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IEA Bioenergy

THE BIOENERGY AND WATER NEXUS

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The present publication is an excerpt of the larger report 'The bioenergy and water nexus'. It highlights key findings from the report, and should be read in conjunction with the full report.

We encourage reader to refer to the full report, which is available as a downloadable pdf on www.unep.fr/energy/bioenergy.

ABOUT

IEA BIOENERGY TASK 43

IEA Bioenergy

IEA Bioenergy Task 43 – Biomass Feedstocks for Energy Markets – is part of the Implementing Agreement on Bioenergy, which forms part of a programme on international energy technology collaboration undertaken under the auspices of the International Energy Agency, IEA.

Task 43 seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This is achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstocks, including biomass markets and the socio-economic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, and USA.

OEKO-INSTITUT

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Oeko-Institut – the Institute for applied ecology - is a leading non-profit European research and consultancy organization working for a sustainable future. Founded in 1977, it develops principles and strategies for realizing the vision of sustainable development globally, nationally and locally. It employs a staff of more than 125 at its Freiburg, Darmstadt and Berlin offices. Oeko-Institut provides research and consultancy for decision-makers in politics, industry and civil society. Its key clients are ministries and federal agencies, industrial enterprises, the European Union and UN organizations. In addition, the institute is commissioned by non-governmental a and environmental associations.

UNITED NATIONS ENVIRONMENT PROGRAMME

UNEP

UNEP is the United Nations system's designated entity for addressing environmental issues at the global and regional level. UNEP's mission is to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations. In 2008, UNEP's new Medium Term Strategy was adopted along 6 strategic priorities: climate change, disasters and conflicts, ecosystem management, environmental governance, harmful substances and hazardous waste, and resource efficiency. In the first and the last two of these priority areas, UNEP's Division of Technology, Industry and Economics (DTIE) plays a leading role. DTIE helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development. To work towards Climate Change Mitigation, UNEP promotes policies that place energy and transport within the broader sustainable development context and steers project developers and the investment community towards greater engagement in renewable energy and energy efficiency. UNEP has an active programme on bioenergy, an issue that cuts across several of the priority areas. It provides scientific assessments on a variety of environmental issues related to bioenergy, tools helping decision-makers to promote sustainable bioenergy development, and ad hoc advisory services to governments.

PREFACE

Energy and water are key to development: they were prerequisites for the first industrial revolution and they will be key to a new kind of 21st century development path that echoes to the risks but also opportunities of modern times.

UNEP's report, "*Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*", estimates that investing 2% of global GDP into ten key sectors - amongst which energy and water are central – can catalyze this transition if supported by forward-looking national and international public policymaking.

Good public policy however requires good scientific and analytical evidence on the risks and the opportunities of different kinds of technologies and development choices.

This new report, building on the work of various new initiatives including UNEP's International Resource Panel, provides recommendations and outlines options in respect to bioenergy in support of a Green Economy transition.

The first point is that all forms of energy have, to a greater or lesser extent, an impact on water resources. Fossil fuel and nuclear power stations for example require a significant quantity of water for cooling.

Bioenergy's water demands are in large part linked with the growing and processing of feedstocks such as crops which in turn has important implications for sustainable agriculture, land use and food production.

Indeed land use has in large part been the key area of debate in respect to bioenergy with implications for not only food security but also biodiversity and the impact such energy may have on aggravating or cutting greenhouse has emissions.

Current and future planning in respect to bioenergy also needs to reflect increasing and competing needs for the same raw materials for uses such as food, fodder and fibre as the world population climbs to around nine billion over the next 40 years.

This may argue against bioenergy developments. But there are circumstances, outlined in this report, where well-planned deployments might actually improve agricultural practices including promoting improved water efficiency and more sustainable fertilizer use.

Meanwhile combining food and bioenergy production systems can deliver win wins in terms of energy and food security with benefits in terms of livelihoods, employment and greenhouse gas emissions.

On the Road to Rio and the UN Conference on Sustainable Development 2012, understanding the risks and harnessing the opportunities by seeing bioenergy as part of a far bigger sustainability picture will prove critical to governments seeking to achieve broad and multiple goals including sustainable energy for all, food security and access to clean water.

Achim Steiner,
UN Under-Secretary General and
Executive Director, UN Environment Programme (UNEP)

INTRODUCTION

THE BIOENERGY AND WATER NEXUS IS COMPLEX

BIOENERGY PRODUCTION[1] AND USE HAVE BOTH POSITIVE AND NEGATIVE ENVIRONMENTAL AND SOCIO-ECONOMIC CONSEQUENCES, INCLUDING THOSE PERTAINING TO WATER

WATER IS ALREADY A SCARCE RESOURCE IN MANY PARTS OF THE WORLD. THE EXPANSION AND INTENSIFICATION OF BIOENERGY PRODUCTION COULD ADD TO EXISTING PRESSURES. THEREFORE, WATER RESOURCES MANAGEMENT AND ADEQUATE POLICIES AND STRATEGIES ARE NEEDED TO HELP ENSURE SUSTAINABILITY AND BALANCE DIFFERENT TYPES OF USE IN THE SHORT AND LONGER TERM.

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[1] The term 'bioenergy production' is used here to capture the various ways of producing biomass and converting it to solid, liquid and gaseous fuels, and to electricity. However, it is recognized that this term is not doing justice to the first law of thermodynamics (energy can be neither created nor destroyed, but only change forms).

Bioenergy and water are inextricably linked. Water quantity and quality have been identified as emerging issues of concern in the bioenergy field. Water availability will undoubtedly affect the extent to which bioenergy can contribute to the overall energy mix.

Freshwater[2] shortages have already begun to constrain socio-economic development in some regions. Among other global trends, population growth and related increases in demand for agricultural and forestry products to provide food, fodder, fibre and fuel will put further pressures on water resources. In addition, the share of the population at risk of water stress is projected to expand greatly due to climate change (water stress index at the watershed level is presented in Figure 1.1). The most recent *Global Environment Outlook* (GEO4) estimates that by 2025 two-thirds of the global population will live in areas experiencing water stress, i.e. where periodic or limited water shortages can be expected[i].

Bioenergy production – in particular, the production of biofuels for transport – has expanded rapidly in recent years, driven by concerns about climate change, oil price volatility and dependency on imports for energy security, as well as options for rural development and income generation. Agriculture accounts for about 70% of global freshwater withdrawals from rivers, lakes and aquifers. Since bioenergy is largely dependent on biomass production, expected growth trends will lead to increasing competition and pressures on water resources. These pressures may be partially attenuated by advances in technology and the use of different feedstocks[ii].

This report primarily addresses the following questions:

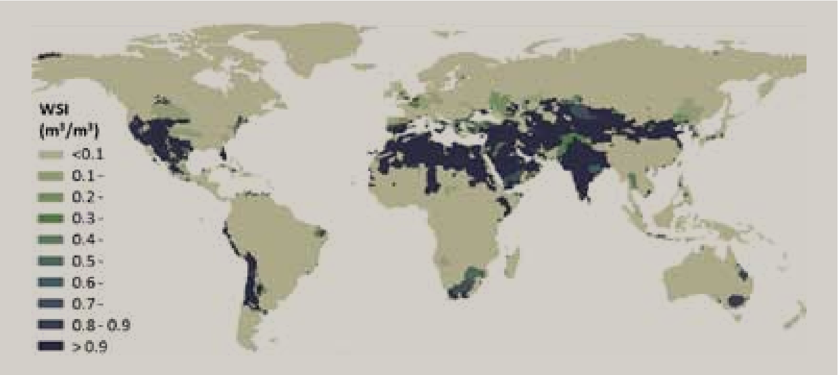
- HOW are the production and use of bioenergy products likely to influence the future state of water resources?
- HOW can society mitigate negative impacts and guide development towards sustainable use of these resources, including groundwater, rivers, and riparian and wetland systems?

In considering the ways bioenergy feedstock production and conversion can impact water resources, the report looks at ways to assess effects at different spatial and temporal scales. A number of indicators and assessment tools exist. They are being used to include the water perspective in analyses and assist strategy development and land use planning. Ideally, such indicators and assessment tools will help not only to reduce risks and avoid undesirable development, but also to identify opportunities and synergies. They should form the scientific basis for policy instruments.

Bioenergy is not the only part of the energy sector that has impacts on water resources. Energy and water are deeply inter-related, although different energy sources have different "water footprints" and other characteristics that need to be assessed.

Furthermore, the concerns raised in this report are not unique to bioenergy, but are examples of larger, systemic issues in agriculture, industry, land use and natural resource management. As a rapidly growing sector, however, bioenergy can serve as a high-profile leverage point to raise awareness of water-related issues and to stimulate the implementation of best management practices where this might not otherwise occur. Bioenergy also offers synergy options with other sectors, which need to be further explored.

Figure 1.1:
Characterization of water stress index at the watershed level per m^3 water consumed[iii]



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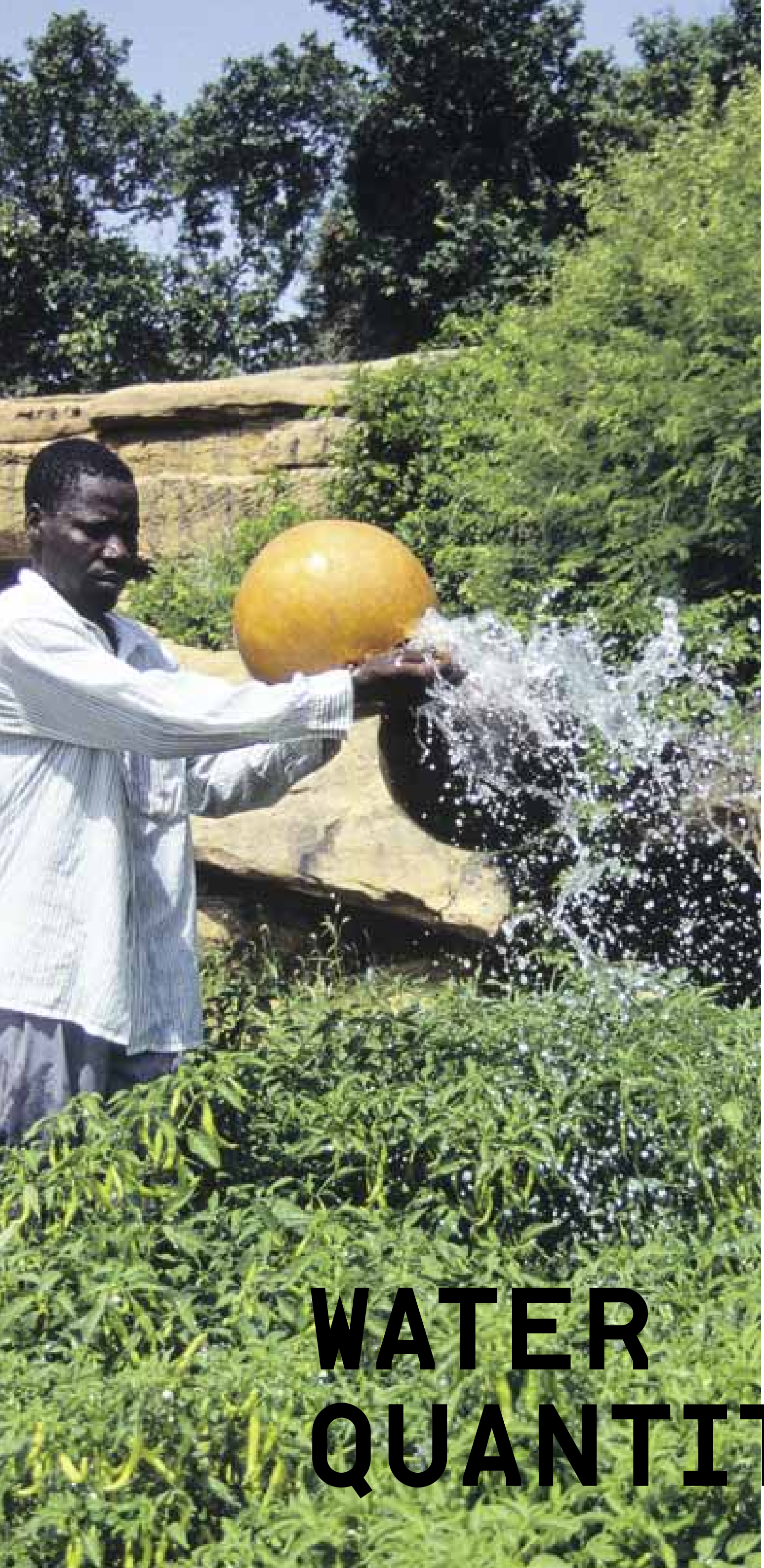
[2] Only freshwater resources are considered in the report. The term water resource(s) may refer to a watercourse, surface water, estuary or aquifer, including the physical or structural aquatic habitats (both instream and riparian), the water, the aquatic biota, and the physical, chemical and ecological processes that link habitats, water and biota.



WATER QUANTITY

WATER USE FOR BIOENERGY NEEDS TO BE EVALUATED AT DIFFERENT SCALES

DIFFERENT BIOENERGY PRODUCTS ARE NOT CREATED EQUAL, AND THIS IS ALSO TRUE FOR THEIR USE OF WATER. INVENTORYING THE WATER REQUIREMENTS OF A BIOENERGY PRODUCT CAN SERVE AS A BASIS FOR WATER RESOURCES MANAGEMENT AND PLANNING. INVENTORIES CAN BE CREATED USING WATER USE INDICATORS, WHICH ALLOW ESTIMATING THE VOLUMES PER TYPE OF WATER ABSTRACTED, CONSUMED AND ALTERED THROUGHOUT THE ENTIRE PRODUCTION CYCLE. THE RELEVANCE OF EACH INDICATOR IS DETERMINED BY LOCAL OR REGIONAL CONDITIONS, AND PLANNING NEEDS TO CONSIDER HISTORIC AS WELL AS ALTERNATIVE FUTURE LAND USE IN AN AREA.

Water use occurs throughout the bioenergy production cycle, including feedstock production and conversion. However, quantifying the impacts of bioenergy production on water resources is complicated because of the multitude of existing and rapidly evolving bioenergy sources (feedstock diversity); variability in site-specific conditions; and the complexities of physical, chemical and biological conversion processes. The different types of indicators that can be used to inventory water use vary in scope, system boundaries, definitions of water use, and the methods employed. When these indicators are used, for example as a basis for designing policy instruments, it is critical to understand the advantages and limitations of each with regard to determining the water demands of bioenergy production at various spatial scales and the associated effects on water flows, ecosystems and water quality.

Figure 2.1 provides an overview of indicators that will be described further below, as well as the types of effects analyzed.

BLUE, GREEN AND GREY WATER

Blue water refers to water in rivers, lakes, wetlands and aquifers that can be withdrawn for irrigation and other human uses; green water is soil moisture held in the unsaturated zone, which comes from precipitation and is available to plants[v]. Consistent with this definition, irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation)[3] while rainfed agriculture only receives green water[vi]. Blue and green water are commonly considered to be "consumed" when removed from the usable resource base for the remainder of one hydrologic cycle. Consequently, evapotranspiration (ET) is considered to be a form of water consumption since the water is functionally lost to the system.

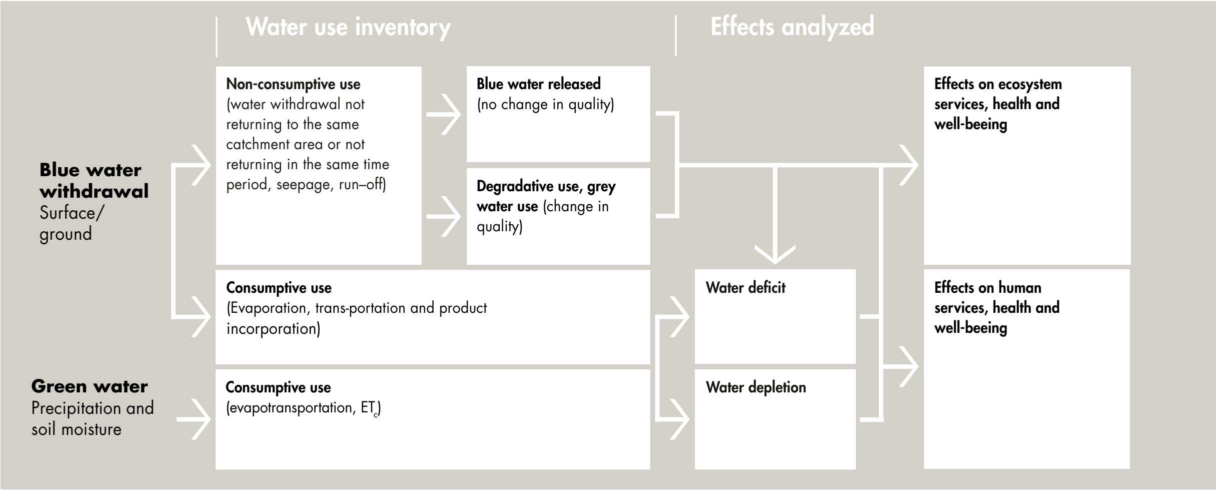
Grey water may refer to water that becomes contaminated during the production process. A "grey water footprint" is thus considered to be the volume of freshwater required for the dilution of total pollutant load to meet a defined ambient water quality standard[vii].

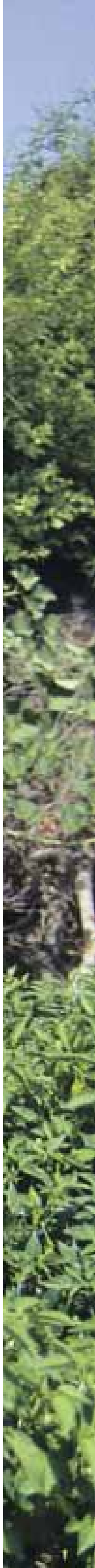
INVENTORIES OF WATER USE

The water requirements of bioenergy production are described in the literature using volumetric assessments of the water needed to produce biomass and convert it to solid/liquid/gaseous fuels subsequently used in transport, heating and electricity generation. Volumes of water abstracted, consumed and altered are estimated in order to create an inventory of the water requirements of a bioenergy product (i.e. a biofuel or bioelectricity).

Inventories express water requirements in terms of the amount of water used per unit of bioenergy produced (referred to as "water intensity"). The amount of bioenergy produced per unit of water use may be referred to as "water productivity"

Figure 2.1:
Types of water use characterized in water LCA studies and the effects analyzed, as measured by various indicators[iv].





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[3] In some definitions, green water also includes the part of irrigation water that becomes available for plant uptake.

or “water efficiency”, as in this report. Such inventories are a useful tool for water resources management and planning at the local and regional levels. However, comparing intensity or productivity estimates that refer to very different biophysical contexts provides only limited information about the relative attractiveness of different bioenergy options from the perspective of water use.

WATER USE CAN BE BENEFICIAL OR NON-BENEFICIAL

Reducing the impacts of water use in bioenergy production can be achieved through (i) reducing non-beneficial consumptive water use throughout the supply chain; and/or (ii) improving the management and planning of beneficial consumptive and non-consumptive water use, including improving productivity across a range of agricultural management regimes, from rainfed to irrigated crops.

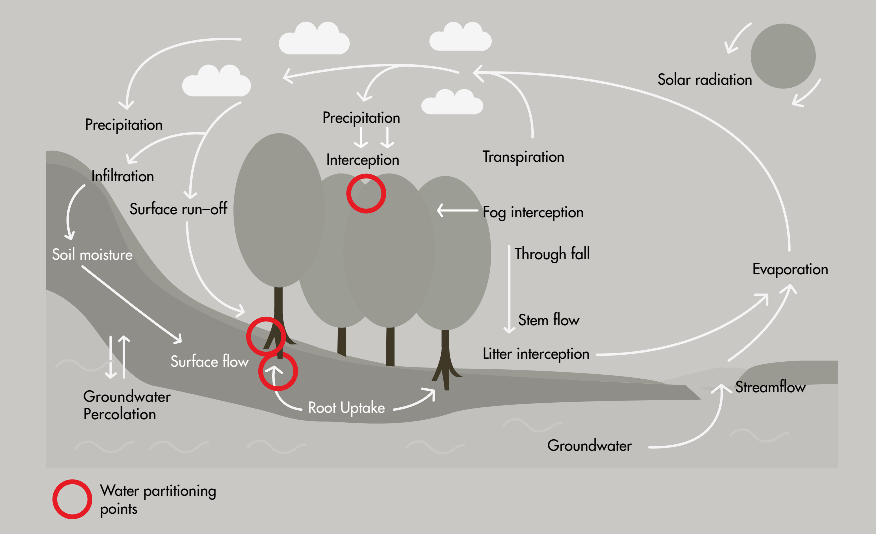
If non-productive evaporation is reduced in favour of plant transpiration, the total biomass harvest may be increased without necessarily increasing pressure on downstream freshwater resources. This can be achieved through changes in soil and water management (including the use of rainwater harvesting), as well as the introduction of suitable bioenergy crops that allow more efficient water use. For instance, drought-tolerant plants with relatively high water productivity can be grown in areas that are unsuitable for conventional food and feed crops. Plants cultivated in rotation with conventional crops can also make better use of rain falling outside the growing season of those crops. Figure 2.2 shows key water partitioning points in the hydrological cycle affected by biofuel feedstock production

THE SPATIAL SCALE MATTERS

The spatial scale of many of these types of analyses is usually at the sub-national (e.g. state/province) or national level, depending on data availability. National or sub-national average data are typically aggregated over wide variations in water requirements (e.g. due to variations in climate and weather conditions) and sources of water use (e.g. due to differences in regional water availability as well as sources). Detailed spatial modelling at the watershed level, where bioenergy feedstock production interacts with hydrological processes, will allow more precise assessment of impacts[viii].

Figure 2.3 shows variations in the blue water footprint of selected energy crops in different regions. These variations point to the need for careful matching of energy crops and production and conversion systems with available water supplies. The rapidly growing global trade in solid and liquid biofuels has created a “virtual water exchange”, with producing countries “exporting” water in the form of biofuels. In the same way as for food and forest products, this type of trade introduces possibilities for spatial decoupling of biofuel production and consumption. It also presents opportunities to make use of resource endowments (e.g. through ethanol

Figure 2.2
Key water partitioning points in the hydrological cycle affected by biofuel feedstock production[xxix]



from Brazil, produced from sugarcane in rainfed agricultural conditions, and biofuel pellets from Canada).

WATER USE INDICATORS

Water use and the associated impacts on water flows and ecosystems are measured by various indicators, depending on the water source, whether removal from the water cycle is via evaporation or transpiration, and the qualitative alteration (degradation). Table 2.1 lists some commonly used water inventory indicators.

BLUE WATER USE INDICATORS: CONSUMPTION AND WITHDRAWAL

Blue water use indicators, integrated over time and space, provide the most direct measurements of the impacts of bioenergy production on freshwater allocation among various end users, and on ecosystems and human health and well-being.

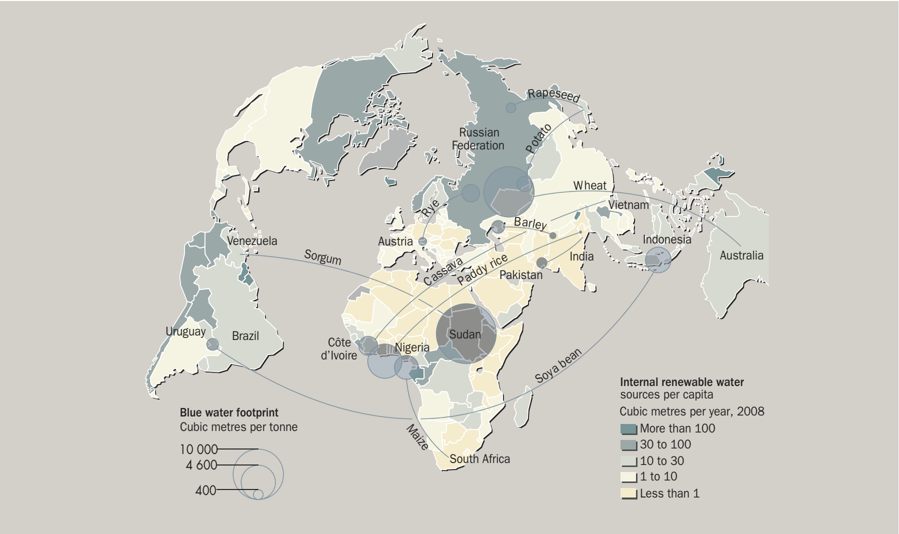
Volumetric estimations and impact assessments of blue water consumption have received detailed treatment in the literature on freshwater life cycle assessment (LCA),[4] including studies dealing with the bioenergy-water nexus. Consumptive blue water use equals water withdrawal minus the portion of withdrawn water that returns to water bodies, where it is available for possible further use. Many estimates of consumptive blue water use quantify the consumptive water requirements of thermoelectric systems, and other agricultural products[ix].

Water withdrawal includes all (blue) water abstracted from a surface water body or aquifer for industrial, agricultural or domestic use. Non-withdrawal water use, by contrast, includes in-stream use for purposes such as hydroelectric power generation, transport, fish propagation and recreation. Thus, non-withdrawal use is not directly relevant to agricultural use of water. Water withdrawn for agricultural use is either used consumptively and removed from the current hydrological cycle through evaporation, transpiration or product incorporation, or released back to the environment (although possibly to a different water body or at a different time) through recycling to water bodies, seepage and run-off.

Most recent studies concerned with estimating the water requirements of biofuel production focus on consumptive water use and do not estimate withdrawal requirements[x].

The difference between withdrawal and consumption is related to the spatial boundary selected for analysis. Excess water run-off from a farm due to irrigation system inefficiencies can be used beneficially on a downstream farm, or it can contribute to meeting environmental flow requirements in nearby rivers. Seepage losses from unlined irrigation canals may recharge groundwater or have other environmental benefits. This concept is summarized by Perry et al. (2009)[xi], who state that "…'losses' at the scale of an individual field or an irrigation project are not necessarily 'losses' in the hydrological sense…". This has implications for how water intensity estimates are scaled up to total water requirements for the

Figure 2.3:
Variations in the blue water footprint of selected energy crops[xii]



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[4] Life cycle assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.

Table 2.1: Selected commonly used water inventory indicators

Indicator	Description (individual studies may use slightly different descriptions)	Selected relevant literature on water use for biofuels
Water use indicators		
Water withdrawal (off-stream use)	Water removed from the ground or diverted from a surface water source for use	King and Webber (2008b), Dominguez-Faus et al. (2009)
Consumptive water use	Includes water use through evaporation, transpiration and product incorporation. When water use over a product's life cycle is assessed, evaporative losses during post-harvest processing may be included (see "“Life cycle water use” below). Consumptive water use may also include water withdrawals not returning to the same catchment area, or not returning in the same time period.	Includes consumptive use of blue and green water. King and Webber (2008b), Chiu et al. (2009), Pfister et al. (2009a), Berndes (2002). Referred to as blue and green water “footprint” by Gerbens-Leenes et al. (2008)
Degradative water use	Withdrawal and discharge into the same watershed after water quality has been (significantly) degraded.	Pfister et al. (2009a)
Grey water use	Volume of freshwater required to assimilate the load of pollutants, based on existing ambient water quality standards.	Gerbens-Leenes et al. (2008)
Life cycle water use	Water consumed/withdrawn throughout the life cycle of biomass-based fuels (including their end use). Life cycle water use may consider water use credits for co-product.	Chapagain and Orr (2009), Mishra and Yeh (2010), Ridoutt and Pfister (2010a)
Effects on water flow balances		
Crop water balance	Evaluates the water balance of cultivated soils. Indicators are expressed in flux per unit of surface area, in millimetres (mm)/period, or in cubic metres per hectare (m^3/ha) per period.	
Hydrologic balance	Expresses various elements of the water balance of land or water basin (m^3/year). Indicators include hydric deficit, annual/dry-period withdrawal and annual/winter drainage.	Bonnet and Lorne (2009)

production of biofuels at a regional or national level. However, it is useful to estimate withdrawal intensity along with consumption intensity[xiii]. Excess irrigation water helps to leach salts in soils, but can lead to higher pumping costs for farmers and water districts. Significant water withdrawals from surface water bodies may have localized and/or seasonal impacts on ecosystems, as observed in the case of thermoelectric plants with once-through cooling systems. In regions that depend on groundwater for irrigation, extraction beyond recharge rates leads to aquifer depletion[xiv].

GREEN WATER CONSUMPTION: CROP EVAPOTRANSPIRATION

Indicators of total water demand for crop evapotranspiration (ET_c) – green water consumption – communicate vital information about how land and water productivity supports/constrains bioenergy expansion. They also help to identify areas where agricultural productivity could potentially be increased through improved soil and water conservation, changes in crop choice, and better crop management.

According to Hoekstra et al. (2009)[xv], the estimation and explicit reporting of green water requirements in water use inventories acknowledge competing demands for limited freshwater resources. Water returned to the atmosphere through green water consumption could otherwise have replenished groundwater levels or contributed to river flows required for the maintenance of healthy aquatic ecosystems. Furthermore, inclusion of green water provides a complete picture of water resource dynamics and is important for water resources management. Berndes (2008)[xvi] and Gerbens-Leenes et al. (2009)[xvii] argue that estimating green water use allows a consistent comparison of water use across different biofuel crops. Accounting for green water may also help to better assess the impacts of agricultural production on water resources in sub-humid and semi-arid regions, and to facilitate the development of strategies to tap the productivity of both blue and green water[xviii].

LIFE CYCLE WATER USE INDICATORS

Life cycle water use indicators provide useful comparisons of the water required for production and conversion of feedstock to various forms of energy, and of opportunities to improve water use efficiency throughout the supply chain. In addition, these indicators may be used to account for water use avoided as a result of displacement of products requiring water for their supply (e.g. an animal feed crop) by co-products of biofuel production, although these applications must be interpreted with care.

Many new water life cycle bioenergy studies combine all types of water use and explicitly state the sources of water inputs throughout the life cycle. These studies generally consider blue and green water use[xix], as well as degradative water use[xx] and grey water use[xxi]. Some studies also account for application losses[xxii] and conveyance losses[xxiii].

Water lost to ET_c during bioenergy feedstock production is not immediately available for food production or to meet environmental needs (until it returns as precipitation). However, such biomass production may generate co-products that displace other products requiring water for their supply (e.g. an animal feed crop). Conversely, use of residue flows in agriculture and forestry for bioenergy production does not lead to additional ET, although it may have an impact on water resources and the environment in other ways. For instance, excess residue removal may result in increased erosion and reduced water retention capacity. Or the residue may already be used for other economic activities.

ASSESSING/EVALUATING WATER USE INDICATORS AND INVENTORIES

In water resources management and planning, local or regional conditions need to be considered. In combination with the objectives of the analysis, they determine which water indicators are most relevant and the relative importance of water use impacts compared to other impacts such as those on soil quality and biodiversity.

Accounting for blue water withdrawal and consumption, and green water consumption, across product life cycles enables better understanding of total water demand within certain time frames and spatial boundaries. These assessments also enable measurements of the efficiency of agricultural and bioenergy production systems, and the identification of potential management strategies or feedstock varieties that could optimize water use at the plant, farm, regional and global scale.

CAREFUL TRANSLATION IS NEEDED FROM THE INVENTORY ASSESSMENT TO IMPACT EVALUATIONS

Water inventory evaluations often employ, by necessity, spatial and temporal aggregations that include more than one form of (blue, green and grey) water consumption in locations where the relative importance of water-related aspects differs. Thus, they often do not clearly indicate potential social and/or environmental harm or trade-offs[xxiv]. Similarly, temporal aggregations over an annual period ignore the inter-seasonal variability of water use and water scarcity (which is often substantial in certain regions). Therefore, they may not convey important information about seasonal water use competition or excess. This limitation should be clearly spelled out.

Recent literature on freshwater LCA has developed regionally differentiated characterization factors that measure water scarcity at water basin level or even higher resolution[xxv] and also account for temporal variability in water availability[xxvi]. Volumetric estimates of blue and green water can be converted to characterization factors, providing a "stress-weighted" or "ecosystem-equivalent" water use estimate that can be compared across regions. Work is ongoing to use explicit water inventory results to undertake impact analysis and accurately assess the effects of biofuel production on water resources (Chapter Impact Assessment).

In addition, water use indicators should be combined with land use indicators and a treatment of baseline versus counterfactual scenarios to provide a more accurate assessment of changes in water resource allocation and impacts in a specific region[xxvii]. At the local/regional level, the critical question to address is how shifting to a bioenergy system influences the character and intensity of water use. Here, too, the relative importance of water aspects compared to others (e.g. impacts on soil quality or on biodiversity) needs to be considered. It is important to compare bioenergy options with possible alternative land use options. Since bioenergy options can have both positive and negative effects, these effects need to be weighed and compared with the effects of an alternative land use. Crops with the same or higher water productivity may have beneficial effects if the annual ET is redistributed over seasons with few water shortage problems, resulting in a reduction of irrigation volume, or they may have adverse impacts on soil moisture and seasonable water flow[xxviii]. Non-productive evaporation can be shifted to productive transpiration through careful selection of biofuel crops and cultivation systems, leading to a further increase in consumptive use of green water without exacerbating run-off and groundwater recharge problems.

IMPACT ASSESSMENTS

IMPACT ASSESSMENTS ARE THE BASIS FOR DECISION-MAKING

GIVEN THE COMPLEXITY OF THE INTERLINKAGES BETWEEN BIOENERGY AND WATER, AN ASSESSMENT FRAMEWORK IS CRITICAL IF OPERATORS AND POLICYMAKERS ARE TO BE ABLE TO EVALUATE THE POSITIVE AND NEGATIVE EFFECTS OF BIOENERGY DEVELOPMENT ON WATER RESOURCES.

THE ASSESSMENT FRAMEWORK NEEDS TO TAKE INTO ACCOUNT THE WATER INTENSITY OF PROPOSED ACTIVITIES, THE STATE OF WATER RESOURCES, AND IMPACTS AT A SPECIFIC LOCATION.

Bioenergy production and its expansion can have significant implications for the state of water resources in the region where it occurs. A variety of impacts can result from the consumption or degradation of freshwater resources, including diminished ecosystem functioning due to reduced natural flows and impacts on human health and well-being due to poor water quality, insufficient quantity or lack of access[xxx]. However, the use of new, drought-resistant plants may help with the adaptation to water constraints, and – if their use is integrated wisely with food, feed, and fibre production contribute to improved overall resource management.

In the past, increasing water supply through the development of new water infrastructure has been a common strategy in water resources management. However, in view of increasing water scarcity it is becoming critical to manage water demand. The challenge for demand management is to achieve physical and economic savings by increasing output per unit of evatransporative water loss, as well as to reduce water pollution and non-beneficial water uses.

Business, policy and resource management decisions related to bioenergy need to take this important consideration into account. Impact assessment, using the tools described below, can be an important first step towards optimizing the opportunities provided by bioenergy production while minimizing any detrimental effects on water resources.

A FRAMEWORK IS NEEDED FOR ASSESSING THE SUSTAINABILITY OF WATER USE IN BIOENERGY PRODUCTION

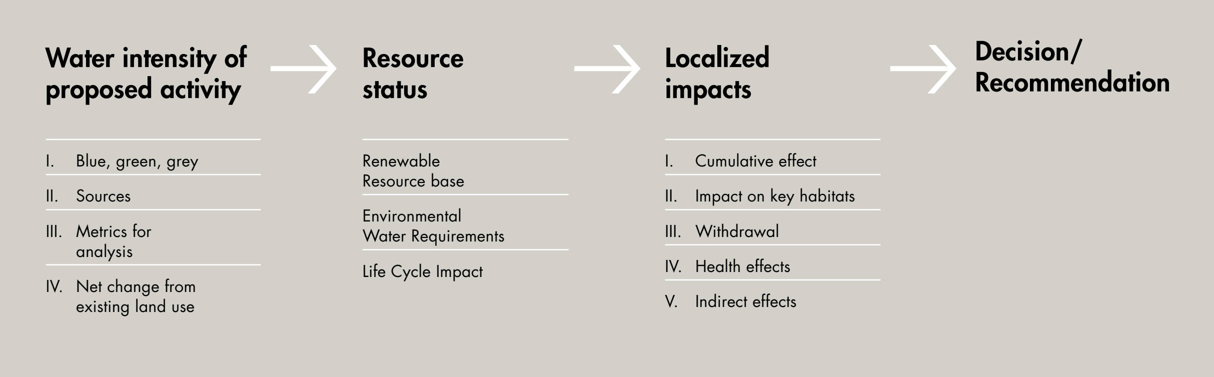
Bioenergy systems need to be analyzed from a comprehensive socio-ecological perspective, considering ecological functions in agricultural and natural landscapes as well as broader livelihood and development implications. Regardless of whether bioenergy demand drives land use change, understanding the outcomes of different land and water management systems (and the options available to sustain critical ecological functions where land use change occurs) is crucial for sustainable land and water use.

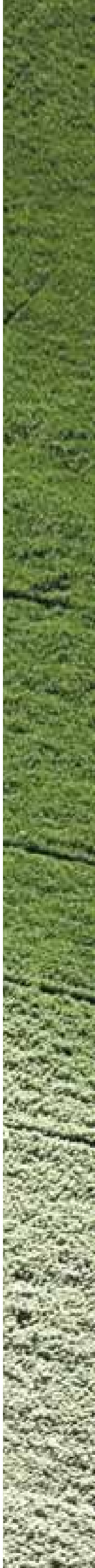
An assessment framework can help operators and policymakers assess the sustainability of proposed bioenergy activities. Such a framework addresses the question of what needs to be assessed in order to determine whether a proposed bioenergy activity would have positive, negative or neutral impacts on the state of water resources in a given area (Figure 3.1).

MEASURING WATER INTENSITY OF PROPOSED ACTIVITIES IS ESSENTIAL, BUT NOT SUFFICIENT

Water is consumed at multiple points along the bioenergy supply chain. Among the different bioenergy supply chains, and across the spectrum of feedstocks and conversion technologies, there is considerable heterogeneity in terms of total water demand.

Figure 3.1:
Assessment framework: key elements for ascertaining the impacts of bioenergy production on water resources.





Water resource impacts can defy easy quantification. Water consumption varies spatially and temporally. Different water sources are not necessarily commensurable, and impacts depend on the state of the resource base that is drawn upon:

- A given activity can require vastly different amounts of water at different locations, and at different times, due to climatic differences and other factors.
- Different water sources are not easily comparable. The use of freshwater withdrawals from surface flows will have different impacts than the use of pumped groundwater, rainfall or brackish water.
- Even where the same resource type (e.g. river flow) is used or polluted, the impacts of an activity can vary widely depending on the context of that use or pollution, where and when it occurs, and the current status of the affected resource base.
- Even when efforts are made to include the various types of water use and sources described above, and at the necessary spatial resolution, results can be misleading. Analyses are generally built around a single "functional unit" in terms of which impacts are measured. The choice of this functional unit can greatly affect the perceived patterns of impact.

Location-specific information about the use of and impacts on water resources is essential to inform responsible decision-making in relation to specific bioenergy projects, or more comprehensive agricultural development plans. This information is not provided by water footprint (WF) studies as conventionally applied,[5] or by water LCA studies, which tend to focus analytical rigour only on the inventory phase of the analysis. These tools measure the amount of water used in the production of various goods, but lack proper characterization of relative water scarcity and the opportunity cost of water use to conduct meaningful life cycle impact assessment (LCIA). As stated by Berger and Finkbeiner (2010)[xxxi], where water intensities are calculated based purely on consumption inventory, they "can be meaningless or even misleading with regard to impact assessment."

In order to describe impacts, a life cycle inventory (LCI) should be comprehensive, accounting for both blue and green water use as well as pollution impacts, different sources, and the spatial heterogeneity of usage. Furthermore, where possible, an LCI should quantify the net impacts of activities, accounting for consumption associated with any prior or displaced land uses rather than only quantifying consumption in absolute terms.

CHARACTERIZING THE LOCAL WATER RESOURCE BASE

Nuanced and disaggregated LCI (taking into account the considerations described above) is an essential component of impact assessment, but does not in itself sufficiently characterize impacts. Unlike greenhouse gases, for example, which have a functionally uniform impact wherever and whenever they are emitted, water consumption has implications that vary depending on its context. While there is no universally suitable quantitative tool for characterizing the impacts of water consumption, the most credible approach is to use tools that quantify consumption in the context of any existing stress on the resource base in question. Tools applied for this purpose should account for the fact that environmental flows need to remain sufficient to maintain a stable ecosystem.

In LCIA, characterization (or weighting) factors are derived with which these different consumption values can be summed and compared across resource bases and locations. LCIA relates the LCI data to "the potential human health and environmental impacts of the environmental resources and releases identified during the LCI"[xxxii]. In the case of water, it is impossible to understand these impacts without assessing the current state of the resource base where the expected change would occur.

This nuanced and comprehensive analysis can require detailed data that may not always be widely available. However, most existing research in this area has been conducted on a large scale and with an eye towards general application. Where considering (or advising on) specific activities, the scale will generally be smaller and human and financial resources may be available for gathering detailed information *in situ*.

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[5] Current water footprint best practice, as laid out in the Water Footprint Manual: State of the Art 2009 (Hoekstra et al., 2009), includes a process of "water footprint assessment". However, such a complete analysis has yet to emerge in the WF literature for biofuels. Use of the term "water footprint" is confounded by the fact that different researchers apply the term in different ways. Some use the term to signify any life cycle water impact. For the purposes of this chapter, however, we will refer to these analyses simply as "water LCA" and will confine our use of the term "water footprint" to the analytical approach pioneered by Arjen Hoekstra and colleagues (Hoekstra et al, 2007), which is most comparable to the life cycle inventory phase of water LCA.

EVALUATING OTHER LOCALIZED IMPACTS IS IMPORTANT

LCIA and/or weighted water footprint values can be important tools for identifying regions of concern with respect to blue, green and grey water impacts. Some local nuance can be lost through this aggregation of detailed information, even when carried out in the thorough and spatially discrete manner described in this chapter. For this reason, localized concerns including cumulative effects, impacts on key habitats, indirect effects, social realities, and resilience to scarcity should be investigated carefully when evaluating a policy or an investment related to bioenergy expansion, as a complement to this type of quantitative analysis:

- While individual projects may have water impacts well below established thresholds, the cumulative effects may become problematic in regions undergoing rapid change or expansion of energy infrastructure.
- Localized effects may be deceptive. In the case of many biofuels, water consumption for biomass conversion represents less than 1% of the total water footprint[xxxiii]. Because refining takes place in a concentrated area, however, it may have greater local effects than more spatially diffuse – and possibly quite distant – feedstock production.
- A variety of non-consumptive uses, such as once-through cooling, exist in the bioenergy supply chain but may not be captured by LCA tools. These withdrawals can be important locally, causing ecosystem disruption, heat pollution and other impacts.
- Impacts on key areas such as aquifer recharge zones, wetlands and flood plains can have considerable impacts throughout a watershed. These local impacts may be missed in watershed-scale evaluations[xxxiv].
- Acute but localized ecotoxicological, eutrophication or human health effects may result from even small pollution flows.
- Indirect land use change has recently been recognized as a critical concern with regard to the impact of bioenergy’s life cycle GHG emissions[xxxv]. Similarly, the perturbation of global commodity markets could affect the use of water resources where bioenergy feedstock production takes place far from the site of the activity in question. This effect has yet to be studied in any depth.
- Shortage of water for human uses does not necessarily derive from absolute scarcity, but can be due to social realities such as equity of access, barriers to entry, poor infrastructure, institutional failure, and other considerations that may or may not be affected by bioenergy expansion.
- Water scarcity does not have the same effects at all locations. Societies and affected populations vary in their ability to adapt to scarcity through altered lifestyles, the development of new resources, and imports of “virtual water”.

It is important to address the challenge of evaluating bioenergy’s impacts on water resources based on a holistic approach that considers the pressures on water from all competing uses. There is considerable scope in many regions of the world to improve water productivity, reduce the amount of water needed for crop production and leave more water for other uses, including environmental flows. The integration of bioenergy production with food and forestry production presents interesting opportunities in this regard. The tools described in this chapter can help identify opportunities to improve water use efficiency and resource management, based on the development of bioenergy feedstock supply systems as a new element in the landscape.

In many cases, along with working to mitigate their own impacts, large water users should engage with others in watershed-level restoration and governance activities. Integrated water basin planning, involving a broad range of stakeholders, will be key to capturing opportunities and avoiding or mitigating detrimental effects on water resources.

WATER QUALITY

WATER QUALITY CONCERNS NEED TO BE ADDRESSED: POINT SOURCE AND CUMULATIVE EFFECTS

BIOENERGY SYSTEMS CAN INFLUENCE THE QUALITY OF WATER NEARBY AND OVER LONG DISTANCES, WITH RESULTING CONSEQUENCES FOR BIODIVERSITY AND HUMAN NEEDS. IMPACTS ON WATER QUALITY NEED TO BE CONSIDERED AT THE PROJECT LEVEL (POINT SOURCE) AND WATERSHED LEVEL (NON-POINT SOURCE OR CUMULATIVE EFFECTS). THERE ARE WAYS TO AVOID OR MITIGATE NEGATIVE IMPACTS, AND IN SOME CIRCUMSTANCES BIOENERGY DEVELOPMENT MAY HELP IMPROVE THE WATER SITUATION.

Water quality is determined by the water's biological, chemical and physical characteristics. The standards used can be related to ecological or to human needs. Biomass production and its conversion to fuels and electricity can affect water quality in rivers, lakes and aquifers. Negative impacts on water quality can drastically affect aquatic ecosystems, and consequently biodiversity and human health. Depending on how a bioenergy system is located and managed, it can lead to water quality deterioration or to improvements. Land use history where bioenergy feedstock is produced – and the continuous surrounding land use – are important determinants of the outcome with regard to water quality. According to Perry and Vanderklein (1996)[xxxvi], water quality needs to be valuated in an integrated manner that considers the wider picture, including hydrology, chemistry, biology, geology, land use, demographics, public attitude and policy.

SOURCES OF WATER POLLUTION IN BIOENERGY FEEDSTOCK PRODUCTION (NON-POINT SOURCE POLLUTION)

Bioenergy-related water quality impacts can occur throughout the entire production chain. From a water quality perspective, the biomass production phase represents a source of diffuse and distributed pollution. It is therefore considered a non-point source of pollution.

Direct impacts on water quality arise through run-off from intensive agricultural production employing fertilizers and different types of pesticides (herbicides, insecticides and fungicides), together with other agricultural practices such as tillage and ploughing of unsuitable soils, irrigation, and contamination through improper manure spreading.

Tillage and ploughing of unsuitable soils can lead to sediment run-off to water bodies causing physical impacts (e.g. water turbidity and siltation of river beds) and chemical ones (e.g. through organic chemicals – like phosphorus and pesticides - absorbed to the sediment particles) and consequently loss of habitats or spawning grounds[xxxvii] . Irrigation has impacts through the run-off of salts, leading to salinization of surface waters, run-off of fertilizers and pesticides to surface waters (causing ecological damage), and bioaccumulation in edible fish species, among other impacts[xxxviii].

In addition to impacts associated with cultivation, other practices related to biomass production for energy (e.g. harvest residue extraction and growing of trees without undergrowth) can have negative impacts, including soil erosion (resulting in sediment run-off and hence sedimentation of water bodies) and reduced ability of precipitation to penetrate soil and replenish groundwater supplies.

The life cycle of energy production from wood produces environmental burdens and impacts on the hydrologic system at various stages[xxxix] . Most concerns have been focused on forest operations, including road networks, site preparation, fertilization and herbicide use, harvesting, ash recycling and regenerated site preparation [xl]. These operations are transitory, but generally well-dispersed throughout watersheds. They can affect the hydrological process and pollute water directly or indirectly through the use of fertilizers and pesticides, among others.

WATER QUALITY IMPACTS DURING THE CONVERSION PHASE (IN GENERAL POINT SOURCE POLLUTION)

Impacts on water quality during the conversion phase are mainly associated with discharges from conversion plants and may be due to chemical, biological and thermal pollution of aquatic systems. Other impacts include uncontrolled discharges of industrial effluents and improper use of wastewater in agriculture. In contrast to the biomass production phase, the conversion phase can be considered a point source of pollution. Where effluents from the conversion process (e.g. vinasse) are applied as fertilizer, this constitutes non-point source pollution.

KEY INDICATORS TO MEASURE BIOENERGY-RELATED WATER QUALITY IMPACTS

Indicators to measure water quality refer to the chemical, physical and biological characteristics of the water and to its final purpose. Water quality indicators vary depending on the goal or applied regulation/standard. They can be classified as those concerning drinking water quality, bathing water quality, water pollution levels, and, depending on other uses, agricultural and industrial uses. In the case of agricultural and forestry systems, indicators tend to be related to the use of agro-chemicals that may pollute surface and groundwater.

The main water pollution indicators have been used extensively for a number of years. In effect in many countries, these indicators are enforced using reference maximum permissible levels of pollutants or physical characteristics. They include:

- BOD (biochemical oxygen demand) to determine the level of oxygen-consuming organic material;

- TSS (total suspended solids) to measure the total amount of suspended matter (primarily inorganic substances from sugarcane and sugarbeet washing water);
- pH, as extreme changes in the pH level are harmful to water fauna;
- other indicators, including conductivity and oxygen reduction potential (ORP).

Standards and regulations vary among regions and countries. For example, in the European Union their use is determined by different directives and rules including the EU Water Directive. In the United States, the National Research Council[xli] has proposed a metric to compare the water quality impacts of various crops by measuring inputs of fertilizers and pesticides per unit of the net energy gain captured in a biofuel. Smeets et al. (2006)[xlii], reporting on the sustainability of biofuel production in Brazil, stated that the emission standards used to monitor water pollution in that country are different from international ones in most cases, as some have been implemented especially for Brazil. This is the case for BOD and pH standards. The parameters of the United States Environmental Protection Agency (US EPA) standards for pH differ from those of Brazil and the World Bank.

WAYS TO MITIGATE WATER POLLUTION

Mitigation measures for water pollution can be incorporated at different stages of the supply chain, from the production of bioenergy feedstock to its conversion. Integrated production schemes hold promise for mitigating and even avoiding some impacts. Furthermore, water resources management may result in better practices throughout the production chain, leading to reduced water pollution.

MITIGATION MEASURES IN FEEDSTOCK PRODUCTION

Measures to mitigate water pollution caused by bioenergy feedstock production include reducing the levels of fertilizers and pesticides applied – which may come into conflict with the aim of intensifying cultivation to improve land use efficiency.

However, there is significant potential to increase the currently low productivity of rain-fed agriculture in large parts of the world, especially in developing countries, through improved soil and water conservation, efficient fertilizer use and crop selection (including drought-adapted crops), and use of best practices involving mulching, low tillage, contour ploughing, field boundaries, terraces, rainwater harvesting, and supplementary irrigation, crop rotation, and (where this is desirable) a reduction of the time that land lies fallow.

Conservation agriculture and mixed production systems (double cropping, crops with livestock, and/or agroforestry) have the potential to sustainably increase land and water productivity as well as carbon sequestration, and to improve food security. Integrated approaches can also be based on combining biofuel feedstock production with conversion, for instance by producing animal feed that can replace cultivated fodder such as soy and corn[xliii] and reduce the grazing requirement. Multifunctional systems that provide multiple ecosystem services represent alternative options for bioenergy production on agricultural land, which could contribute to the development of farming systems and landscape structures that are beneficial for soil and water use as well as for biodiversity conservation.

Shifts from conventional food/feed crops to increased production of perennial herbaceous plants and short rotation woody plants for bioenergy are likely to reduce the problem of nutrient pollution loads since such biomass plantations commonly use smaller amounts of inputs. In addition, similarly to when plantations are established as irrigated vegetation filters, certain types of plantations can be located in the agricultural landscape and managed as buffer strips to capture nutrients in passing run-off water.

Plantations can be located and managed for reduction of water erosion and for flood prevention. Besides the on-site benefits of reduced soil losses, there are off-site benefits such as reduced sediment load in reservoirs and irrigation channels, as well as less deterioration of river water quality due to the suspended load that accompanies flood waters (formed mostly by run–off).

Examples of good practices and standards demonstrate that measures to avoid and mitigate impacts are available and affordable.

MITIGATION MEASURES AT THE A CONVERSION STAGE

Cleaner production approaches focus attention on maximizing output, minimizing wastage of resources of any kind, and recycling and reuse of all by-products. Hence, these approaches can be good for business and the environment.

To reduce water pollution, it is crucial:

- to know wastewater characteristics, such as flow and physical, chemical and biological parameters;
- to define the objective of treatment. For instance, treating water effluents may aim at plant water recycling or safe irrigation of cropland;

- to define the necessary reduction;
- to develop process water reduction options.

With regard to reduction options, proven technological solutions and future development of such solutions play an important role.

In Brazil, for instance, a range of techniques to reduce pollution (discharge and physico-chemical parameters) and water use have been implemented in sugarcane ethanol plants. They include process water recirculation, wastewater treatment and reuse, more efficient equipment, less polluting processes, and irrigation using treated vinasse effluent. The advantage of implementing these techniques include: reduced use of power and water pumping; more efficient use of raw materials; and better management of nutrients (e.g. nitrogen, phosphorous and potassium) and organic matter in agriculture, resulting in better yields and soil improvement. Overall costs are also reduced.

There are well-developed systems for fermentation of wastewater from bioenergy factories, integrated in a sewage treatment system. However, a conventional type of wastewater treatment plant with an anaerobic system of liquid waste treatment is widely used in developing countries. Following this treatment, wastewater is no longer harmful to the environment and can be discharged to a municipal sewerage system.

Moreover, natural systems for wastewater treatment, such as constructed wetlands, may be used. Constructed wetlands, regarded as an emerging option for the treatment of industrial effluent, are designed to treat wastewater by using plants such as cattails (*Typha* spp.), reeds (*Phragmites* spp.) and rushes (*Juncus* spp.). Similarly to the use of plantation systems as vegetation filters, these natural systems can provide large quantities of biomass, which may be burned for electricity generation in a sugarcane mill in the same way as solid waste such as bagasse and sugarcane waste, reducing demand for other bioenergy feedstocks and avoiding water quality implications associated with their growth.

Finally, in addition to considering technical mitigation measures, it is important to develop an environmental policy framework.

POLICY INSTRUMENTS ARE NEEDED TO ADDRESS THE WATER IMPLICATIONS OF BIOENERGY PRODUCTION

POLICY INSTRUMENTS CAN DIRECTLY OR INDIRECTLY INFLUENCE HOW BIOENERGY PRODUCTION AFFECTS WATER AVAILABILITY AND QUALITY. THEY SHOULD BE DESIGNED TO HELP AVOID LONG-TERM ADVERSE CONSEQUENCES WHILE MAXIMIZING POTENTIAL BENEFITS, E.G. NEW RURAL JOBS AND NEW OPTIONS FOR SUSTAINABLE LAND AND WATER USE. BIOENERGY-RELATED WATER POLICY INSTRUMENTS NEED TO BE DESIGNED TO BE COHERENT WITH REGARD TO INSTRUMENTS IN RELATED POLICY SECTORS AND WITH EXISTING WATER POLICY INSTRUMENTS, INCLUDING THOSE CONCERNED WITH IRRIGATION AND OTHER AGRICULTURAL PRACTICES AND INDUSTRIAL WATER USE.

POLICY INSTRUMENTS

Effective and efficient water policy instruments are required in order to address impacts on water resources, in terms of both quantity and quality, which may result from bioenergy production.

Recognizing that these impacts may result at different stages of the bioenergy life cycle, policy instruments need to target feedstock production, conversion to solid/liquid/gaseous biofuels, and final end use. Moreover, policy instruments should be consistent with each other to promote efficient bioenergy systems that are optimal in terms of specific objectives.

The general classification of water policy instruments by Bhatia et al (1995)[xliv] is relevant to bioenergy:

- *Enabling conditions*, that is, actions taken to change the institutional and legal environment in which water is supplied and used. Water rights constitute a key enabling condition. Systems not firmly grounded in formal or statutory law are likely to be more vulnerable to expropriation. On the other hand, if well-defined rights are established, the water user can benefit from investing in water-saving technology. When property rights are difficult to define or enforce (e.g. for common pool resources, such as small reservoirs), collective action is needed to achieve sustainable water management[xlv]. Appropriate institutions are needed to enable and administer property rights and to support collective action.
- *Market-based incentives*, which directly influence the behaviour of water users. They include water pricing, water markets (e.g. tradable water use rights) and, more recently, water pollution trading, as well as effluent charges and other taxes and subsidies;
- *Non-market instruments or command-and-control approaches*, such as quotas, licenses and pollution controls; and
- *Direct interventions*, such as investments in efficiency-enhancing water infrastructure or conservation programmes.

Each type of instrument has its benefits and challenges in terms of their effectiveness and efficiency. For example, command-and-control approaches are the policy instruments most often used to address problems directly, while market-based approaches provide more flexibility with regard to how to achieve objectives and can therefore be more cost-effective. In most cases, a mix of policy instruments is used.

The specific set of policy instruments used varies from one location to another, depending, for instance, on the level of economic development, degree of water scarcity, historical development and institutional capability.

Implementation of water policies faces a number of challenges. This is due to the variety of water sources, ranging from precipitation to groundwater; the different types of surface water bodies; the fluidity of the resource; the many claimants on its use; variations in quality demand associated with different uses; and the distinction between consumptive and non-consumptive uses. Moreover, water policies are implemented at different levels, ranging from local to district, national, regional and up to the global level.

An overview of environmental policy instruments that are applicable to water management related to bioenergy production is provided in Table 5.1.

POLICY INSTRUMENTS THAT ADDRESS IMPACTS ON WATER QUANTITY DURING FEEDSTOCK PRODUCTION

Policy instruments that address the impacts of feedstock production on water quantity should help ensure efficient water use by inducing changes in feedstock crop selection where the need for these changes is indicated, as well as supporting the adoption of, for instance, sustainable land and water management practices and advanced irrigation systems to reduce the amount of water applied per unit of biomass produced. Such policies can include incentives for enhanced soil moisture conservation measures, including rainfall capture, conservation tillage and precision agriculture[xlvi].

Comprehensive water and land use planning are the basis for ensuring the effectiveness of these policy instruments. Such planning comprises the following:

- Production of bioenergy feedstocks needs to be matched with specific rainfall and other biophysical conditions in regions where they are grown.
- Changes in total ET_c related to land use changes and alternative farming options need to be factored in. For example, converting cropland or grassland to bioenergy feedstock production generally changes total annual ET and/or shifts its seasonal distribution, which subsequently changes soil moisture and downstream water availability. It is also possible that very substantial land use change

will affect the regional climate over the long term. Thus, regulations need to be enforced and/or incentives provided to ensure that feedstock production does not have negative impacts such as increased occurrence of local or seasonal water shortages.

- The use of agricultural residues as raw materials is likely to reduce water use for feedstock production, as residues are a by-product and additional amounts of water resources would not be required. However, this type of feedstock use also needs to be carefully considered. In many countries, particularly in Sub-Saharan Africa, crop residues are used as animal feed or for mulching to retain soil moisture and increase soil fertility. Adverse impacts on local water availability are likely to occur if crop residues are used for biofuels. Furthermore, complete removal of agricultural residues results in erosion and nutrient run-off to the water supply, as well as soil impoverishment requiring further application of nutrients for future crops.
- The consequences of the use of water for bioenergy need to be compared with those of alternative water uses (including with regard to environmental flow requirements) and consideration should be given to alternative ways of meeting energy demand.

Hence, integration of economic, agronomic, environmental and hydrological aspects is needed. This is aligned with the concept of integrated water resources management (IWRM), "a process which promotes the co-ordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems."[6]

POLICY INSTRUMENTS THAT ADDRESS WATER QUANTITY DURING FEEDSTOCK CONVERSION

With regard to the regulation of feedstock production, the focus of water policy instruments concerned with the conversion of feedstock into biofuels will differ depending on the specific context (e.g. whether water is scarce). From the water resources perspective, water use efficiency may not be a primary concern everywhere. However, promoting solutions that reduce the pollution load (see below) often improves water use efficiency since water reuse and safe recirculation are among the options available for reducing the pollution load.

Table 5.1:
Environmental policy instruments applicable to water management for biofuel feedstock production

POLICY INSTRUMENT	DESCRIPTION/GOAL
Enabling conditions	
Statutory water use right	Government-defined bundles of rights related to access to and use of water
Intellectual property rights	Creations of the mind to which property rights are recognized
Command-and-control approaches*	
Level-based water standards	Uniformly determine level of allowed water removal or maximum allowable effluent concentrations in water resources for users/Serves as a goal to be reached, taking into account impacts on quantity and quality of water resources
Technology-based water standards	Determine type of technology that must be adopted in the utilization of water resources. Purpose: To ensure specific levels of water removal or effluent emissions by determining how these levels can be obtained
Ambient-based water standards	Establish allowable ambient-based water quantity and quality standards, which can be for a basin or reservoir, usually with multiple users. Purpose: to ensure adequate levels of quantity and quality for water bodies. In this case, neither the technology nor reduction levels per user have been established
Market-based instruments*	
Charges	Rates are charged according to quantity and/or quality of water used. Social costs of water resources use are assigned
Subsidies	Payment or concession of tax reduction to provide conditions for economic activities to reduce impacts on water resources. Internalization of social benefits due to non-use or pollution of water resources
Payment system per land reservation	Means an amount paid to a landowner as a guarantee of land conservation, ensuring that there will not be any impact on water resources. Combines the subsidy incentive with a focus on cost control fiscalization
Water markets	Market established for water use rights, referring to both water quality and quantity. Decision-makers use the price-amount relationship as opposed to other market based tools. Quantity and quality of socially desirable water are established, whereas the market will establish the price
Direct interventions	
Awareness campaign	To increase the knowledge of the general public with regard to certain topics
Efficiency-enhancing water infrastructure investments	Investments to improve functioning of government services in various sectors

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[6] Definition of IWRM by the Global Water Partnership.

Note: Items marked with an asterisk (*) are based on Thomas and Callan (2010)[lvi].

EXAMPLES OF APPLICATION	EVALUATION: ADVANTAGES	EVALUATION: DISADVANTAGES
Can help ensure that local water users retain access to water or are compensated when biofuel plantations are implemented, e.g. as foreign direct investment (FDI)	(i) Supports water investments, as access to water is considered secure (ii) Supports claims for compensation when water is diverted for other (e.g. biofuel) uses	It is generally difficult to extend statutory rights to remote/illiterate communities
Can support development of water-conserving feedstock	Helps support R&D investments in water-efficient crops	Can reduce access to new feedstocks in countries with subsistence farmers
Quotas, water rights, discharge permits and effluent-based water quality standards	(i) Ease of implementation and policing (ii) In general, can be adapted to effluent sources (iii) Can be integrated into other command-and-control instruments and market solutions	(i) Do not necessarily establish levels that consider associated benefits and costs (do not ensure allocative efficiency). In general, only social benefits are considered (ii) When standards are uniform for several polluting sources (e.g. in the case of maximum allowed effluent concentration), this approach is not cost-effective since economic resources will be wasted insofar as producers for which reductions are expensive are forced to reduce pollution in the same extent as those for which the cost is lower
Technology-based water standards and technology-based water quality standards	Allow implementation of level-based water standards	(i) Do not necessarily establish levels that consider associated benefits and costs (do not ensure allocative efficiency). In general, only social benefits are considered (ii) Have the potential to prevent each economic agent from minimizing acquisition costs (is not cost-effective)
Ambient-based water standards and ambient-based water quality standards. Total maximum daily load (TMDL) in the United States	Allow polluting sources to choose how to reduce impact by observing legal limits, thus favouring cost reductions if compared with technology-based water standards (and so favouring cost-effectiveness)	(i) Do not necessarily establish levels that consider associated benefits and costs (do not ensure allocative efficiency). In general, only social benefits are considered (ii) This instrument alone does not ensure cost-effectiveness when the costs of the producers' reductions differ
Water pricing, taxes, etc./Water use legislation in the State of São Paulo, Brazil	(i) Encourage users' natural economic motivation, so that those achieving reductions at lower cost achieve the greatest reductions and those achieving reductions at higher costs pay more (ii) Internalize externalities of minimum resources use (cost-effective strategy or technically efficient) (iii) Generate income that can help enforce the law	(i) Difficulty in determining the amount of charges that will induce beneficial use for society (do not ensure allocative efficiency) (ii) Distributive implications related to higher prices of products that use water as raw material, unemployment, etc (iii) Cost increase due to making sure programmes do not make illegal use of the resource
Concessions, discounts, tax exemption, fiscal credits. Best management practices (BMPs) in the United States	(i) If subsidies are viable per unit of water resources, this can lead to cost-effectiveness as the subsidies would be independent of the method used and would also prevent technological distortions (ii) Can lead to reductions of total impact on water resources insofar as each polluter reduces its individual emissions, and can prevent aggregate emissions which are higher than the original	(i) In general, established in association with a method or equipment for impact reduction, rather than encouraging a user's natural economic inclination to aim for cost-effectiveness (ii) Can increase total impact on water resources since the activity's lower costs and higher profits may encourage new entrepreneurs (iii) Difficulty in establishing the value of the subsidy that leads to a real increase in social benefits (does not ensure allocative efficiency) (iv) Financed by taxes on government loans
Reimbursement systems. Conservation reserve program (CRP) contracts in the United States	Reimbursement encourages appropriate behaviour, i.e. no impact on water resources without adding significant amounts to supervise costs	Identification of reimbursement values compatible with the activities' opportunity costs that lead to environmental impacts can take some time for adjustment, therefore incurring costs for society without the desired benefits
Tradeable permits, tradeable water quality permits. Water markets in Australia, Chile and the United States	(i) Sources that can reduce impacts on efficiency receive incentives to do so by selling their rights to less efficient sources (results reach cost-effectiveness or technical efficiency) (ii) A benefit for society is obtained due to a select group of users who, encouraged by natural economic motivation minimize costs (technical efficiency) (iii) Decision-makers do not need to identify prices that will show the amount of the desired impact reduction. Starting from the level that is socially desirable, the market establishes the price (thus favouring allocative efficiency) (iv) The negotiation system is more flexible with regard to the number of permits and can be adjusted to change the environmental goal	(i) The system does not generate income unless the government sells or puts the initial permit distribution up for bidding (ii) Dangerous areas can be created with high concentrations of pollutants where most bidding purchases are made (iii) Higher administrative costs are possible for maintaining buyers' and sellers' trading and emission records
Water pollution awareness campaign to explain how point and non-point source pollution affects health and environment	(i) Can have considerable impacts (ii) Can be inexpensive	It is often difficult to remain neutral, e.g. campaigns often advocate only one point of view/perspective
Reduction of losses from water distribution services; growth in water treatment plants	Effective in addressing water availability and use issues	Often expensive, require training and qualified workers; long-term development

Given that water use generally represents only a small share of total production cost, it is unlikely that water efficiency will be increased without regulations or other measures that promote efficiency improvements and reflect the water's true economic value.

Policy instruments that have been used successfully to increase water efficiency include regulations concerning the volume and quality of water supply and return flows, water pricing, and support for R&D through intellectual property rights, as well as capital investment support for new water recycling technologies.

POLICY INSTRUMENTS THAT ADDRESS WATER QUALITY DURING FEEDSTOCK PRODUCTION (NON-POINT SOURCE POLLUTION)

The main water quality concerns on the feedstock production side are non-point source pollution related to possible sediment and nutrient loadings to water bodies resulting from soil erosion[xlvii] and the application of fertilizers and pesticides.

Agricultural policies to prevent the use of highly erosive land, and policy instruments targeted at better nutrient use efficiency, as well as incentives to change tilling practices, are already being implemented – mainly in developed countries. Developed and emerging countries have made considerable progress in controlling non-point source pollution through both non-market-based (or command-and-control, e.g. standards, quotas) and market-based instruments (e.g. subsidies). For instance, farmers have received subsidies for using specific best management practices such as reduced tillage or no-till practices. Reduced tillage reduces the rate of mineralization[xlviii], leading to lower mineral nitrogen content in the soil in spring and thus to reduced nitrogen leaching and to reduced erosion. Trading water quality permits is a new approach being tried in the United States. The focus of this approach is on achieving least-cost water pollution reductions.

These approaches have had considerable success in developed countries, but are more difficult to implement in developing countries with weaker legal and enforcement systems.

It should be noted, however, that controlling non-point source pollution is challenging. According to Dzikiewics (2000)[xlix], the difficulty of traceability results from the dispersion of agricultural products (sediments, pesticides, fertilizers, manure, and other sources of inorganic and organic matter), which is a result of stochastic factors as well as the watershed's own unique characteristics. Identification, monitoring and enforcement of ambient-based water quality standards require significant data collection and generally benefit from modelling. Putting non-point source pollution control into practice would benefit from a series of characteristics suggested by Segerson (1988)[l], including:

- increasing the probability that pollutant levels in the environment are below ambient-based water quality standards;
- minimum government interference in polluters' day-to-day business, so as to achieve lowest-cost pollution reduction;
- a focus on environmental quality, i.e. monitoring of pollutants, not emissions;
- having defined parameter values, so as to ensure that emission reduction levels are socially optimal;
- eliminating free-riding in the case of multiple pollutants;
- avoiding an excessive burden in the polluting sector in the short term; and
- ensuring long-term efficiency in the polluting sector.

POLICY INSTRUMENTS THAT ADDRESS WATER QUALITY DURING FEEDSTOCK CONVERSION (POINT AND NON-POINT SOURCE POLLUTION)

The major challenge on the bioenergy conversion side is potential chemical and thermal pollution due to the discharge of effluents (point source pollution) and the fate of waste or co-products from today's refineries in aquatic systems (non-point source pollution)[li].

The best utilization of these by-products, with consequently less impact on water quality generally, requires strict regulation as well as the existence of a market and a return to stillage by-products or recoverables. As water quality impacts, from stillage through land disposal, can also be considered non-point source pollution, policy instruments used on the feedstock production side are also valid for addressing water quality implications on the conversion side when stillage is disposed of on cropland or other types of land. This includes the establishment of standards, discharge permits, or tradable water quality permits for stillage to match total maximum daily load (TMDL) levels.

If not properly developed, these instruments can discourage investors, especially in less developed regions, thereby affecting the income of many people and infrastructure investments by governments as well as the achievement of the country's or region's own bioenergy goals. Moreover, policies are needed to promote a balance between energy production and water quality maintenance. These policies also need to be part of IWRM.

POLICY COHERENCE WITHIN THE WATER SECTOR

Policy instruments that can be used in the area of bioenergy production are similar to those applied to irrigation, the promotion of modern agricultural practices and industrial water use. Any instrument newly introduced in the context of bioenergy should therefore be coherent with regard to existing instruments, and efforts should be made to establish synergies between these instruments.

POLICY COHERENCE WITH REGARD TO OTHER SECTORS THAT RELATE TO THE WATER AND BIOENERGY SECTORS

Bioenergy and water are both areas that cut across many different policy sectors. Any bioenergy-related water policy needs to be designed with a view to overall policy coherence.

In addition to water policies that affect bioenergy production directly, many policies affect it indirectly. They include macroeconomic and trade policies, and input and output price support policies (subsidies), together with investment strategies for infrastructure and agricultural research.

In many countries (both developed and developing) policies related to water are developed and implemented by different agencies or ministries, including those focusing on the environment, agriculture, public health, construction, energy and fisheries, as well as those that focus on water such as the Ministry of Water Resources. Besides this fragmentation across governmental bodies, management of water resources themselves (e.g. surface water and groundwater resources) is often fragmented. In the case of bioenergy production, water policies in the environmental, agricultural, energy, industrial and forestry sectors are particularly relevant. In several countries, bioenergy policy, research and development are housed with the Ministry of Energy, while the Ministry of Agriculture would likely have responsibility for research (and trial fields). This fragmentation calls for co-ordination between responsible bodies, weighing full costs and benefits including the opportunity costs of using water.

It is critical for any decision on policy instruments related to bioenergy and water not only to focus on relative effectiveness and efficiency insofar as the use and quality of water resources are concerned, but also to incorporate socio-economic costs and benefits (e.g. see WEAP[7] applications;[lii]), reflecting the need for IWRM. This covers a range of aspects:

- Because biomass production is based in rural areas, and in many cases is labour-intensive, expansion can lead to the creation of jobs and rural development;
- Generation of "clean" energy can stimulate industrialization and development, as well as improvements in quality of life in poorer areas and reduction of air pollution that results from burning of traditional fuels[liii].
- The challenges related to the environmental impacts of bioenergy production on water resources in some countries are considerable. Forward-looking studies (e.g. Berndes, 2002[liv]) have shown that, in water-scarce countries like China and India, water shortages can increase rapidly in scale and intensity even without the development of new, large-scale bioenergy production. In Brazil, water availability appears not to be a constraint on the assumed level of bioenergy production although there may be considerable implications for water quality. Different water allocation values not only lead to differing economic impacts that affect all water users and uses, but also have backward and forward linkages associated with the inputs and outputs of the bioenergy life cycle.
- Impacts need to be differentiated according to different social strata to assess impacts on the most vulnerable and the poorest[lv].

Economic models that integrate water quantity and quality and the overall socio-economic consequences of biofuel use should be developed to support policy formulation for bioenergy production. This would avoid potential long-term adverse impacts on the poor from large-scale developments.

A number of governments have developed sustainability criteria and indicators for bioenergy, which usually also have a water component. Moreover, under the Global Bioenergy Partnership, "relevant, practical, science-based, voluntary sustainability criteria and indicators" are being developed to guide analysis and inform decision-making.[8] While the final set of these criteria and indicators is still being developed, two preliminary agreed water-related indicators (quality and quantity) already exist. It is expected that, through their use, more weight will be given to water concerns in bioenergy development, which will allow a balance between different policy objectives and concerns. Since these indicators are relatively new, their effectiveness and practicability, especially in developing countries, remain to be determined.

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[7] "Water Evaluation and Planning: WEAP." http://www.weap21.org

[8] "Global Bioenergy Partnership (GBEP)." http://www.fao.org/bioenergy/20540-0e78649ac409baf57784d7d0589403d38.pdf

CERTIFICATION

USE OF VOLUNTARY CERTIFICATION SCHEMES IS ONE WAY TO RESPOND TO WATER-RELATED CONCERNS ON A PROJECT LEVEL

MANY VOLUNTARY CERTIFICATION SCHEMES FOR SUSTAINABLE BIOENERGY PRODUCTION HAVE IDENTIFIED WATER AS A CORE ISSUE, AND HAVE DEVELOPED RELATED CRITERIA AND INDICATORS. AMBITIOUS SCHEMES EXIST COVERING EXCESSIVE WATER CONSUMPTION, WATER SCARCITY, AND PROTECTION OF WATER QUALITY.

CERTIFICATION IS A TOOL WITH WHICH DECISION MAKERS ON A PROJECT LEVEL CAN RESPOND TO ENVIRONMENTAL AND SOCIAL CONCERNS. THE PRACTICABILITY OF CERTIFICATION SCHEMES, AS WELL AS THEIR EFFECTIVENESS IN PREVENTING HARMFUL IMPACTS, NEED TO BE MONITORED AND EVALUATED IN THE COMING YEARS.

A number of voluntary certification schemes relevant to bioenergy production and water exist. They include feedstock-related schemes such as the Roundtable on Sustainable Palm Oil (RSPO), the Round Table on Responsible Soy (RTRS) and the Better Sugarcane Initiative (BSI); bioenergy-specific schemes such as the Roundtable on Sustainable Biofuels (RSB), the International Sustainability and Carbon Certification (ISCC) and the Green Gold Label (GGL) programme; forestry-related schemes such as the Sustainable Forestry initiative (SFI) and the Forest Stewardship Council (FSC); agriculture-related schemes such as the Sustainable Agriculture Network (SAN)/ Rainforest Alliance; and water-related schemes such as the Alliance for Water Stewardship (AWS).

All the schemes listed above have been analyzed by the authors of this chapter with regard to how they address impacts on water (Table 6.1). Most cover three key issues: excessive water consumption, water scarcity, and protection of water quality.

WATER QUALITY, IN PARTICULAR, IS WELL-COVERED

Regarding effluents from conversion processes, useful water quality indicators for customary and legal threshold values are mostly in place. Certification schemes benefit from the use of legal references.

The impacts of agricultural activities, such as the application of fertilizers and pesticides, are more complex. Good agricultural practices are considered to provide protection. However, impacts on surface and groundwater are time-delayed, and tracing measured pollution to a specific source (the polluter) may be inconclusive in many cases. Thus, controlling and auditing agricultural practices have a key role in ensuring protection of water quality. Nearly all the analyzed systems address this point.

AVOIDANCE OF EXCESSIVE WATER CONSUMPTION IS ADDRESSED BY MOST SCHEMES

Certification schemes require water management plans, efficient use and reuse, and optimization of irrigation if it is used. The criteria and indicators in place appear to be useful, effective and practical.

On the other hand, even efficient and economical use of water can be excessive if consumers are large enough to absorb modest water resources. If availability and the entire consumer context are not taken into account, negative impacts cannot be avoided despite good management.

WATER SCARCITY IS DIFFICULT TO STANDARDIZE

This leads to the final and most crucial point: the identification of 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 (e.g. the Water Availability Index or Water Scarcity Index) to classify levels of availability and scarcity that can support a basic global definition of areas where water is physically scarce.

However, information concerning physical scarcity will not address the whole problem. A number of aspects need to be considered, such as:

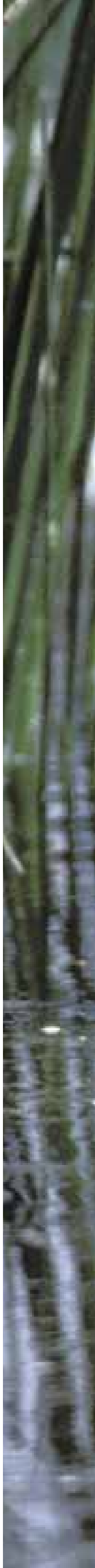
- Regional resolution of the data:
  - Does it correspond to actual water flow conditions on the catchment or watershed level?
  - How far downstream could users be affected?

- Economic aspects of water scarcity: In some regions sufficient amounts of water are physically available, but the population cannot afford an appropriate supply system. This “economic water scarcity” is difficult to consider because:
  - Irrigation projects can afford to exploit available water resources and aggravate the situation for the local population; and
  - Such projects could facilitate improvement of the general water supply by investing in infrastructure.

There is also a possibility that switching to cultivation of suitable plants as feedstock would represent a strategy for adapting to a difficult water situation. In such a situation, not allowing farmers to produce for the bioenergy sector due to water scarcity might prevent development towards improved conditions under which they could make better use of available water.

THE OVERALL CONTEXT MATTERS

When a biomass project is to be certified according to water-related sustainability, the overall context, such as water rights, rural and social development and food security, should be taken into account. A number of the certification systems analyzed are prepared to consider this context. In particular, the Green Gold Label (GGL) programme, the Roundtable on Sustainable Biofuels (RSB) and the Sustainable Agriculture Network (SAN) have adopted ambitious related criteria.



CERTIFICATION AT THE PROJECT LEVEL ALONE MAY NOT SUFFICE

While certification systems may promote sustainable handling of water and help to avoid the creation or aggravation of water scarcity, a country's overall water policy can undermine efforts by single projects. Within a watershed, users are interdependent. Water management needs to involve all affected parties. A biomass-producing and water-consuming project cannot be responsible for overall water policy. Certified good practice at the project level will not prevent negative developments when sound water policy is absent.

The Alliance for Water Stewardship (AWS) is a promising initiative for putting such a policy in place at watershed level. Since AWS uses an overall water-related approach, it can include bioenergy as well as any other water-relevant sector or process. The key feature of AWS is involvement of the whole range of concerned decision makers and stakeholders. It might constitute added value if an AWS-based certification standard were endorsed by bioenergy certification systems wherever water is a crucial aspect.

Certification of bioenergy-related water impacts will remain a challenge. Ambitious schemes are in place. However, in the coming years there will be a need to verify the practicability of schemes and consider how to successfully avoid adverse effects and unintended outcomes. 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 on the watershed level.

Table 6.1: Synopsis of voluntary certification systems

Certification scheme	RSB	RSPO
Relation to bioenergy	Biofuels	Palm oil
Water is addressed by	1 dedicated principle with 4 criteria	2 criteria with 2 generic principles
Water quantity	No depletion of surface/ groundwater resources beyond replenishment capacities; 7 indicators	Maintain availability of surface/ groundwater; 1 indicator
Water quality	Enhancement or maintenance of quality of surface/groundwater resources; 6 indicators	Maintain quality of surface/ groundwater; 1 indicator
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
Monitoring of effects	Yes, according to management plan	Yes, consumption and effluents (BOD) of mills
Watershed considered	Yes	No
Water rights	1 dedicated criterion regarding formal, customary rights/ indigenous communities; 8 detailed indicators	No
Related aspects	Rural and social development, food security, buffer zones, soil erosion	Soil erosion, riparian buffer zones
Addressed to	Market operators: biofuel production chain	Market operators: palm oil production chain
Experience	Began in 2010	Began in 2009; 3 million tonnes oil capacity certified by end of 2010

RTRS	BSI	ISCC	SAN	GGL-S2	AWS	FSC
Soybean, soybean oil	Sugarcane ethanol from sugarcane	Biofuels	Agricultural products	Biomass	Generic	Wood fuel wood
1 criterion with a generic principle	Diverse indicators with 4 generic criteria	2 criteria with a generic principle	1 dedicated principle with 9 criteria	1 dedicated principle with 4 criteria		2 criteria with a generic environmental principle
2 indicators: good agricultural practice (GAP) and best irrigation practice	Report on volumes used	Minor requirement to maintain watercourses; requirements for irrigation	Operation must have water conservation programme, permits, best irrigation practice	Increased efficiency, monitoring of irrigation	water is the focus of AWS	Indirectly by protection of water resources (plantations: no adverse impacts from drainage)
2 indicators: GAP and monitoring	Monitor efficiency, assess impacts on ecosystems, mitigation measures, improvements	Extensive list of criteria regarding fertilizer and chemical use, storage, etc.	Appropriate wastewater treatment, threshold values	Sewage control (manure), monitoring of water quality	water is the focus of AWS	Protection of water resources, avoidance of chemical pesticides
No	Embedded in environmental management plan	No	Embedded in environmental and social management system	Embedded in agricultural management system	There is a focus on water management	No (forest management plan)
Yes, effectiveness of practices, contamination	Yes, production efficiency	No	Yes, wastewater	Irrigation performance, water quality		Yes, within environmental effects
Yes	Yes	No	Not directly addressed	Not directly addressed	Watershed is the basic unit	No
No	No	Irrigation has to be justified	Not directly addressed	Not directly addressed	Implicit	No
Soil erosion	Soil erosion, riparian areas, wetlands	GAP, integrated pest management (IPM), riparian areas, waste management	Soil erosion, waste management	Diverse aspects of agricultural management system	All consequences of water impacts	Soil erosion, maintenance or enhancement of value as watershed
Market operators: soybean oil production chain	Market operators: sugarcane ethanol production chain	Market operators: biofuel production chain	Market operators: biofuels in general	Market operators: biofuel production chain and electricity producers	Policymakers, stakeholders, civil society, public sector, business	Forest owners, wood producers
First certifications anticipated	Began in 2010	Began in 2010	Began certification system in 1992	Began in 2003; established certification system	Initiated in 2008	Began in 1993; established certification system

RECOMMENDATIONS

TAKE A HOLISTIC APPROACH AND A LONG-TERM PERSPECTIVE

- Address competition for water resources for different uses though integrated water planning and management.
- Consider the context – regional, national and local conditions – to identify the best use of a drop of water. There is no “one size fits all”.
- Apply a life cycle perspective, as water use and related impacts can occur along the entire production chain, from feedstock production to conversion and final use of a bioenergy product.
- Take into account possible beneficial effects/synergies, e.g. for food *and* fuel production through combined systems, or irrigation using grey water.
- Consider inter-relationships with other resource needs, as there are potential tradeoffs between land and water use, biodiversity, GHG emission reduction, soil, etc.
- Reflect global trends, particularly climate change adaptation needs, in development strategies.

COOPERATE ON A WATERSHED LEVEL

- Take action on appropriate levels (local, national and regional), taking into account the entire watershed.

BASE DECISIONS ON IMPACT ASSESSMENTS TO ENSURE SUSTAINABLE WATER MANAGEMENT

Analyze the water intensity of proposed bioenergy activities;

↓

Determine existing and projected resource use, based on indicators for water availability;

↓

Assess localized impacts when developing tools and regulations for water resources management and planning at local, regional and global scales.

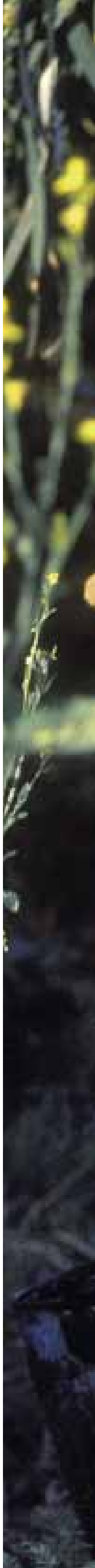
- Analyze bioenergy systems from a comprehensive socio-ecological perspective, with consideration given to underlying ecological functions in agricultural and natural landscapes and broader livelihood and development implications.
- Promote sustainable land and water use, including understanding the outcomes of different land and water management systems and the options available to sustain critical ecological functions where land use change occurs.

DESIGN AND IMPLEMENT EFFECTIVE WATER-RELATED POLICY INSTRUMENTS

Addressing the impacts of bioenergy production on water availability and quality will require the implementation of judicious water policy instruments and legislation for both feedstock production and energy conversion, together with effective monitoring of the competition between sectoral uses of water.

It is of fundamental importance that instruments be applied and continuously reviewed in an environment in which:

- publicly available records are maintained on water consumption by bioenergy systems and other water-using activities;
- water regulations and laws are established to support integrated water resources planning and monitoring;
- effective participation by all users/uses is ensured;
- indicators and transparent criteria are established that are consensus-based and practical;
- models are applied to simulate the behaviour of water users confronted by different environmental policy instruments, in order to assess water allocations across users and sectors, with consideration given to regulatory and technical restrictions (an example could be WEAP modelling[9]);
- models are applied that measure economic effects associated with different environmental policy instruments and water allocation outcomes, both on the economy as a whole and on various economic sectors; and
- scenarios are used to evaluate technological trends in bioenergy production, as well as in demand for bioenergy products, and development options for competing water uses.



ESTABLISH/SUPPORT APPROPRIATE INSTITUTIONS AND PROCESSES, FOR EXAMPLE:

- inter-ministerial task forces to co-ordinate different policy objectives;
- stakeholder engagement from the planning through implementation phases; and
- ground-truthing on the watershed level, to verify information gathered through remote sensing by collecting information "on location".

DISSEMINATE BEST PRACTICES, FOR EXAMPLE:

- through upgrading of extension services; and
- through promotion of special training through certification schemes.

PROMOTE TECHNOLOGY DEVELOPMENT

- New technologies may help mitigate pressure on water resources, but they need to undergo a due diligence check prior to widespread deployment.

INTENSIFY DIALOGUE ON THE TOPIC AND ON CAPACITY BUILDING

This report is an important first step towards improving knowledge and exchanges concerning the bioenergy and water nexus in the global community. It provides a basis for:

- intensifying dialogue with groups and organizations working on the issue, including the editors of this report, the International Energy Agency (IEA) Bioenergy Task 43, the Oeko-Institut and UNEP, as well as processes referred to in this report, such as the Global Bioenergy Partnership and the different certification schemes; and
- building the capacity of the different groups concerned by this report. This is especially valid for decision makers in emerging and developing countries.

CONDUCT FURTHER RESEARCH, FILL DATA GAPS, AND DEVELOP REGIONALIZED TOOLS

- Support international co-operation in research on the impacts of bioenergy development on water quantity and quality as compared to reference scenarios, including other energy sources (oil, nuclear, etc.).
- Address emerging and largely unexplored issues such as the potential and risks of coastal zones/macroalgae, land-based microalgae and genetically modified organisms (GMOs).
- Fill data gaps. Especially in developing countries, one of the main constraints on water management is lack of updated data. Some monitoring needs to be conducted on a regular basis to comply with regulations and with sustainable production. Nuanced and comprehensive analysis requires detailed data, while most existing research in this area has been conducted on a large scale and with an eye towards general application. When considering or advising on specific activities, the scale will generally be smaller and human and financial resources may be available to gather detailed information in situ.
- Develop regionalized tools further. Life cycle impact assessment (LCIA) and water footprint (WF) are inadequate without the differentiation of localized impacts.

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GLOSSARY

Bagasse: Bagasse is the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice. Earlier, bagasse was considered a waste and was burned without energy recovery, but today it is commonly used as fuel in sugarcane ethanol production

Basin: Area of land drained by a river and its branches.

Best management practices (BMPs): Methods determined to be the most effective and practical means of preventing or reducing pollution.

Biochemical oxygen demand (BOD): Measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The higher the BOD, the greater the organic matter loads.

Bioenergy: Bioenergy: Renewable energy made available from materials derived from biological sources/biomass.

Biofuel: Fuel produced from biomass. Biofuels include fuelwood, charcoal, bioethanol, biodiesel, biogas (methane) and biohydrogen.

Biomass: Non-fossil material of biological origin. Biomass sources for bioenergy include conventional food/feed crops, perennial grasses, short rotation woody plants, trees, agricultural and forestry residues, manure, process by-flows in the food and forest sector, and organic post-consumption waste such as paper, wood waste and organic residential waste.

Blue water: Water in rivers, lakes, wetlands and aquifers that can be withdrawn for irrigation and other human uses.

By-product: In the case where an additional demand for one of the jointly produced products does not affect the production volume of the process, the product is called a by-product.

Consumptive water use: Water is considered consumed when it is removed from the usable resource base for the remainder of one hydrologic cycle. Evapotranspiration (see separate definition), therefore, is considered a form of consumption; although the water molecules have simply changed physical forms, we do not control where evaporated water will fall next, so the water is functionally lost to the system.

Conversion of biomass: Physical, chemical and biological processes for converting feedstock into various energy forms.

Co-product: Any product that is produced together with others. Any product from multi-products system (including joint production and subsidiary production) can be referred to as a co-product.

Crop (or plant) water balance: Describes the water balance during crop (plant) production. A common model is given as: ET=P+I-S-D-R, where ET is evapotranspiration, P is precipitation, I is irrigation, S is change in soil water storage, D is deep drainage, and R is runoff. ET, P and I are positive, while S, D, and R can be both positive and negative.

Environmental flows: Defined by the Brisbane Declaration (2007) as “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” (www.eflownet.org).

Evapotranspiration (ET/ET_c): Evapotranspiration (ET) is the sum of evaporation from soil and plant surfaces (E) and plant transpiration (T) from the Earth’s land surface to the atmosphere. T can sometimes be further divided into T_c (crop transpiration) and T_w (weed transpiration), where a farmer tries to maximize T_c and minimize T_w and E. Hence, ET_c is crop-specific ET.

Green water: Soil water held in the unsaturated zone, formed by precipitation and available to plants.

Grey water: Water that becomes contaminated during a production process. A “grey water footprint” is considered to be the volume of freshwater required for dilution of total pollutant load to meet a defined ambient water quality standard. The term “grey water” may also be used to refer to domestic wastewater consisting of, for example, wash water from kitchen, bathroom and laundry sinks, tubs and washers.

Groundwater: The supply of freshwater beneath the Earth’s surface, usually in aquifers, which supply wells and springs. Since groundwater is a major source of drinking water, concern is increasing about contamination from leaching of agricultural or industrial pollution or leakage from underground storage tanks.

Hydrologic balance: Expresses various elements of the water balance of land or a water basin. Indicators include hydric deficit, annual/dry period withdrawal, and annual/winter drainage.

Integrated water resources management (IWRM): Integrated water resources management is the practice of making decisions and taking actions while considering multiple viewpoints of how water should be managed. These decisions and actions relate to situations such as river basin planning, organization of task forces , planning of new capital facilities, controlling reservoir releases, regulating floodplains , and developing new laws and regulations. The need for multiple viewpoints is caused by competition for water and by complex institutional constraints. The decision-making process is often lengthy and involves many participants.

Land use change (LUC): Change in the human use of land, especially regarding both above- and below-ground carbon. *Direct LUC* (dLUC) refers to LUC that takes place within the system boundaries of an analysis, or to the LUC that is a direct cause of a human action. Can for instance be the change from food or fibre production (including changes in crop rotation patterns, conversion of pasture land, and changes in forest management) or the conversion of natural ecosystems. *Indirect LUC* (iLUC) refers to the LUC that takes place outside the system boundary, or as an indirect consequence of human action. For example, if bioenergy plantations are established on agriculture land, displaced food producers may re-establish their operations elsewhere by converting natural ecosystems to agriculture land, or due to macro- economic factors, the agriculture area may expand to compensate for the losses in food/fibre production caused by the bioenergy project. A wide definition of iLUC can include changes in crop rotation patterns and/or intensification of land use.

Life cycle assessment (LCA): Tool for systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.

Life cycle inventory (LCI): Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (ISO 14040:2006).

Life cycle impact assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (ISO 14040:2006).

Life cycle water use: Life cycle water use is defined as water use throughout the life cycle of a product (including end use).

Pollution: Generally, the presence of a substance in the environment that, because of its chemical composition or quantity, prevents the functioning of natural processes and produces undesirable environmental and health effects.

Rainwater harvesting: Rainwater harvesting is the accumulating and storing, of rainwater for reuse.

Stillage: Stillage is a residue from the ethanol fermentation process. In sugarcane ethanol production the stillage (called vinasse) is commonly recirculated as a fertilizer to the sugarcane fields through irrigation

Vinasse: The residual slurry after the distillation of the fermented juice from crops (e.g. sugarcane, sweet sorghum).

Water availability index: The water availability index takes the temporal variability of water availability into account. The index includes surface water as well as groundwater resources, and compares the total amount to the demands of all sectors. The month with the maximum deficit or minimum surplus respectively is decisive. The index is normalised to the range –1 to +1.

Water balance: Accounting of the flows of water into and out of a system.

Water footprint (WF): Different researchers apply the term in different ways. The following definition is given on the Water Footprint Network website: "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." (http://www.waterfootprint.org/?page=files/Glossary)

Water intensity, productivity and efficiency: Water intensity is typically expressed as the amount of water used per unit of product output. The reciprocal of intensity, i.e. the product output per unit of water used is often referred to as water productivity or water use efficiency. These indicators can refer to different types of water use (e.g., crop ET, blue water input) and can be applied for both total systems (e.g., ethanol production and use) system components (e.g., ethanol feedstock production).

Water scarcity index: The water scarcity index is often expressed as the ratio between gross water abstraction and total renewable water resources.

Water stress: The Falkemark water stress indicator defines 1,700m^3/capita/year as the threshold above which water shortage occurs only irregularly or locally. Below 1,700m^3/capita/year water stress appears regularly, below 1,000m^3/capita/year water scarcity is a limitation to economic development and human health and well being, and below 500m^3/capita/year water availability is a main constraint to life. In addition to average water availability, average water shortages in dry seasons or in certain regions within a country, water quality and a country's ability to use the resources can determine water stress.

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Bioenergy and water are inextricably linked. For the first time, this report examines in depth these interlinkages, highlights the risks and opportunities, and offers an outlook on ways to address them. It provides policymakers with scientific information to support informed strategies and policies. The report also points to the need for further research, filling data gaps, and the development of regionalized tools.

Water quantity and quality are factors that determine the extent to which bioenergy can contribute to the overall energy mix. For example, in a world already facing water stress, largely due to over 70% of freshwater being consumed by the agricultural sector, bioenergy development is likely to add to this – through feedstock production and conversion processes - and hence increase the pressure. At the same time, there are opportunities to harness bioenergy development to help increase access to water by leveraging the introduction of efficient water management techniques, by increasing soil absorption capacity in dry areas, by selecting appropriate crops, by providing energy for water pumping and cleaning water.

Some 45 international experts have contributed to this report through a process facilitated by UNEP, Oeko-Institut and IEA Bioenergy Task 43, and kicked off at the International Workshop: "Spotlight on Bioenergy and Water" held in Paris in July 2010.