	Global Environment Outlook
GHG	Greenhouse Gases
GWP	Global Water Partnership
IEA	International Energy Agency
IWMI	International Water Management Institute

IPCC	Intergovernmental Panel on Climate Change
IIASA	International Institute for Applied System Analysis
IRWM	Integrated Water Resource Management
IP	Increased Productivity (livestock)
ISO	International Organization for Standardization
LMI	Land Marginality Index
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCA	Life Cycle Assessment
LC	Lethal Concentration
NWA	National Water Act
OECD	Organization for Economic Co-operation and Development
ORP	Oxygen Reduction Potential
RS	Ruminant meat Substitution
RED	Relevant for Environmental Deficiency
SFRA	Stream Flow Reduction Activity
SQI	Soil Quality Index
SCENES	Water Scenarios for Europe and for Neighbouring States Project
SIRIS	Système d'Intégration des Risques par Pesticides
SOER	State of the Environment Report
SETAC	Society of Environmental Toxicology and Chemistry
SWAT	Soil and Water Assessment Tool
SEI	Stockholm Environment Institute
TSS	Total Suspended Solids
TFI	Treatment Frequency Index
TEC	Technology, Economics and Private sector
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO IHE	Institute for Water Education



As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

