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IEA Bioenergy

THE BIOENERGY AND WATER NEXUS

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[1] There is a list of workshop participants in (Annex I)

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About

IEA Bioenergy Task 43

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 (January 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, and USA.

Oeko-Institut

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 and environmental associations.

United Nations Environment Programme

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 six 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 - among 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 gas 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)

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AWS ... Alliance for Water Stewardship

BMELV ... German Federal Ministry of Food, Agriculture and Consumer Protection

BMPs ... Best Management Practices

BOD ... Biochemical oxygen demand

BOD_5 ... Biochemical oxygen demand after 5 days

BOD/COD ... Biochemical oxygen demand/chemical oxygen demand

BSI ... Better Sugarcane Initiative (now Bonsucro)

BTL ... Biomass-to-liquids (Fischer-Tropsch)

BW ... Blue water

Ca ... Calcium

CAC ... Command-and-control

CCCP ... Former Soviet Union

CDM ... Clean Development Mechanism

CETESB ... Environmental Protection Agency of the State of São Paulo (Brazil)

CFSUN ... Committee on World Food Security

CGIAR ... Consultative Group on International Agricultural Research

COD ... Chemical oxygen demand

CRP ... Conservation Reserve Program (United States)

CSP ... Conservation Security Program (United States)

CSS ... Compagnie Sucrière Sénégalaise (Senegalese Sugar Company)

DDGS ... Dried distillers grains with solubles

DG ... Distillers grains

DGS ... Distillers grains with solubles

dLUC ... Direct land use change

DME ... Department of Minerals and Energy (South Africa)

DWA ... Department of Water Affairs (South Africa)

E ....Evaporation

ECS ....Energy conversion side

EISA ....Energy Independence and Security Act (United States)

EJ ....Exajoule

ELOHA ....Ecological Limits of Hydrologic Alteration

EQIP ....Environmental Quality Incentives Program

ET.. Evapotranspiration

ET_a ....Evapotranspiration from cultivated land

ET_c ....Crop evapotranspiration

EtOH..Ethanol

EWR..Environmental Water Requirements

FAO..Food and Agriculture Organization of the United Nations

FD .... Freshwater depletion

FDI .... Foreign direct investment

FEI..Freshwater ecosystem impact

FFB.. Fresh fruit bunch

FPS .... Feedstock production side

FSC.. Forest Stewardship Council

GATS ....General Agreement on Trade in Services

GBEP..Global Bioenergy Partnership

GDP ....Gross domestic product

GEO4 .... Global Environment Outlook 4

GGL.. Green Gold Label

GHG.. Greenhouse gas(es)

GJ ....Gigajoule

GW ....Green water

GWh ....Gigawatt hour

GWP .... Global Warming Potential; Global Water Partnership

IFAD...International Fund for Agricultural Development

IFPRI .... International Food Research Policy Institute

iLUC...Indirect land use change

IPCC .... Intergovernmental Panel on Climate Change

IPIECA.........................Global oil and gas industry association for environmental and social issues

ISCC .... International Sustainability and Carbon Certification

ISEAL...Global association for social and environmental standards

IWRM ....Integrated water resources management

LCA ....Life cycle assessment

LCI..Life cycle inventory

LCIA ....Life cycle impact assessment

LUC.. ... Land use change

MDGs...Millennium Development Goals

MENA .... Middle East and North Africa

Mg ....Magnesium

MJ ....Megajoule

MONERIS ....Modeling of Nutrient Emissions in River Systems

NBIS...National Biofuels Industrial Strategy (South Africa)

NGO.. Non-governmental organization

NH_3-N ....Ammonia nitrogen

NO_3-N ....Nitrate-nitrogen

NPDES .... National Pollutant Discharge Elimination System

NPP ....Non-point (source) pollution

NRC..National Research Council (United States)

NRDC .... Natural Resources Defense Council (United States)

NTUs...Nephelometric turbidity units

NWA .... National Water Act (South Africa)

ORP .... Oxygen reduction potential

PEFC .... Program for the Endorsement of Forest Certification

PM .... Particulate matter

PO_4-P .... Orthophosphate

POME .... Palm oil mill effluent

R&D .... Research and development

RFA .... Renewable Fuel Agency (United Kingdom)

RSB .... Roundtable on Sustainable Biofuels

RSPO .... Roundtable on Sustainable Palm Oil

RTFO .... Renewable Transport Fuels Obligation (United Kingdom)

RTRS .... Roundtable on Responsible Soy

SAM .... Social Accounting Matrix

SAN .... Sustainable Agriculture Network

SBA .... Sustainability Boundary Approach

SBM .... Soybean meal

SFI .... Sustainable Forestry Initiative

SFM .... Sustainable Forest Management

SFRA .... Stream Flow Reduction Activity

SMZ .... Streamside management zone

SRC .... Short rotation coppice

SSA .... Sub-Saharan Africa

SWAT .... Soil and Water Assessment Tool

T .... Plant transpiration

T_c .... Crop transpiration

T_w .... Weed transpiration

TMDL .... Total maximum daily load

TSS .... Total suspended solids

UASB........ Upflow Anaerobic Sludge Blanket

UNCTAD .... UN Conference on Trade and Development

UNEP .... United Nations Environment Programme

UNFCCC .... United Nations Framework Convention on Climate Change

UN HLTF .... High Level Task Force on Global Food Security

USDA .... United States Department of Agriculture

US EPA .... United States Environmental Protection Agency

UWFR .... Unified Water Flow Regulation

VKT .... Vehicle kilometres travelled

WB........ The World Bank

WBCSD .... World Business Council on Sustainable Development

WEAP .... Water Evaluation and Planning System

WF .... Water footprint

WFD .... Water Framework Directive

WFP .... World Food Programme

WRPC........ Water use per capita

WS .... Water scarcity

WSI(Pfister) .... Water Stress Index as defined by Pfister

WSI(Smakhtin) .... Water Stress Indicator as defined by Smakhtin

WTA........ Withdrawal to availability

WTO .... World Trade Organization

WUE .... Water use efficiency

WUPR .... Water use per resource

Glossary

Advanced biofuels: Subsume all non-first generation biofuels. Many authors refer only to second generation biofuels, but some also to third and fourth generation biofuels. The traditional way of defining the “generations” of biofuels refers mainly to efficiency in conversion and the wider availability of feedstocks. Second generation biofuels mainly comprise cellulosic ethanol, which is generally produced through hydrolysis of woody or fibrous biomass, and the Fischer-Tropsch biomass-to-liquids (BTL) fuels, which can have varying properties. Third generation biofuels are generally defined as those derived from algae. Other advanced biofuels (fourth generation biofuels) are associated with synthetic biology and, more generally, the use of biotechnology to “design” biofuels with specific technical characteristics to meet particular end-user needs or market demands.

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

Baseflow: Part of the stream discharge that is not attributable to direct run-off from precipitation or melting snow; it is usually sustained by groundwater.

Basin: Area of land where water from precipitation drains into a water body. Also referred to as a “drainage basin”, “catchment” or “catchment area”. A “watershed” is the line separating neighbouring (drainage) basins or catchments.

Best Management Practices (BMPs): Methods determined to be the most effective and practical means of achieving an object (e.g. preventing or reducing pollution).

Bioaccumulation: “The absorption and concentration of toxic chemicals, heavy metals, and certain pesticides in plants and animals. Toxicity can be expressed in several ways: lead that is ingested by calves can bioaccumulate in their bones, interfering with calcium absorption and bone development; stored chemicals may be released to the blood stream at a later time, e.g., during gestation or weight loss; and chemicals may concentrate to lethal levels at upper ends of the food chain. Bioconcentration is a synonym for bioaccumulation” (http://www.sciencedictionary.org/agriculture-term-details/Bioaccumulation).

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

Bioenergy system: Combination of subsequent processes within the production chain of a certain type of bioenergy; typically including feedstock production, processing and final use.

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

Biomass: Non-fossil material of biological origin. Biomass sources of bioenergy (see definition above) 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: Where additional demand for one of two or more jointly produced products does not affect the production volume of the process, the product or products for which there is additional demand are referred to as "by-products".

Catchment/catchment area: See "basin" above.

Consumptive water use: Water is considered to be consumed when it is removed from the usable resource base - through evaporation, evapotranspiration or product incorporation - for the remainder of the current hydrological cycle. "Evapotranspiration" (see definition below) is therefore a form of consumption; although the water molecules have simply changed physical forms, it is not possible to 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 (bio)energy forms.

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

Crop (or plant) water balance: 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 moisture content, D is deep drainage, and R is run-off. ET, P and I are positive, while S, D, and R can be both positive and negative.

Customary: In accordance with custom or habitual practice; founded upon long continued practices and usage (e.g. with respect to water access and rights) rather than law. "Customary" may also refer to a statement in writing of customary laws and practices, or a body of such laws and customs.

Degradative water use: Withdrawal and subsequent discharge to the same watershed after water quality has been (significantly) degraded.

Drainage basin: See "basin" above.

Embedded water: Water used in the production of a good or service. Also referred to as "virtual water", "embodied water" or "hidden water".

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" (http://www.eflownet.org).

Eurythermic: Refers to an organism that is adaptable to a wide range of temperatures.

Evapotranspiration (ET/ET_c): Evapotranspiration (ET) is the sum of evaporation (E) from soil and plant surfaces and plant transpiration (T) from the Earth's land surface to the atmosphere. ET_c is crop-specific ET. Plant transpiration (T) can sometimes be further divided into crop transpiration (T_c) and weed transpiration (T_w).

Feedstock: Raw material required in industrial production.

First generation biofuels: Nearly all the liquid biofuel crops used today belong to the so-called "first generation", including the sugar and starch crops from which ethanol is made and the oilseed crops which are the source of biodiesel.

Flegmass: By-product obtained from the rectifying column of phlegm during the process of alcohol production.

Fluxes: Movement pathways of water within watersheds. Fluxes consist of interception, evaporation, transpiration, stemflow, throughfall, infiltration, surface run-off, interflow, baseflow and stormflow. They convey variable amounts of dissolved or suspended solids, which constitute the physical component of water quality.

Green water: Soil moisture held in the unsaturated zone, formed by precipitation and available to plants. In some definitions, green water also includes the part of irrigation water that becomes available for plant uptake.

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 the 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, there is increasing concern about its contamination, e.g. from leaching of agricultural or industrial pollution and 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.

Hydrosphere: Combined mass of the water found on, under and over the Earth's surface.

Infiltration: The process by which water on the ground surface enters the soil.

Integrated water resources management (IWRM): The practice of making decisions and taking actions while considering multiple viewpoints with respect to how water should be managed. These decisions and actions relate to, for example, river basin planning, organization of task forces, planning of new capital facilities, control of reservoir releases, regulation of floodplains, and development of new laws and regulations. Multiple viewpoints are needed due to competition for water and to complex institutional constraints. The decision-making process is often lengthy, with many participants involved.

Interflow: Water, from precipitation, that infiltrates the soil surface and then moves laterally through the upper layers of soil above the water table until it reaches a stream channel or returns to the surface at some point downslope from its point of infiltration.

Land use change (LUC): Change in 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. For example, it can be the change from food or fibre production (including changes in crop rotation patterns, conversion of pasture land, and changes in forest management) or 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 agricultural land, displaced food producers may re-establish their operations elsewhere by converting natural ecosystems to agricultural land. Or due to macro-economic factors, the area devoted to agriculture 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 throughout all stages of its life cycle. The principles and framework for life cycle assessment are described in International Organization for Standardization standard ISO 14040:2006. They include: definition of the goal and scope of the LCA; *the life cycle inventory (LCI)* analysis phase (see definition below); the *life cycle impact assessment (LCIA)* phase (see definition below); the life cycle interpretation phase; reporting and critical review of the LCA; limitations of the LCA; the relationship between the LCA phases; and conditions for use of value choices and optional elements (http://www.iso.org/iso/catalogue_detail?csnumber=37456).

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.

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.

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

Lignocellulosic biomass/feedstock: Biomass/biomass feedstock, such as woody materials, grasses, and agricultural and forestry residues, composed of cellulose, hemicellulose and lignin. It can be broken down in a number of ways to be used as biofuels.

Litter: "The surface layer of the forest floor which is not in an advanced stage of decomposition, usually consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits" (http://www.cof.orst.edu/cof/teach/for341/Boyle.forestSoils.terms.htm).

Oligotrophic: Refers to an environment that offers little to sustain life.

Percolation: Slow movement of water through the pores in soil or permeable rock.

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

Rainwater harvesting: The accumulation and storage of rainwater for reuse.

Roundwood: Wood in its natural state as felled, with or without bark. Roundwood can be round, split, roughly squared or take other forms. It may be used for industrial purposes, either in its round form (e.g. as transmission poles or piling) or as raw material to be processed into industrial products such as sawn wood, panel products or pulp.

Short rotation coppice: Fast-growing tree species (e.g. willow and poplar) cut down to a low stump (or stool) when they are dormant in winter. They go on to produce many new stems in the following growing season.

Stemflow: The flow of intercepted water down a plant's stem or trunk. Together with "throughfall" (defined below), it is the means by which precipitation and nutrients are transferred from the canopy to the soil.

Stillage: Residue from the ethanol fermentation process. In sugarcane ethanol production the stillage (called "vinasse"; see definition below) is commonly recirculated as fertilizer in sugarcane fields through irrigation.

Stomata: Pores in the epidermis of leaves and stems.

Stormflow: Part of "streamflow" (defined below) that occurs in direct response to precipitation.

Stover: Dried stalks and leaves of a cereal crop, used as fodder or as feedstock for cellulosic ethanol after the grain has been harvested.

Streamflow: The flow of water in streams, rivers and other channels. Also referred to as "channel run-off". Streamflow is composed of "baseflow" and "stormflow" (both defined above).

Throughfall: Process by which wet leaves shed excess water onto the ground surface.

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

Water Availability Index: Index that takes the temporal variability of water availability into account. It 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 is decisive. The index is normalized to the range -1 to +1.

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

Water footprint (WF): This single index builds on the concepts of "blue", "green" and "grey" water (see definitions above) and can be obtained by combining these three components. 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 use 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. ET_c, blue water input) and can be applied in the case of both total systems (e.g. ethanol production and use) and system components (e.g. ethanol feedstock production).

Water Scarcity Index: Often expressed as the ratio between gross water abstraction and total renewable water resources.

Watershed: See “basin” above.

Water stress: The Falkenmark water stress indicator (see Section 3.5.1 in this report) defines 1 700 m^3/capita/year as the threshold above which water shortage occurs only irregularly or locally. Below 1 700 m^3/capita/year, water stress occurs regularly; below 1 000 m^3/capita/year, water scarcity is a limitation on economic development and human health and well-being; below 500 m^3/capita/year, water availability is a main constraint on 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 resources can determine water stress.

Water withdrawal: All (blue) water abstracted from rivers, lakes, wetlands and aquifers for irrigation and other human uses. The withdrawn water 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. “Non-withdrawal” water use includes in-stream use for purposes such as hydroelectric power generation, transport, fish propagation and recreation. Non-withdrawal use is not directly relevant to agricultural use of water.

1 The bioenergy and water nexus – setting the scene

1.1 Overview/context

Bioenergy and water are inextricably linked. Water has been identified as an emerging issue of concern in the area of bioenergy development, in terms of both its quantity and quality. Water availability will undoubtedly affect the extent to which bioenergy can contribute to the overall energy mix.

Freshwater[2] is already scarce in some regions of the world. Because of climate change, the share of the population at risk of water stress could greatly increase in the future. The most recent *Global Environment Outlook* (GEO4) estimates that 1.8 billion people will live in areas where there is "absolute water scarcity" and two-thirds in areas experiencing water stress by 2025 (UNEP, 2007). Figure 1.1 shows the Water Stress Index (WSI) at the watershed level globally.[3] In addition, global trends such as increasing population, rapid urbanization, and changes in dietary trends will increase demand for agricultural and forestry products used as food, fodder, fibre and fuel, and hence put further pressure on water resources.

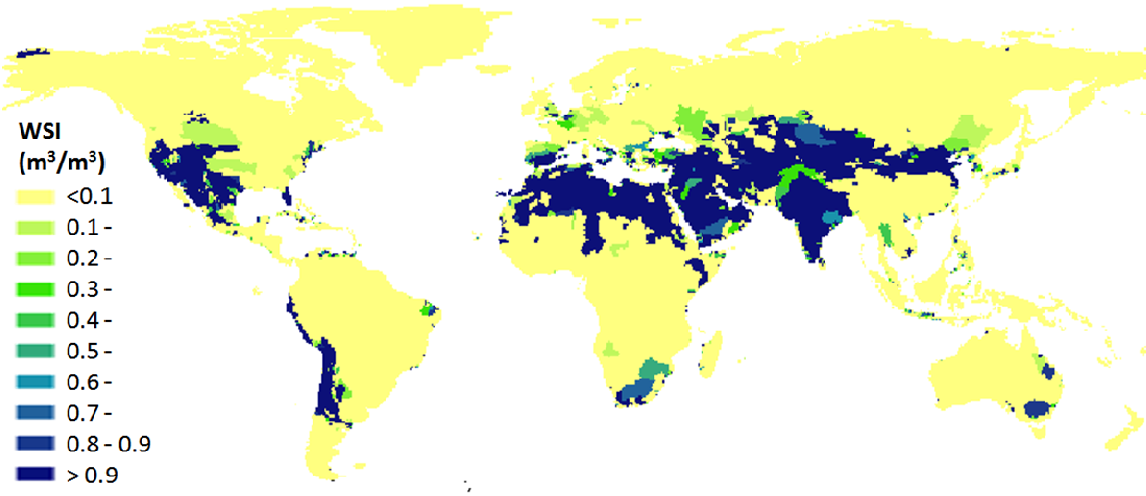


Figure 1.1: Characterization of the Water Stress Index (WSI) at the watershed level per m^3 of water consumed. Source: Pfister et al. (2009)

Bioenergy production[4] has been expanding rapidly, driven by concern about climate change as well as about oil price volatility and dependency on imports for energy security. Bioenergy is also being promoted in many countries as a possible source of job creation and improvements in livelihood conditions, especially in rural areas. This will lead to further demand for biomass.

[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.

[3] The Water Stress Index (WSI) is discussed in Section 3.5.1.

[4] The term "bioenergy production" is used in this report to capture the various ways of producing biomass and converting it to solid, liquid and gaseous biofuels for heating, power and transport. However, it is recognized that the use of this term does not fully take into account the first law of thermodynamics (i.e. energy can be neither created nor destroyed, but only change forms).

Historically, the availability of suitable land has been the primary focus when bioenergy potentials have been studied (see, for example, Berndes et al., 2003 and Dornburg et al., 2010 for overviews of studies). While studies have arrived at different conclusions, it is not uncommon for them to estimate that several decades into the future it should be possible to produce biomass corresponding to several hundred exajoules (EJ) of energy per year. Current global industrial roundwood production, by comparison, corresponds to 15-20 EJ/year, and the global harvest of major crops (cereals, oil crops, sugar crops, roots and tubers, and pulses) to about 60 EJ/year (FAOSTAT, 2011).

Clearly, biomass extraction in agriculture and forestry would need to increase substantially, and both land use intensification and the expansion of managed land might be required, in order to realize such potentials.

Bioenergy strategies emphasizing high land use efficiency (i.e. maximization of bioenergy output per unit of land) to mitigate the risk of (direct and indirect) emissions from land use change may lead to a preference for high-yielding systems that receive large inputs of fertilizers, pesticides and irrigation water. Such bioenergy systems could place large demands on local water resources while increasing the pollution load from fertilizer and pesticide run-off. Thus, at some locations there may be trade-offs to manage between climate change mitigation activities and sustainable use of water resources (Berger and Finkbeiner, 2010). Furthermore, increasing the amount of biomass dedicated to bioenergy, through the establishment of large-scale bioenergy plantations in sparsely vegetated areas, may increase evapotranspiration, leading to diversion of water from run-off to surface water as well as reduced groundwater recharge (Zomer et al., 2006; Berndes, 2008). On the other hand, if bioenergy plantations are located in such a way as to reduce run-off, reductions in soil erosion at the site, flooding, and sedimentation in rivers and dams could be achieved.

In this context, growing demand for bioenergy presents opportunities to adapt to difficult water situations and promote more sustainable water management. New technologies have the potential to reduce some pressures, but in many cases more research is required. In Section 1.2 as well as Chapter 7 of this report some consideration is given to future developments, particularly technological developments which could affect bioenergy-related water impacts.

While these aspects of water use are as relevant to agriculture in general as to the cultivation of bioenergy feedstock in particular, the latter may further increase competition for water. Of all sectors, the agricultural sector is already the biggest user of water resources, consuming approximately 70-80% of global freshwater supplies (World Water Assessment Programme, 2009).

The largest component of water use associated with bioenergy is the cultivation of feedstocks. Depending on location, agricultural practices and the crops' growing period, the source of water may be either rainwater or surface and groundwater used to supplement rainfall through irrigation. Pollution of water by agro-chemicals can also be characterized indirectly as a "water use" since it may reduce freshwater availability by contaminating water resources. From a life cycle perspective, in addition to direct water use associated with bioenergy feedstock production, consideration should be given to the water "embedded" in agro-chemicals and to water use during post-harvest processing of the feedstocks used to produce the energy carrier (e.g. pellets, wood chips, bioethanol, biodiesel).

In conventional studies on the potentials of bioenergy, water has often been *considered implicitly*, as amount of precipitation and soil moisture characteristics are two of the parameters that determine suitability for bioenergy crops. Nevertheless, these studies provide little insight into the consequences for water resources, locally or regionally, of actually realizing estimated bioenergy potentials by shifting land use to the cultivation of bioenergy feedstocks. It is of the utmost importance for the future state of freshwater resources how – and where – biomass is produced for energy.

So far, projections of how growth in bioenergy demand could become a driver of sustainable rural development and sustainable land use (especially in developing countries) have paid limited attention to the relationship between water and land use. For example, a common proposition is that establishing bioenergy plantations can help reclaim degraded land. This proposition is primarily based on potential on-site benefits, such as increased soil productivity and the sequestration of atmospheric carbon in soil and above-ground vegetation. In this regard, watershed level analyses are needed to improve our understanding of the effects on water resources of converting land with sparse vegetation to more productive bioenergy plantations. Such analyses should consider potential positive and negative effects. Positive effects might include reduced run-off, soil erosion and sedimentation in rivers and dams, together with increased water retention. Negative effects might include reduced groundwater recharge and downstream water availability, leading to increased scarcity, and greater competition for access and use – including with respect to environmental flows.

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? And how can society mitigate the impacts and guide development towards sustainable use of these resources, including groundwater, rivers, and riparian and wetland systems?

The characterization of bioenergy-related water use is necessary at different spatial and temporal scales if its effects are to be understood and options developed for minimizing negative effects and optimizing positive opportunities. Key points to note when considering the interaction between bioenergy and water resources are that interactions between land use associated with bioenergy and water resources vary over time and space; and that any influence on water quantity or quality can have a significant impact downstream. Furthermore, thresholds may exist beyond which there could be far-reaching consequences – including complete transition to new ecosystem states, which may take place rapidly once these thresholds are crossed. A return to the previous ecosystem state would then be difficult.

In considering the ways bioenergy can impact water resources, the report looks at appropriate tools to assess effects at different spatial and temporal scales. A number of indicators and assessment tools have been developed to include the water perspective in analyses and to 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. If done well, careful integration of bioenergy feedstock production into the agriculture/forest landscape could improve overall water productivity while mitigating water quality impacts associated with current land use. If done poorly, however, such integration could create new problems and exacerbate existing ones related to unsustainable use of land and water.

1.2 Future developments

The most common use of biomass for bioenergy remains the traditional burning of charcoal, wood and manure for cooking, space heating and lighting, generally by poorer populations in developing countries. Modern use of bioenergy in industry and for power generation, heating and transport corresponds to about 20% of the world's total bioenergy use. This share is growing rapidly. While wood and other lignocellulosic biomass is currently used mostly for heat and electricity generation, certain conventional food/feed crops are used as feedstocks in the production of liquid biofuels.

Liquid *biofuels* (Box 1.1) are mainly used in the heat/power and transport sectors, although they can also be used for cooking, heating or in small-scale engines to provide mechanical power. Unrefined oils (e.g. straight vegetable oil) have various uses in the transport and energy sectors, but they are principally used in the food and pharmaceutical industries. These oils can be further refined into *biodiesel*, an internationally tradable commodity. There has been significant research on and demonstration of technologies for converting **lignocellulosic material** into various types of advanced biofuels such as alcohols, diesel substitutes and methane. If such technologies become commercially available, there may be a shift in the preferred bioenergy feedstock types, with the crops currently used for conventional/"first generation" biofuels (sugar and starch, and oilseeds) being replaced by lignocellulosic feedstocks such as dedicated, high-yielding plants grown in both short and long rotations as well as agricultural and forestry residues.

Such a shift would significantly change the way bioenergy feedstock production affects water resources. In view of the possibility that large areas of high-yielding lignocellulosic plantations will be established to meet growing bioenergy demand, the hydrologic effects of such land use change need to be studied.[5] Advanced biofuels, if produced and converted sustainably, are expected to lead to decreased reliance on food crops and less use of arable lands, to be accomplished through using wastes and residues, relying on non-edible plants (or portions of plants), and greater conversion efficiency.

Box 1.1: Types of liquid biofuels

Conventional/first generation biofuels

Nearly all the liquid biofuel crops used today belong to the so-called "first generation", including the sugar and starch crops from which ethanol is made and the oilseed crops which are the source of biodiesel. Some first generation crops such as sugarcane and oil palm are highly efficient photosynthetically and thus likely to be competitive for some time; furthermore, due in part to their photosynthetic efficiency, the supply of raw biomass and the associated availability of co-products is also greater than in the case of other crops. These characteristics could help minimize conflicts with food production. Another issue is the value of co-products with respect to provision of food and feed. Successful incorporation of co-products could help reduce impacts on food prices and land use.

Advanced biofuels

Advanced biofuels subsume all non-first generation biofuels. Many authors refer only to second generation biofuels, but some also to third and fourth generation biofuels. The traditional way of defining the "generations" of biofuels refers mainly to efficiency in conversion and the wider availability of feedstocks. It does not always imply greater sustainability. Sustainability depends upon how feedstocks are developed and

[5] Also see Chapter 4 (Section 4.1.2, Box 4.2 and Section 4.4.1) and Chapter 5 (Section 5.2.2 and Box 5.1).

managed, and under what socio-economic conditions. Consequently, despite their greater efficiency, various sustainability challenges associated with advanced biofuels need to be addressed.

Second generation

Second generation biofuels mainly comprise cellulosic ethanol, which is generally produced through hydrolysis of woody or fibrous biomass, and the Fischer-Tropsch biomass-to-liquids (BTL) fuels. In addition to the physical difference in conversion platforms due to reliance on biological vs. thermo-chemical methods, there are two key differences in the use of biomass and the resulting fuels. One is that the lignin is separated in biochemical conversion and can therefore be used separately for heat and power production, whereas with BTL the lignin is also converted into synthesis gas. A second difference lies in the fact that the biochemical route produces only ethanol, whereas BTL can produce a range of fuels with different properties, including aviation fuels as well as substitutes for gasoline and diesel. Projections of production cost tend to show a close equivalence for the two second generation options. The speed of market commercialisation for second generation biofuels will depend on technological learning, with its associated cost reductions.

Third generation

Third generation biofuels are generally defined as those derived from algae. Not only do algae-based biofuels have much higher energy yields, but since they are grown in water, they may avoid most of the land use conflicts that characterise first and second generation biofuels (although they could contribute to water competition and conflicts). Algae-based biofuels also extend the versatility of end uses beyond those of second generation biofuels because they can be used to create many different types of fuels, including not only substitutes for gasoline or diesel but also photobiological hydrogen gas (Brennan and Owende, 2010). Again the versatility of end uses, fuels and energy carriers (gas, electricity, solid, hydrogen) represents an improvement over the previous generation of biofuels.

Other advanced biofuels (fourth generation)

Other advanced biofuels are associated with synthetic biology and, more generally, the use of biotechnology to "design" biofuels with specific technical characteristics to meet particular end-user needs or market demands. These advanced biofuel technology platforms will combine genetically optimized feedstocks designed to capture large amounts of carbon with genomically synthesized microbes; the microbes will actually produce fuel and absorb CO_2. Consequently, these advanced (or fourth generation) biofuels would be carbon negative, unlike their carbon-neutral predecessors (Kivits et al., 2009). Advanced biofuels can also have spin-offs in many other sectors – health, industry, chemicals, or almost any sector that relies on resource inputs, whether renewable or non-renewable.

Source: FAO et al., 2011

It is likely that growers of crops used to produce first generation biofuels will increasingly consider the relative value of their **residues**. In particular, in the future these crop residues may be used as bioenergy feedstock similarly to the way residues and processing by-products in the food, feed and forest sectors are used today to produce solid biofuels. This is especially crucial in the case of first generation biofuels, where the "main" product represents only a fraction of the actual biomass produced (Gheewala, 2011). Use of residues and processing by-products could substantially reduce the water intensity of bioenergy feedstock production since the water used to produce food and conventional forest products provides residues and by-products for bioenergy. Water productivity could also increase, as more utility (e.g. both food and bioenergy) would be obtained per unit of water used.[6]

[6] Also see Chapter 2 (Section 2.3.4 and case study 2.4), Chapter 4 (Section 4.1) and Chapter 5 (Section 5.2.2).

Possible effects of **climate change** on the hydrological cycle need to be taken into account in the planning of large-scale bioenergy feedstock production. A key issue is that the spatial and temporal variations of the impacts on water resources are predicted to be accentuated due to climate change. Climate change may alter the frequency, intensity and duration of precipitation events that affect water supply. Changes in run-off are expected to reduce water availability in rivers and aquifers. Effects on water quality and increases in seasonal water demand for crops are also anticipated (World Water Assessment Programme, 2009).

In this context, the growing demand for bioenergy also presents opportunities to adapt to difficult water situations and promote more sustainable water management. Some bioenergy crops are drought-tolerant and relatively water-efficient and can be grown in areas that are unsuitable for conventional food and feed crops. Some can be cultivated as vegetation filters for treatment of nutrient-bearing water (e.g. pre-treated wastewater from households and run-off from farmland). Soil-covering plants and vegetation strips can be located so as to limit water erosion, reduce evaporation of surface run-off, trap sediment, enhance infiltration, and reduce the risks of shallow landslides (Berndes, 2008). Thus, there is an urgent need to continue studying the hydrologic effects of different types of bioenergy systems (at the local, regional and global levels) to better understand how the expansion of bioenergy feedstock production may influence the state of water resources.

1.3 Structure of the report

The following chapters discuss different elements that are important in order to adequately understand, responsibly react to, and manage issues associated with the impacts of bioenergy on water resources.

Chapter 2 reviews the types of indicators used to inventory water use, focusing on their value as tools for better understanding the water demands of bioenergy feedstock production at different scales. This information is critical in order to evaluate bioenergy production's potential impact on water resources and on human and ecosystem health (Chapter 3); its potential impact on water quality (Chapter 4); and necessary policies and instruments to reduce potential adverse impacts (Chapter 5).

Since the expansion of bioenergy production can result in ecological and social advancement or detriment, sound, science-based decision-making is of critical importance. The probable consequences of proposed activities need to be considered holistically, taking a long-term perspective. To the extent that bioenergy projects have unwelcome social and/or environmental effects, trade-offs between benefits and costs need to be managed. This is, of course, true not only for the water-bioenergy nexus, but extends to all impact categories. *Chapter 3* seeks to inform decision-making through examining the complex bioenergy-water nexus, while *Chapter 4* focuses specifically on bioenergy's influence on water quality, including ways to assess and mitigate negative impacts.

Sound bioenergy development requires careful consideration of local and regional contexts, including policies and other instruments put in place to ensure sustainable management of water resources. Demand management is increasing in importance as a strategy for addressing water scarcity as well as water pollution. *Chapter 5* reviews policies and instruments that can directly or indirectly influence how bioenergy feedstock production and conversion affects the availability and use of water.

Water has been a core issue wherever environmental (and social) criteria have been discussed with respect to certification schemes for bioenergy production and use. *Chapter 6* presents an overview of a number of relevant certification schemes that include criteria and indicators for water stress and/or pollution. Use of such indicators and criteria can help identify sustainable approaches to bioenergy.

Chapter 7 looks at ways to address the identified issues. It summarizes the findings of the previous chapters, ranging from technical tools to processes, and from policy to project level measures such as certification. It also points to the need for further research, the filling of data gaps, and the development of regionalized tools.

2 Evaluating water use for bioenergy production at different scales

2.1 Introduction

The growing literature on the characterization of bioenergy-water links, which includes the use of indicators such as "embedded" or "virtual" water, the "water footprint" (Box 2.1) and "consumptive water use", has helped to raise awareness of the increasing demand for water to use in bioenergy production. However, generally valid quantifications of the impact of bioenergy production on water resources are complicated because of the multitude of existing and rapidly evolving bioenergy sources (i.e. feedstock diversity); the complexities of physical, chemical and biological conversion processes; and variability in site-specific conditions. Obtaining an adequate general understanding of the impact of bioenergy production on water resources from the existing literature is also hampered by differences in scope, system boundaries, definitions of water use, and methods employed.

This chapter reviews the different types of indicators that can be used to inventory water use, focusing on their value as tools to better understand the water demands of bioenergy production. The information these indicators provide is critical for understanding the potential impact of bioenergy production on the health of water resources and on human and ecosystem health (Chapter 3); its potential impact on water quality (Chapter 4); and the policies necessary to reduce potential adverse impacts (Chapter 5). Case studies on bioenergy production using various types of feedstock at different locations, and at different spatial scales, illustrate appropriate uses of these indicators and highlight their usefulness in specific contexts. Caveats on their use are summarized at the end of the chapter, along with future needs.

Box 2.1 The water footprint

The "water footprint" builds on the concepts of blue, green and grey water (Falkenmark, 1999) (Box 2.3). It is a single index that can be obtained by combining these three components (Hoekstra et al., 2009a). 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."

The water footprint concept has received significant popular media attention, as it is an effective communication tool. However, because it reduces complexity to a single value based on average spatial and temporal conditions, it has been criticized for failing to consider (strongly varying) local water contexts, i.e. impact, including dynamic and spatial variations of water resource availability and competing use, and the possibility that laymen do not understand differences between different types of water use (see, for example, Ridoutt and Poulton, 2010, and the further discussion of water indicators in Chapter 3). In other words, the water footprint discards too much detail and scientific rigour for the sake of conceptual clarity and requisite simplicity (Stirzaker et al., 2010). Attempts have been made to modify this concept through separating water use by source and using regionalized water stress indices to make a more meaningful presentation of water use (Ridoutt and Pfister, 2010a).

Among other sources, more information concerning the use of the water footprint can be found on the Water Footprint Network website: http://www.waterfootprint.org.

2.2 Inventories of water use

The literature on the water requirements of bioenergy production largely concerns 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. Studies may concentrate on part of the bioenergy supply chain or consider the entire life cycle. Volumes of water abstracted, consumed and altered are estimated in these studies in order to create an inventory of the water requirements of a bioenergy product (i.e. a liquid biofuel for transport or bioelectricity). Table 2.1 summarizes selected water inventory indicators commonly used in the literature.

Box 2.2: Water balances

Based on the reasoning that water use and losses are essentially transfers within the broader hydrosphere, water engineering approaches have been developed that utilize water balances (i.e. inputs and outputs given a defined system) to identify and quantify all water flows so as to estimate water use (Wiedemann and McGahan, 2010). Depending on how the studied system is defined, such approaches may or may not allow consideration of effects over varying spatial and temporal scales. They may also leave out water quality aspects, and therefore fail to consider that water may become degraded beyond the point of critical pollution – limiting further use to those that can make use of such degraded water, or requiring additional water for dilution to meet quality requirements for other uses.

Water use and the associated effects on water flows and ecosystems are measured by various metrics, depending on the water source, removal from the water cycle via evaporation or transpiration, and qualitative alteration (degradation). Blue water withdrawn from surface bodies and aquifers is used both consumptively and non-consumptively. Consumptive use removes water from the current hydrological cycle (Box 2.4) through evaporation, evapotranspiration or product incorporation. By definition, consumption implies that the water consumed is not immediately available for use by humans or the ecosystem in the watershed from which the water was originally withdrawn. Blue water used non-consumptively is released back to the environment, with or without change in quality, and is available for downstream uses such as agriculture, industry and human consumption. Unlike the use of blue water, use of green water is considered only in a consumptive sense. However, modification of green or soil moisture storage can influence blue water availability (also see a).

Box 2.3 Definitions of blue, green and grey water

Following the definitions of Rockström et al. (2009), blue water refers to water in rivers, lakes, wetlands and aquifers, which can be withdrawn for irrigation and other human uses, while green water is the soil moisture held in the unsaturated zone, formed by precipitation and available to plants. Consistent with this definition, irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation), but rain-fed agriculture only receives green water (Hoff et al., 2010).

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 (Hoekstra et al., 2009a).

Table 2.1: Selected water inventory indicators commonly used in the literature

Indicator	Description (studies may use slightly different descriptions)	Selected relevant literature on water use for bioenergy	Case study presented in this chapter
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)	Sugarcane (Brazil)
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 green water and blue water (Box 2.3). King and Webber (2008b), Chiu et al. (2009), Pfister et al. (2009), Berndes (2002). Referred to as blue and green water "footprint" by Gerbens-Leenes et al. (2008a und b)	Bioenergy crops (global)
Degradative water use	Withdrawal and subsequent discharge to the same watershed after water quality has been (significantly) degraded.	Pfister et al. (2009)	See Chapter 4
Grey water use	Volume of freshwater required to assimilate the load of pollutants, based on existing ambient water quality standards.	Gerbens-Leenes et al. (2008a und b)	
Life cycle water use	Water consumed/withdrawn throughout the life cycle of biomass-based fuels (including their end use) (see Box 2.5). Life cycle water use may consider water use credits for co-products (see case study 2.4).	Chapagain and Orr (2009), Ridoutt and Pfister (2010b), Mishra and Yeh (2011),	Corn (maize) (United States)
Effects on water flow balances			
Crop water balance	Evaluates the water balance (Box 2.2) 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.		Jatropha (India)
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)	Jatropha (India), bioenergy crops (global)

Box 2.4: The hydrological cycle and bioenergy production

A bioenergy production-related perspective of the hydrological cycle is shown in Figure 2.1. The key water partitioning points and components of the hydrological cycle are highlighted, i.e. the points at which land cover in general and bioenergy production in particular are likely to have an impact on the way incoming precipitation is partitioned.

1. At the plant canopy level, incoming *precipitation* is partitioned into vertically oriented fluxes, i.e. upward, represented by evaporating water (*interception loss* and transpiration from the stomata), and downward, represented by *throughfall, stemflow* and canopy drip, ultimately forming *net precipitation* once it passes through the litter layer.

2. At the soil surface, net precipitation is partitioned horizontally into *surface run-off* and vertically into *infiltration,* as well as into water vapour through direct *evaporation* from the soil or litter layer.

3. In the root zone, upward water fluxes are generated, i.e. direct *evaporation* from the soil and, more importantly, uptake of water by the root system for *transpiration*. In this zone water is also partitioned both into downward percolation, ultimately providing *groundwater recharge,* and horizontally into "interflow", provided by unsaturated flow which moves downslope to eventually form *streamflow*.

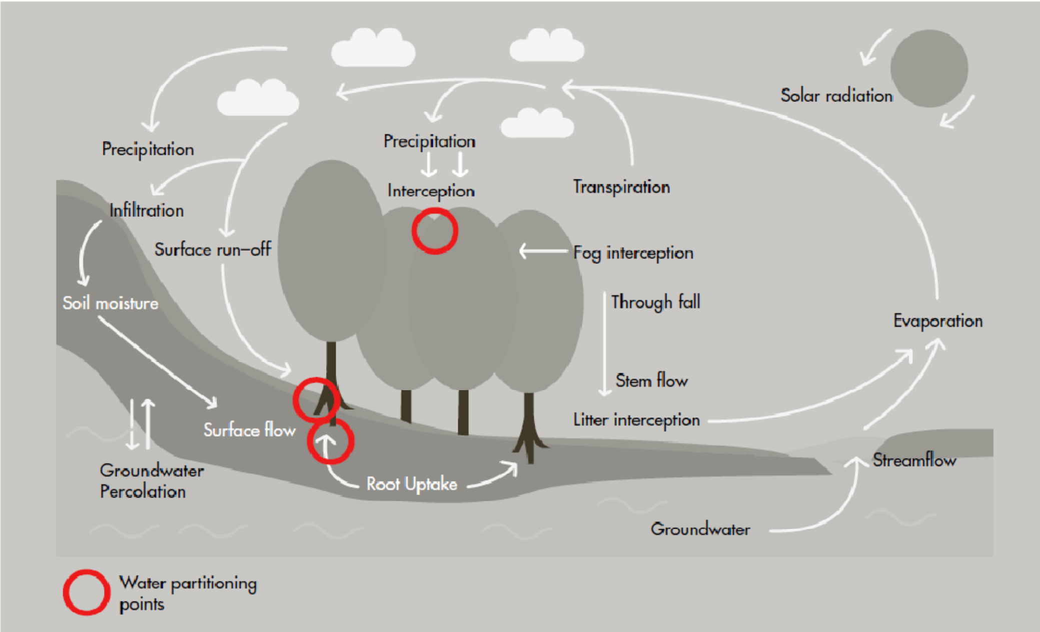


Figure 2.1: Key water partitioning points in the hydrological cycle affected by bioenergy production

The land cover in the catchment partitions rainfall between water vapour flows to the atmosphere as evaporation and transpiration and the flow of water to rivers and groundwater. Water use by a bioenergy crops is driven by ground structure above (leaf area and pattern) and below (rooting depth and pattern) and the rate at which water is used (interception and transpiration), which is further controlled by atmospheric and soil conditions. In arid and semi-arid areas, run-off to rivers is generally less than 10% of precipitation. Thus, a small change in the partitioning of rainfall by land cover, which typically occurs when plantations are established, can have a relatively large impact on run-off and groundwater recharge.

Source: Based on Jewitt (2005)

Inventories express water requirements as the amount of water use per unit of bioenergy produced (referred to as *"water intensity"* in this chapter). The reciprocal of intensity, i.e. the amount of bioenergy produced per unit of water use, is referred to as *"water productivity"* or *"efficiency"* in this chapter. The bioenergy produced may be expressed in terms of energy content, volume, or vehicle distance travelled if used as transport fuel.

2.2.1 Productive versus non-productive uses of water

Metrics measuring water use could potentially classify such use as productive or non-productive, as indicated in Figure 2.2. Reducing the impacts of water use in bioenergy production can be achieved through *(i)* reducing non-productive evaporation and consumptive water use in the field and at the conversion facility throughout the supply chain; and/or *(ii)* improving the management and planning of productive consumptive and non-consumptive water use, including improving productivity across a range of agricultural management regimes, from rain-fed crops to irrigated ones.

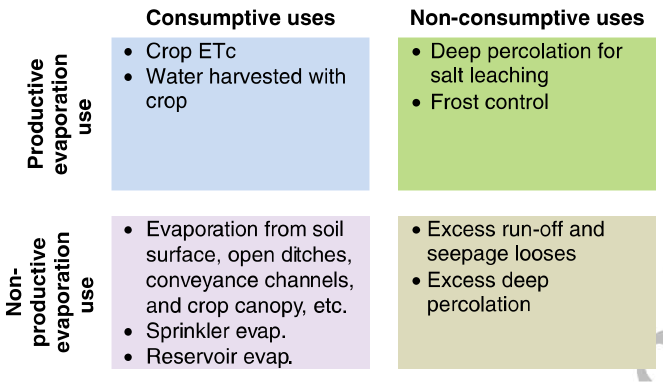


Figure 2.2: Schematic diagram showing different types of water use in a production system. Source: Modified from Burt et al. (1997)

Excess run-off may be consumptive if water is discharged to a watershed different from that of the withdrawal point.

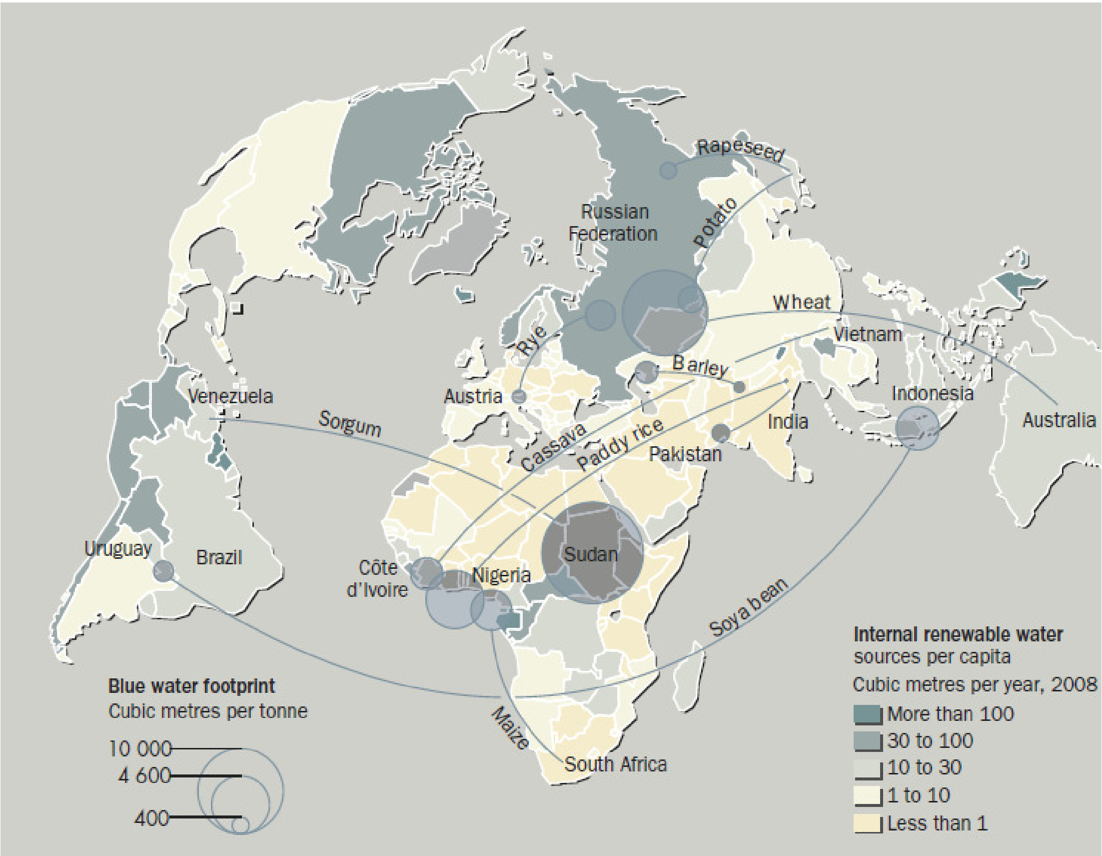
If non-productive evaporation is reduced in favour of plant transpiration, the total biomass harvest may increase without necessarily increasing the pressure on downstream freshwater resources. This can be achieved through changes in soil and water management (including rainwater harvesting), as well as through the introduction of suitable bioenergy crops that allow more effective water use. For instance, some plants that are suitable as bioenergy feedstock are considered to be drought-tolerant, to have relatively high water use productivity, and to be suitable for cultivation in areas that are not suitable for conventional food and feed crops (case study 2.3). Plants cultivated in rotation with conventional crops can also make better use of rain falling outside the growing season of the conventional crops.

2.2.2 Spatial scale of analysis

The spatial scale of many of these types of analysis is usually at the sub-national (e.g. state/province) or national level, depending on data availability. National or sub-national average data typically aggregate over wide variations in water requirements (due to variations in climate and weather conditions) and sources of water use (due to differences in regional water availability and sources). On the other hand, detailed spatial modelling at the watershed level, where bioenergy feedstock production interacts with hydrological processes, allows more careful assessment of impacts (NAS, 1999; Pfister et al., 2009). These trade-offs will be discussed in greater detail in the following sections.

Figure 2.3 shows variations in the blue water footprint of selected bioenergy 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 from Brazil, produced from sugarcane in rain-fed agricultural conditions, and biofuel pellets from Canada).

Figure 2.3: Variations in the blue water footprint of selected energy crops. Source: UNEP/GRID (2011)



2.3 Water use categories

Water use (consumptive or non-consumptive; productive or non-productive) accounting is generally based on the volumes of water used. Various water use categories identified in the literature are reviewed below.

2.3.1 Blue water consumption

Volumetric estimation and impact assessment of blue water (BW) consumption has received detailed treatment in freshwater life cycle assessment (LCA) literature (Box 2.5), including studies dealing with the bioenergy-water nexus. Consumptive BW use is equal to the water withdrawal minus the portion of withdrawn water that returns back to water bodies, where it is available for possible further use. Many estimates of consumptive BW use quantify the consumptive water requirements of bioenergy production, thermoelectric systems and other agricultural products (King and Webber, 2008b; Chiu et al., 2009; et al., 2009a). Consumptive BW use is a relevant metric for analysis of freshwater consumption as a basis for quantifying impacts on ecosystems and human health and well-being (Pfister et al. 2009).

2.3.2 Blue water withdrawal

Water withdrawal includes all (blue) water abstracted from surface water bodies or groundwater aquifers for industrial, agricultural, or domestic use (Box 2.3). Withdrawal is contrasted with non-withdrawal water use, which includes in-stream use for purposes such as hydroelectric power generation, transport, fishing and recreation. Thus, non-withdrawal use is not directly relevant to agricultural use of water. Withdrawn water is either used consumptively and removed from the current hydrological cycle through evaporation, transpiration or product incorporation; or it is 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 that estimate the water requirements of bioenergy production focus on the consumptive use of water and do not estimate the withdrawal requirements (Gerbens-Leenes et al., 2008 a and b, 2009; Mubako and Lant, 2008; Chiu et al., 2009; Wu et al., 2009; Fingerman et al., 2010). The difference between withdrawal and consumption arises because of the spatial boundary selected for analysis. Water run-off from a farm due to irrigation system inefficiencies can be used productively on a downstream farm, or it can contribute to environmental flow requirements in nearby rivers. Seepage losses from unlined irrigation canals may recharge groundwater or have other environmental benefits. For example, estimates of overall water use efficiencies for individual systems in Egypt's Nile Basin are as low as 30%, but the overall efficiency of the entire Nile system is estimated at 80% (Rosegrant et al., 2002). The concept is summarized by Perry et al. (2009), who indicate that "...'losses' at the scale of an individual field or an irrigation project are not necessarily 'losses' in the hydrological sense...". This has implications on how water intensity estimates are scaled up to total water requirements for the production of bioenergys at a regional or national level.

However, estimation of the withdrawal and non-consumptive use of BW, essentially excess irrigation water, is also informative. Excess irrigation water helps leach salts, but non-consumptive use of BW can lead to higher pumping costs for farmers and water districts. Significant water withdrawals from surface water bodies may exert localized and/or seasonal impacts on the ecosystem, as in the case of thermoelectric plants with once-through cooling systems. For regions dependent upon groundwater for irrigation, extraction of groundwater beyond recharge rates could lead to aquifer depletion (Shah and Burke, 2007). Therefore, estimation of water withdrawal intensity along with consumption intensity is also useful (Fargione et al., 2010) and has been incorporated in some recent LCA literature (Mishra and Yeh, 2011).

2.3.3 Green water consumption

Green water (GW) consumption refers to crop evapotranspiration (ET_c) requirements met through precipitation. For rain-fed crops, demand for ET_c is met entirely through precipitation and soil moisture depletion. Irrigation (blue) water is applied in regions where GW is insufficient to meet ET_c requirement (Box 2.3).

Studies estimating consumptive water use differ with respect to whether and how to include GW. Ridoutt and Pfister (2010b) and Pfister et al. (2009) argue that since GW processes also occur in natural vegetation and are integrated with and conditioned to the land (in terms of geological, geographic and hydrological processes) in the region under consideration, cultivation provides access to GW just as it does to solar radiation, wind and soil. Therefore, they argue that GW use should be integrated with the land use category in LCA when quantifying its environmental impacts. Similarly, Milà i Canals et al. (2009) recommend only estimating changes in BW formation due to land use changes when quantifying the environmental impacts associated with water consumption. For understanding water flow dynamics, however, including GW in the analysis – as opposed to using it as an indicator for water use impact in LCA context – is critical in many cases: conversion of natural or managed vegetation to bioenergy feedstock plantations can alter interception of GW and affect BW formation (case study 2.3 on jatropha). This change in hydrology can result in rising groundwater levels and increased river run-off in some cases (Jackson et al., 2005; Zomer et al., 2006; Scanlon et al., 2007; Malmer et al., 2010; b and Pfister, 2010b). Changes in land use can also influence infiltration and run-off rates through influencing soil properties such as soil organic matter and vegetation cover over the year.

Hoekstra et al. (2009b) favour estimation and explicit reporting of GW requirements, arguing that their inclusion acknowledges competing demands for limited freshwater resources. Water returned to the atmosphere through GW consumption may otherwise have replenished groundwater levels or contributed to river flows required for maintaining healthy aquatic ecosystems. Further, inclusion of GW provides a complete picture of water resource dynamics and is important for water resources management. Accounting for GW may also help to better assess the effects on water resources in agricultural production in sub-humid and semi-arid regions, and facilitate the development of strategies to tap the productivity of both GW and BW (Rockström et al., 2009).

2.3.4 Life cycle water use

Literature from the LCA community tends to focus on the development of methods to quantify the impact of water consumption considering spatial differences in water scarcity and water use consequences on surrounding ecosystem. To address the argument concerning system boundaries and whether to account for GW, many new water life cycle bioenergy studies combine all water use and explicitly state sources of water inputs throughout the life cycle (Box 2.5). Water inputs can include green and blue (surface and ground) water uses (Chapagain and Orr, 2009; Ridoutt and Pfister, 2010b; Mishra and Yeh, 2011), as well as degradative use (Pfister et al., 2009) and grey water consumption (Chapagain, 2006; Gerbens-Leenes et al., 2008 a and b, 2009). Some studies also account for application losses (Mubako and Lant, 2008; Mishra and Yeh, 2011) and conveyance losses (Mishra and Yeh, 2011).

Water that is lost to ET_c during biomass production for energy 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 influence water resources and the environment in other ways. For example, excess residue removal may increase erosion and reduce water retention capacity. Or the residue may already be used for other economic activities.

Studies comparing water use for biofuels and fossil fuels have generally found that the total water requirements (GW + BW) of fuel production are higher in the case of biofuels than in that of fossil fuels (Gerbens-Leenes et al., 2009) and that BW consumption for biofuels from rain-fed crops and residue is generally lower than that for gasoline, although it is orders of magnitude higher if the biofuels are produced from irrigated crops (Wu et al., 2009; Mishra and Yeh, 2011). However, such a comparison of the volumetric BW consumption intensity of biofuels and fossil fuels is simplistic. For example, in some cases cultivating rain-fed crops on marginal land can reduce unproductive evaporation loss and increase water productivity and soil moisture levels, reduce run-off, and provide other sustainability benefits. On the other hand, as discussed earlier, the use of GW in some other areas can have impacts on terrestrial ecosystems and BW availability downstream.

Although the water intensity of fossil fuels is low on average compared with that of biofuels, it has been widely reported that bituminous or oil sands production and shale oil extraction could result in substantial stream water withdrawals and significant alteration of water flows during critical low river flow periods (Griffiths et al., 2006; Davidson and Hurley, 2007), groundwater depletion and contamination, and wastewater discharges (GAO, 2010; Kelly et al., 2010). A detailed comparison of biofuel versus fossil fuel water use should carefully examine the impacts of water use on changes in water availability and quality and other ecosystem health effects at the local level (and/or taking into account seasonal variations).

Box 2.5: Life cycle assessment

Water is increasingly considered in life cycle assessment (LCA) studies, where methods continue to be developed (Chapter 3). Earlier, water was coarsely aggregated as a volume over a product's entire life cycle, the only distinction being qualitative (regarding the source). There was no attempt to model the final impacts, unlike in other impact categories. More recently, however, the desire to characterize water at a more refined level has motivated significant activities at both the inventory and impact assessment stages (Milà i Canals et al., 2009; Pfister et al., 2009; Bayart et al., 2010). Further development of water accounting in LCA is currently taking place due to initiatives of the World Business Council on Sustainable Development (WBCSD) and the UNEP/SETAC Life Cycle Initiative (Berger and Finkbeiner, 2010). The UNEP/SETAC Life Cycle Initiative, among others, recommends that the assessment method be regionalized in regard to the hydrological context. It recognizes freshwater consumption as a phenomenon that has impacts because it lowers freshwater levels and also reduces water availability to meet other needs, including maintenance of ecosystem function and diversity. The consequences of water use can be modelled at the mid-point level as resource depletion, and at the end-point level as human health effects and biodiversity loss (Bayart et al., 2010).

Attempts are being made to integrate local and regional conditions – including water quality, water availability, socio-economic considerations and water allocation requirements – within the impact assessment scheme. These assessments can be made at the watershed level, national level or across these levels, depending on the scope and conditions. Temporal variations (e.g. seasonality) are also important for assessing water stress. They should therefore be included in future modelling efforts, as explained in more detail in Chapter 3.

2.4 Case studies

Consistent with the order in Table 2.1 and Section 2.3, the four case studies in this section are concerned with measuring BW consumption and withdrawal; GW consumption and crop water balance; life cycle water use at the farm system, field and state level; and global bioenergy water analysis.

The selection of assessment tools depends largely on the questions asked, as well as on their relevance to the local/regional context. For example, in regions where crops are mostly rain-fed, water withdrawal and BW consumption provide more direct measurements of the effects of bioenergy production on local water allocation among various users (case study 2.1 on sugarcane ethanol in Brazil).

If the same measurement is used to evaluate bioenergy water demand globally, it clearly underestimates crop water demand, especially in arid regions. Thus, accounting for crops' total ET_c use is clearly needed for consistent comparison across feedstocks (case study 2.2 on global bioenergy production).

Such an accounting method allows further studies to recognize the importance of potentially positive and negative effects of GW use, and to identify appropriate management strategies needed to minimize the impacts of GW use and promote the use of non-productive GW at the local level without increasing local BW stress (case study 2.3 on jatropha in India).

Lastly, the case study of corn (maize) production in the United States (case study 2.4) illustrates an innovative life cycle approach that accounts for *avoided* water use due to displacement by co-products of bioenergy production, together with a methodology that can be used to account for water use by agricultural waste and residues.

Case study 2.1: Sugarcane ethanol in Brazil: measuring BW withdrawal at the farm-system level and overall effects on streamflow

Sugarcane cultivation in Brazil traditionally does not require irrigation. The practice of irrigation is more prevalent in the Brazilian northeast, which accounts for about 10% of total sugarcane production. While irrigation is becoming more common in the midwestern part of the country, it is still associated with supplementary or rescue irrigation, either to restore soil moisture at field capacity or to provide water needs during periods of water stress. Irrigation volumes are low, ranging from 100 to 200 mm per year, and largely use nutrient-rich wastewater generated from industrial production of sugar and bioethanol instead of freshwater. Therefore, the primary opportunity to reduce consumptive BW use in the sugarcane industry in Brazil lies in reducing water use at the mills.

Water withdrawal in the sugarcane industry was substantially reduced as a result of environmental legislation and the gradual deployment of systems for recharging water resources, both of which followed promulgation of the Brazilian Constitution in 1988. Water withdrawal was about 15-20 m^3/tonne of cane around three decades ago due to the use of water open-circuit technology. Today, withdrawal has been reduced to about 1.85 m^3/tonne through water recycling and other measures to improve water use efficiency (Figure 2.4). Further improvements in wastewater treatment systems that allow increased reuse of water are moving the sector towards the water withdrawal goal of 1.0 m^3/tonne of cane (Elia Neto and Shintaku, 2010).

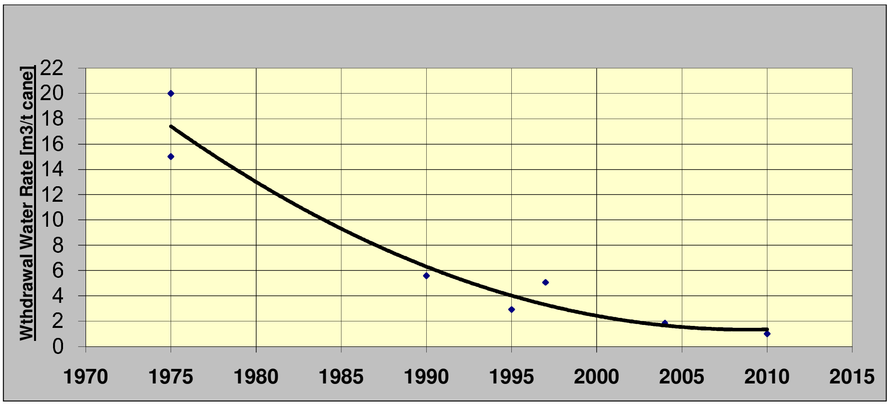
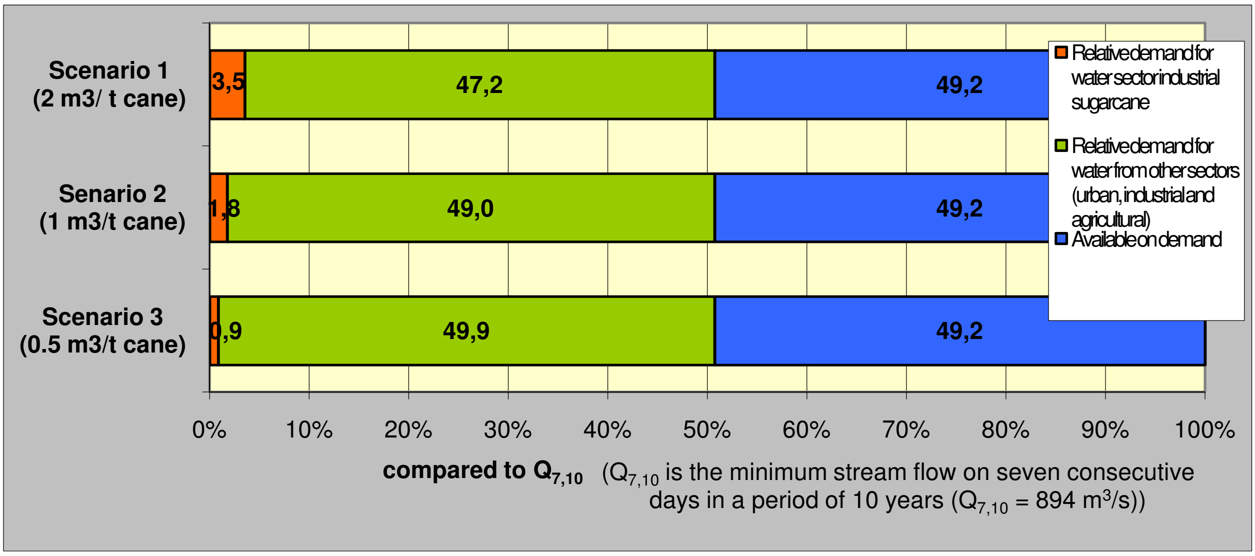


Figure 2.4: Tendency curve of the rate of water withdrawal for the sugarcane ethanol industry in Brazil. Source: Elia Neto et al. (2010a)

In the State of São Paulo, which has the largest concentration of ethanol and sugar mills in Brazil, water use by the sugarcane sector accounted for about 13% of state-wide total water use and about 40% of use by the entire industrial sector in 1990.[1] Over the last two decades, the sugarcane industry in the State of São Paulo has greatly increased its production and, at the same time, reduced its relative water use. It now accounts for 8% of state-wide total water use and 25% of industrial sector use, and its share of state-wide total water use is projected to decline further to less than 1% by 2015 (Elia Neto et al., 2010a). Figure 2.5 shows water demand in the sugarcane industry and in the State of São Paulo as a whole. Demand is represented as a percentage of modelled minimum stream flow using three scenarios, including different assumptions for water reuse and the use of existing and future technology.

Figure 2.5: Scenarios of water demand in the sugarcane industry and in the State of São Paulo as a whole, Brazil



For more information about sugarcane ethanol production in Brazil, see Section 4.2.1.

Case study 2.2: Global assessment of bioenergy feedstock: options for enhancing water productivity through agronomic improvements and regional shifts in production

Water scarcity can limit intensification possibilities and the prospects for expansion of agriculture. Increased bioenergy demand presents both challenges and opportunities in this context, and the outcome for the state of water depends on where and how (and obviously how much) bioenergy feedstock production expands. Under strategies that focus on first generation biofuels for the transport sector, mainly using conventional agricultural food/feed crops as feedstock, the associated water use will resemble that driven by increasing food sector demand. However, the geographical pattern may be different since the demand for biofuels for transport may be distributed differently from increasing demand in the food sector. International trade in biofuel feedstock and biofuels may also influence the geographical pattern of crop production and associated water use.

There is significant potential to increase the currently low productivity of rain-fed agriculture in large parts of the world through improved soil and water conservation, including on-site water management (Lal, 2003; Rockström and Barron, 2007; Rost et al., 2009; Rockström et al., 2010). Investment in agricultural research, development and deployment could produce a considerable increase in land and water productivity (Rost et al., 2009; Herrero et al., 2010; Sulser et al., 2010). Ecosystem modelling can be used to assess the impacts of bioenergy expansion in relation to food production and water, but can also help increase the understanding of improvement potentials in agriculture, and of the relative importance of different options for land and water management to improve water productivity and land use efficiency.

The ecosystems modelling package LPJmL[7] was used to quantify water productivity for selected agricultural crops that are suitable as bioenergy feedstock. Consumptive water use was calculated as total water evapotranspiration (ET) on grasslands over the whole year and on cropland during the growing season (i.e. the sum of interception, soil evaporation and transpiration). Yield levels were calibrated against average 1999-2003 yields as reported by the Food and Agriculture Organization of the United Nations (FAO). The crop production and related water flows were corrected for multi-cropping by applying country-specific cropping factors, calculated as the ratio of harvested area and LPJ cropland extent. This correction was applied for rain-fed and irrigated areas separately. Consumptive conveyance losses of irrigation water were not accounted for. Consumptive water use for bioenergy production per country was estimated from the crop-specific national water productivity values (i.e. yield per unit ET for the growing season).

The results shown in Figure 2.6 suggest that water productivity varies considerably among the different crop-biofuel combinations, and that there is a significant geographic variation for the same crop-biofuel combination. This underlines the importance of soil and climatic factors. However, agronomic management is also a strong determinant of water productivity, as it influences yield levels and is also relatively important for transpiration and soil evaporation.

[7] LPJ is a dynamic global simulation model of vegetation biogeography and vegetation/soil biogeochemistry. Taking climate, soil and atmospheric information as inputs, it dynamically computes spatially explicit transient vegetation composition in terms of plant functional groups, and their associated carbon and water budgets. LPJmL (mL for managed lands) additionally simulates the carbon and water budgets of agricultural land and of land use change. It uses land use and land management data as inputs.

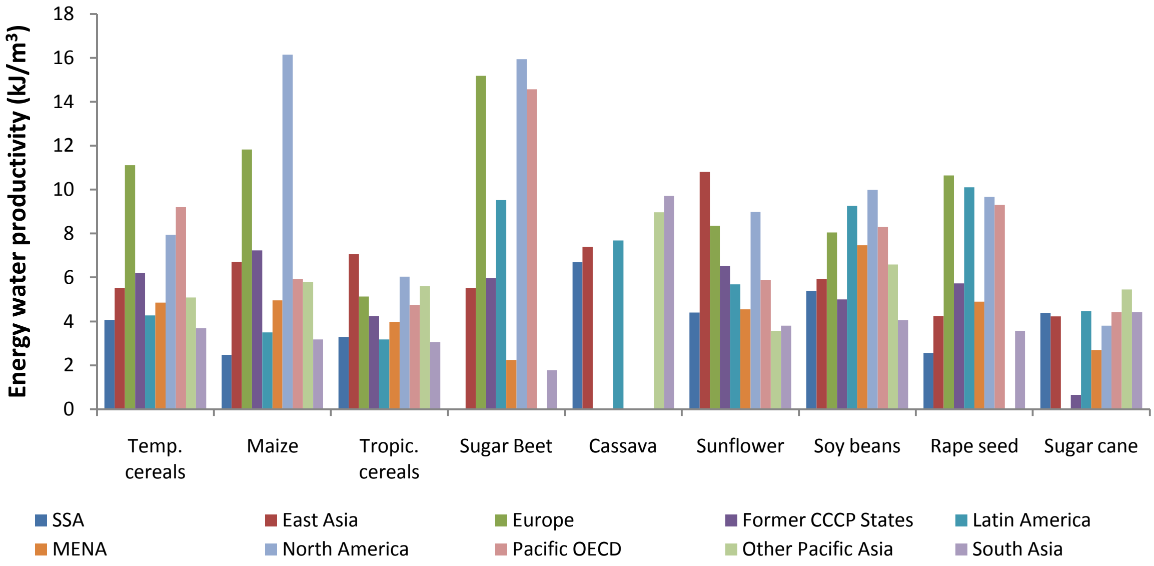


Figure 2.6: Bioenergy produced per unit of water consumed for selected agricultural crops. Average of national bioenergy water productivities without any weighting for country sizes. Modelled data correspond to average values for the simulation period 1998-2003.

Scenarios depicting ways to increase crop production for food or bioenergy were also developed, including: *(i)* changes in crop choice; and *(ii)* improved crop management. The impact of crop choice from a water perspective was illustrated by assuming that the total amount of water currently used by different bioenergy crops was instead used to cultivate only the most water-efficient crop (in terms of amount of energy produced per unit water consumed). Crop management scenarios were created by closing the yield gap to different degrees. In this context, yield gap was defined as the difference between current and maximum attainable leaf area index.

On a global basis, assuming that resources other than water are not limiting to growth, changing crop type to more water-efficient crops could theoretically increase energy outputs from bioenergy crops by about 60% without impacting on run-off, i.e. leaving downstream users unaffected by this increase in output. Improved management could improve crop yields by 10-40%, depending on the degree of management improvements. The increased biomass production resulted in higher water consumption during growth, reducing run-off generation. However, this run-off reduction was found to be small in comparison with total run-off levels (below 1%).[8]

Case study 2.3: Biodiesel from jatropha in India: measuring the impact of land use changes on GW balances and BW formation

Jatropha (*Jatropha curcas* L.), commonly known as purging nut or physic nut, is a perennial deciduous, multipurpose shrub belonging to the family Euphorbiaceae (Tatikonda et al., 2009; Divakara et al., 2010). The decorticated seeds of this plant yield about 28-40% oil, which can be transesterified, blended with diesel and used as biodiesel. There is a need for breeding and genetic improvement of the species to achieve improved yield stability and insect and pest resistance. While

[8] This case study will be presented in more detail in a forthcoming paper by G. Berndes, L. Karlberg, J. Heinke and C. Hamelinck: "Global water use for bioenergy production: policy impacts and options for water savings."

jatropha is a drought-tolerant wild plant with low nutrient demands, little is known about its actual water requirements and production potential in different agro-ecological regions.

A water balance for fallow waste land and jatropha-cultivated land is shown in Table 2.2. The table partitions rainfall into three hydrological components: soil evaporation (E) or evapotranspiration from cultivated land (ET_a), run-off (outflow) and groundwater recharge. The share of rainfall lost as surface run-off from the watershed boundary was reduced from 43% to 31% following cultivation of jatropha on fallow waste land. Correspondingly, water consumption increased from 52% to 64% of total rainfall due to a shift from soil evaporation to crop evapotranspiration, indicating that cultivation of jatropha on wasteland could potentially utilize GW more effectively. The share of rainfall recharging groundwater remained constant in both scenarios.

Table 2.2: Annual water balance of Velchal village waste land under two different land uses. Source: Wani et al. (2009)

	Fallow waste land	Jatropha-cultivated land with land management practices
Rainfall (mm)	896	896
Outflow from the watershed (mm)	393 (43%)	274 (31%)
E or ET (mm)	460 (52%) (primarily non-productive*)	580 (64%) (high share of productive use)
Groundwater recharge (mm)	43 (5%)	42 (5%)

*Extensive grazing on waste land results in a small share of the total ET on the waste land being productive.

The E or ET component for both fallow waste land and jatropha-cultivated land is shown in Figure 2.7.

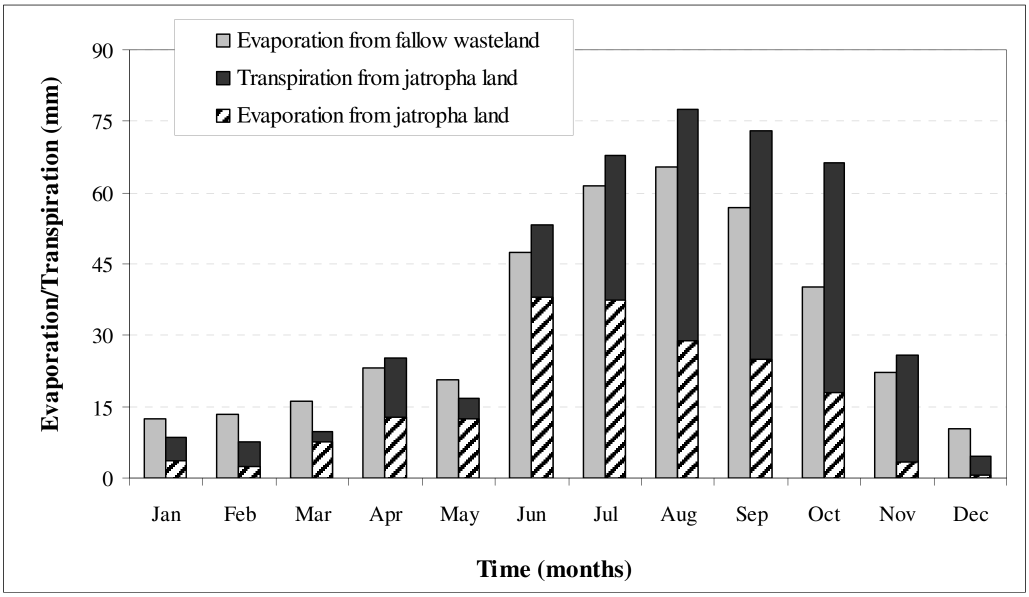


Figure 2.7: Evaporation/transpiration from fallow waste land and jatropha-cultivated waste land in India. Source: Wani et al. (2009)

In fallow waste land, a large fraction of rainfall absorbed by the soil (in the form of soil moisture) was being lost through soil evaporation in both monsoon and non-monsoon periods. Diversion of water from run-off and evaporation to evapotranspiration led to increased plant growth. This benefited the landscape by increasing soil moisture content and reducing soil erosion and nutrient losses. Measured agronomical data show that jatropha produced approximately 1 to 1.5 tonnes of biomass/ha annually and biomass containing 1 tonne per carbon/ha per year was added to soil during dormancy (leaf fall) along with pruned plant parts. Thus, jatropha could be a suitable candidate for sequestrating carbon and rehabilitating waste land into productive land over a long time period.

It is found that the amount of rainfall and its distribution affect crop yield substantially. Despite high rainfall in 2009, seed yield in that year was poor due to erratic rainfall distribution compared to 2008. Contrary to the belief that jatropha needs less water, this study indicates that it could use large amounts of water under favourable soil moisture conditions for luxurious growth and high yield. Moreover, crop yield is found to be affected substantially by water stress. Integrating a watershed development programme, together with improved germ plasm, may help to achieve an economical jatropha crop yield in the semi-arid tropics.[9]

Case study 2.4: Corn (maize) ethanol in the United States: life cycle water use for bioenergy from corn grain and agricultural residue and "avoided" water use due to co-products

The existing literature measuring water use for bioenergy production does not account for co-products from the process. For example, conversion of corn grain to ethanol also produces distillers grain with solubles (DGS). When DGS is used as animal feed, it displaces other feed such as corn grain, urea and soybean meal (SBM), which in turn displaces raw soybean (ANL, 2010; Wang et al., 2010). Production of DGS therefore precludes the need to produce other animal feed, as shown in Figure 2.8. The figure also shows the ratios of DGS displacement of other animal feed after normalization for feed efficiency.

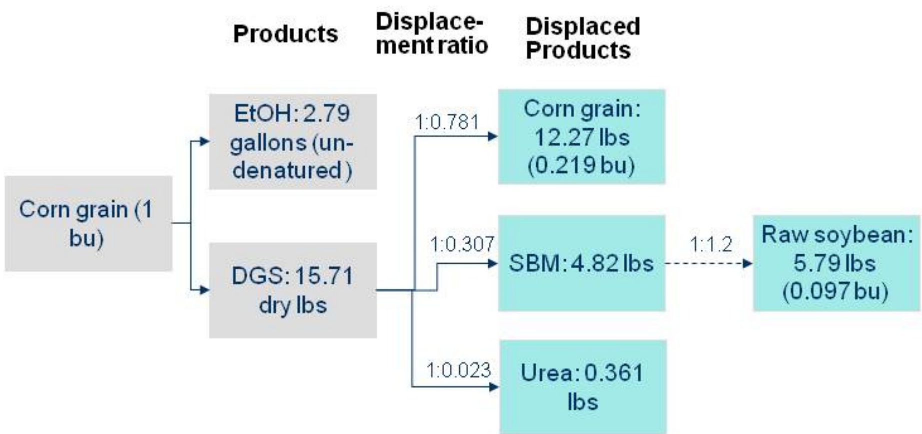


Figure 2.8: Yield of ethanol and co-products from dry mill and masses of displaced products (per bushel of corn grain input) in the Unted States. Source: Mishra and Yeh (2011)

[9] This case study will be presented in more detail in a forthcoming paper by K. Garg, L Karlberg, S. Wani and G. Berndes: "Biofuel production on waste lands in India: Opportunities and trade-offs for soil and water management at the watershed scale."

The displacement ratios, based on relative nutrient content and market share of DGS and displaced products (Arora et al., 2008), are used to calculate the amount of displaced products and the amount of water saved by not producing them. Similarly, combustion of the lignin component of agricultural residues such as corn cob produces electricity for plant consumption and surplus that can be exported to the grid, displacing electricity that has an average water intensity of 2.46 litres/kWh in the United States (King and Webber, 2008a).

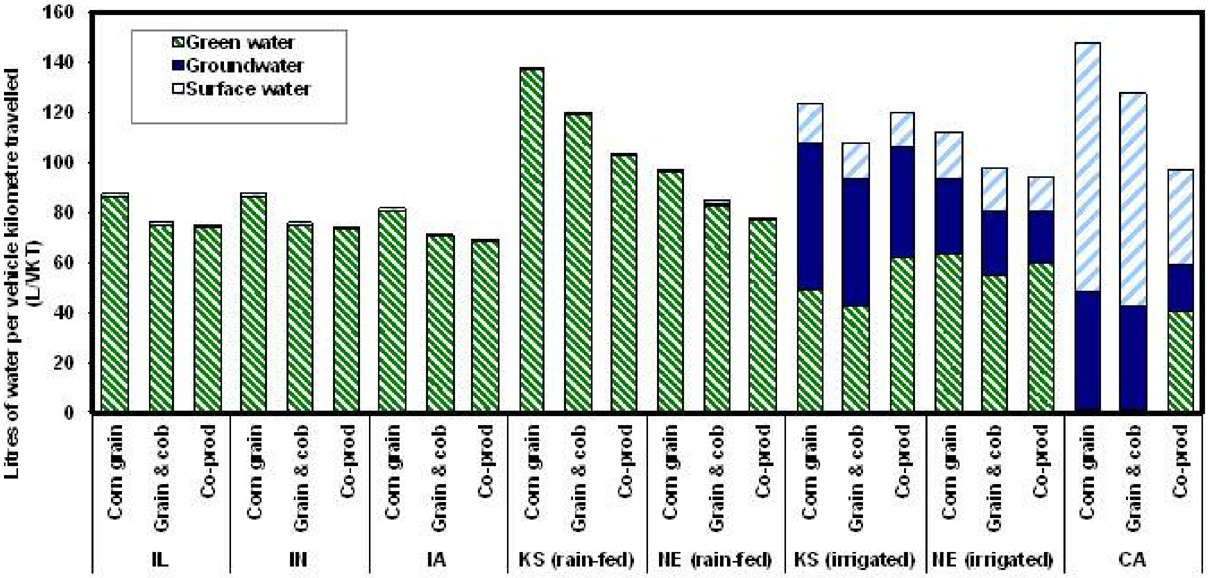


Figure 2.9: Estimation of the water use intensity of corn (maize) grain ethanol and the *avoided/displaced* water use credits assigned to co-products in the United States. States represented are: Illinois (IL), Indiana (IN), Iowa (IA), Kansas (KS), Nebraska (NE) and California (CA). Source: Mishra and Yeh (2011)

In the examples here, co-product credits are around 5% and 45% of total BW used to produce ethanol from rain-fed and irrigated corn (maize), respectively; and around 50% of GW in both cases. The results (Figure 2.9) reflect displaced corn grain and soybean, along with lower yields and hence higher water intensity of soybean. The study assumes that displaced corn (maize) and soybean are grown in the same region (except in California, where DGS displaces soybean from the midwestern United States). Harvesting and converting the cob to ethanol reduces both the BW and GW intensity by 13%. Cellulosic ethanol from the cob alone (not shown in the figure) has a BW consumption intensity of 0.85 litre per vehicle kilometre travelled (VKT), which is contributed from biorefinery water use, and zero GW requirement.

The case study estimated the water intensity of cellulosic ethanol using the displacement method, which assigns water use during corn (maize) cultivation entirely to corn (maize). However, once cob is established on a commercial scale, it will cease to be treated as an agricultural residue and the revenue potential of both grain and cob will influence farming decisions. Under these circumstances, an allocation procedure based on economic value may be more appropriate (Wang et al., 2010), which will reduce the water intensity of grain ethanol but increase that of cellulosic ethanol.

The water requirement of agricultural wastes can also be estimated using a life cycle approach. This necessitates partitioning water used during corn (maize) cultivation between grain and cob. Allocation methods based on mass, energy or economic value are possible, although the system expansion/displacement method is generally preferred (Kim et al., 2009; Wang et al., 2010). In this method, feedstock in the new system where both grain and residues are harvested displaces the reference system where residues are incorporated back into the soil. Thus, the displacement method is equivalent to partitioning to residues only the incremental environmental burden that results from harvesting of residues, while the entire baseline environmental burden is partitioned to grain (EPRI, 2002; Kim et al., 2009; Wang et al., 2010; Mishra and Yeh, 2011;).

The water effects of displacement illustrated above need to be interpreted with great caution. The inventory approach may be different from the impact assessment, in that the displaced water may be widely separated from the water effects of ethanol production in both time and space. Deduction of avoided water use due to co-products from total water use associated with ethanol production can therefore result in incorrect information about the local/regional effects. Evaluation of local impacts should consider total water use from feedstock production, rather than *net* water use after consideration of co-products.[10]

2.5 Future directions

As illustrated in this chapter, tools for the assessment of water use are useful in water resources management and planning at the local, regional and global levels. Accounting for GW consumption and BW withdrawal and consumption across product life cycles enables us to better understand the total water demand within certain time frames and spatial boundaries. These assessments also enable us to measure the efficiency of the agricultural and bioenergy production systems, and to identify the potential management strategies or feedstock varieties to optimize water use at the plant, farm, regional and global scale.

However, a careful translation is needed from the water use assessment to impact evaluation. Water use evaluation often employs, by necessity, *spatial* and *temporal* aggregation that sums more than one form of water consumption (blue, green and grey water) in locations where the relative importance of water-related aspects differs. Thus, it often gives no clear indication of potential social and/or environmental harm or trade-offs (Pfister et al., 2009; Ridoutt and Pfister, 2010b). Similarly, *temporal* aggregation over an annual period ignores the inter-seasonal variability of water use and water scarcity (which are often substantial in certain regions). It therefore may not convey the important information about seasonal water use competition or excess unless this simplification is clearly spelled out.

Recent literature on freshwater LCA has developed regionally differentiated characterization factors that measure water scarcity at a water basin level or even higher resolution (Milà i Canals et al., 2009) and also account for temporal variability in water availability (Pfister et al., 2009). Volumetric estimates of BW and GW 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 the explicit water inventory results to undertake impact analysis and accurately assess the

[10] This case study is presented in more detail in G. Mishra and S. Yeh (2011), “Lifecycle water consumption and withdrawal requirements of ethanol from corn grain and residues”, *Environmental Science & Techno*logy 45 (10): 4563-4569.

effects of bioenergy production on water resources. These impacts are discussed in greater detail in Chapter 3.

In addition, water use indicators may not always convey the most salient information if they fail to include other critical information regarding land use and the current and future reference systems. For instance, production systems with lower yield levels may be preferred in water-scarce areas since high-yield systems might reduce downstream water availability for ecosystem and human uses, necessitating a balance between upstream benefits and downstream costs. Thus, water use indicators when combined with land use indicators and a treatment of baseline versus counterfactual scenarios provide a more accurate assessment of changes in water resource allocation and impacts in a specific region (Alcamo et al., 2003).

On the local/regional level, the critical question to be addressed is how a shift to a bioenergy system influences the character and intensity of water use. Local/regional conditions determine what water aspects – and hence water use indicators – are most relevant to consider, as well as the relative importance of water aspects compared to other aspects such as effects on soil quality or biodiversity. It is also important to compare bioenergy options with possible alternative land use options; the bioenergy option can cause both positive and negative effects, and these must be weighted and compared with the effects of an alternative land use. Crops with the same or higher water productivity could have beneficial effects if the annual ET is redistributed over seasons with little water shortage problem, resulting in a reduction of irrigation volume or in other adverse impacts on soil moisture and water flow (McIsaac et al., 2010). Non-productive evaporation can be replaced by productive evapotranspiration through careful selection of bioenergy crops in arid regions, leading to a further increase in GW consumptive use without exacerbating run-off and groundwater recharge.

Ultimately, the land use choice will be determined by land users' prioritization of bioenergy products versus other products obtained from land – notably food, fodder, fibre, and conventional forest products such as saw wood and paper – which will then be determined by the (positive and negative) environmental, social and economic consequences associated with different types of production. This, in turn, depends on natural conditions (e.g. climate, soils, topography) and on agronomic and forestry practices in producing the biomass, but also on how societies understand and prioritize water-related aspects versus others such as nature conservation and soil/biodiversity protection. All these important considerations will affect how the production systems are shaped to reflect these priorities.

2.6 Conclusions

This chapter reviews water use indicators for estimating the total water demand of bioenergy production at various spatial scales. Figure 2.10 summarizes the types of water use indicators introduced in the chapter and effects that link to different levels of protection: resource depletion at midpoint and human and ecosystem health at the endpoint.

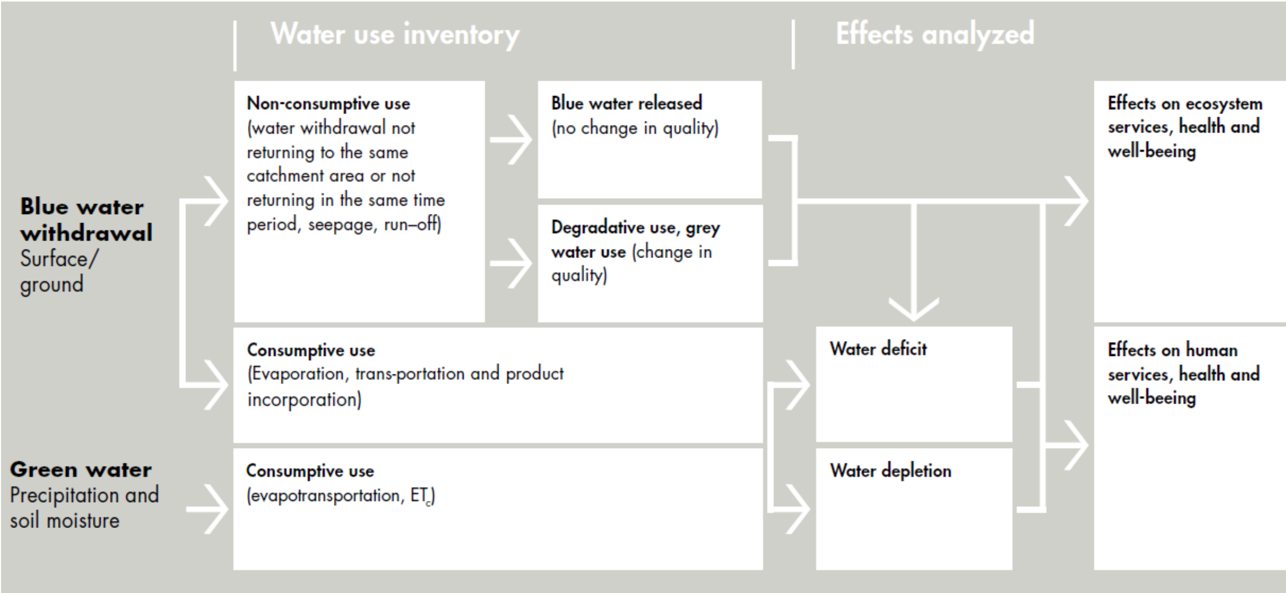


Figure 2.10: Different types of water use characterized in water LCA studies and resulting effects, measured by various indicators. Souces: Guinee et al. (2004), Milà i Canals et al. (2009), Pfister et al. (2009), Bayart et al. (2010)

Volumes of water abstracted, consumed and altered are estimated so as to arrive at an assessment of the water requirements of a bioenergy product, providing useful tools for water resources management and planning at local, regional and global levels. BW use indicators, integrated over time and space, provide the most direct measurements of the effects of bioenergy production on freshwater allocation among various end users, and on human and ecosystem health and well-being. Indicators for total water demand for crop evapotranspiration (ET_c) communicate vital information about how land and water productivity supports/constrains bioenergy expansion, and help to identify areas where the productivity of agriculture could potentially be increased through improved soil and water conservation, changes in crop choice, and improved crop management. Life cycle water use indicators provide a useful comparison of the water required for production and conversion of feedstock to various forms of energy, and opportunities to improve water use efficiency throughout the supply chain. In addition, life cycle water use indicators may be used to account for water use *avoided* as a result of displacement of products by co-products of bioenergy production, although these applications must be interpreted with care.

Local or regional conditions, and the objective of the analysis at hand, 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. In Chapter 3, the potential impacts of bioenergy developments on water resources and on human and ecosystem health are further discussed in the light of the pros and cons of existing tools and an assessment framework for decision makers is proposed.

3 Impact assessment for decision-making at the bioenergy-water nexus

3.1 Introduction

The expansion of bioenergy production, and its attendant shift and expansion in agricultural and forestry activity, have raised a number of environmental and social concerns, ranging from potentially increased greenhouse gas (GHG) emissions to labour rights abuses, deforestation and reduced food security. Another important concern that has received little attention – although it could prove to be the "Achilles heel" of bioenergy production (Keeney and Muller, 2006) – is that biofuels are very water-intensive relative to other energy carriers. This increased water demand can place considerable stress on available water supplies. Similarly, little attention has been paid to the opportunities that bioenergy may present for adaptation to water constraints. New drought-tolerant plant types could be cultivated as biofuel feedstock, and might be integrated with food and forestry production in ways that improve overall resource management.

Differing patterns of population growth, lifestyle changes, pollution of available water, and climate change will present different scenarios in every region. However, water users, managers, regulators and planners are challenged to meet growing water needs virtually everywhere. Population growth and changing diet are projected to drive a 70-90% increase in demand for food and feed by 2050, resulting in a comparable expansion of global water demand barring major changes in production patterns and water productivity (Molden, 2007). By 2025, two-thirds the world population is expected to live in areas experiencing water stress (UNEP, 2007).

This scarcity is intimately connected to both poverty and health concerns for human populations, as well as hindering the proper functioning of local ecosystems. Bioenergy expansion must be seen in this wider context of water scarcity, particularly with regard to its competition for water needed to grow food.

Energy and water are deeply inter-related, although different energy carriers have very different "water footprints" (Chapter 2) depending on the processes involved in their production. In the United States, for example, thermoelectric power generation accounts for 49% of total freshwater withdrawals (Kenny et al., 2009). However, most of this water is used only briefly for once-through cooling. On a consumptive basis,[11] bioenergy derived from purpose-grown agricultural feedstocks are the most water-intensive of all major energy types, usually by at least an order of magnitude (King and Webber, 2008; Chiu et al., 2009; Dominguez-Faus et al., 2009; Gerbens-Leenes et al., 2009; Wu et al., 2009; Fingerman et al., 2010). Their influence on water resources and the wider hydrological cycle depends on where, when and how the bioenergy feedstock is produced.

Among different bioenergy supply chains, across the spectrum of feedstocks and conversion technologies, there is a great deal of heterogeneity in total water demand. Where fuel made from irrigated crops requires large volumes of water, the use of agricultural or forestry residues as

[11] Use of the term "consumption" is complicated by the fact that most of the processes considered in this chapter do not actually destroy water molecules. A commonly used definition of water consumption is relied on here: water is considered to be consumed when it is removed from the useable resource base – through evaporation, evapotranspiration or product incorporation - for the remainder of the current hydrological cycle. Evapotranspiration is therefore a form of consumption; although the water molecules have simply changed physical forms, it is not possible to control where evaporated water will fall next, so the water is functionally lost to the system.

bioenergy feedstocks does not generally require much additional land or water. Similarly, the establishment of rain-fed cultivation may not greatly influence local/regional water resources unless it causes a substantial change in hydrologic flows. The net hydrologic effect depends on what types of vegetation (if any) are removed to make room for bioenergy feedstock production, and how land use and management are changed.

Further variation derives from *spatial* heterogeneity in the water impact of bioenergy production. A given production activity will consume varying amounts of water, depending upon where and when it occurs, and the consumption of a certain amount of water has very different social and ecological consequences, depending upon the state of the resource base from which that water was drawn.

Policy, infrastructure and business decisions related to bioenergy expansion can entail ecological and social advancement or detriment. We must therefore consider the probable consequences of proposed activities holistically. To the extent that bioenergy projects have unwelcome effects of social, political and environmental concern, trade-offs between upstream benefits and downstream costs will need to be managed.

This chapter seeks to inform these decisions in light of the complexity of the bioenergy-water nexus. The goals of the chapter are to:

1. describe the ways in which tools commonly applied to assess the water impacts of bioenergy production can be insufficient for the purposes of business or government decision-making;
2. lay out an assessment framework that should be followed in order to make informed decisions at the bioenergy-water nexus;
3. describe considerations and tools that can be usefully brought to bear on these questions;
4. indicate some location-specific impacts that may be of concern in introducing or expanding bioenergy production, but that may not be revealed even through rigorous and nuanced application of common analytical approaches.

3.2 Common analytical tools at the bioenergy-water nexus

Water footprint (WF) (Box 2.1)[12] accounting and, more generally, water life cycle assessment (LCA) (Box 2.5), as they have been applied to bioenergy (De Fraiture et al., 2008; King and Webber, 2008; Dominguez-Faus et al., 2009; Gerbens-Leenes et al., 2009; Wu et al., 2009; Fingerman et al., 2010) are currently insufficient in their treatment of ecological and social impacts for the purposes of decision-making and mitigation of detrimental effects (also see Chapter 2). LCA was designed, and has been most commonly used, to evaluate industrial products and activities, which generally require relatively low volumes of water. LCA tools have therefore not been developed so as to sufficiently address the water impacts of activities (Milà i Canals et al., 2009; Berger and Finkbeiner, 2010).

Furthermore, many LCA tools were developed largely for use in calculating life cycle greenhouse gas (GHG) emissions, which have a functionally uniform impact wherever they occur. Water

[12] 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.

consumption, however, has implications that vary greatly depending on what resource base is affected, the previous state of that resource, and the location and timing of the use in question.

Water use has been considered in the life cycle inventory (LCI) phase of LCA analyses of various goods (Hoekstra and Chapagain, 2007), as well as in a few studies of bioenergy (Berndes, 2002; De Fraiture et al., 2008; King and Webber, 2008; Gerbens-Leenes et al., 2009; Wu et al., 2009; Fingerman et al., 2010). This work generates salient figures – establishing, for example, that producing a litre of corn (maize) ethanol requires between 10 and 324 litres of water (Service, 2009). Such quantified water demand can be useful in high-level policymaking, particularly when used to compare different activities in a given region. However, water volumes alone are of little use in efforts to minimize impacts, since a given level of consumption in a watershed with still-abundant water supplies can be expected to have far less impact than the same consumption in a watershed experiencing severe water scarcity. The above LCA studies have not made localized assessments, distinguishing among types of water use and the sources from which water was drawn or accounting for local conditions.

Location-specific information on water resource use and impacts is essential to inform responsible decision-making in relation to specific bioenergy projects, or more comprehensive agriculture development plans. This information is not provided by WF studies as conventionally applied,[13] 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), "pure inventory based water footprints can be meaningless or even misleading with regard to impact assessment."

3.3 Framework for assessing the water sustainability of bioenergy

Because of the significant interface between water and energy, responsible policy or industry development for bioenergy requires careful consideration of water requirements and potential effects on the local and regional water resource base, as well as on ecological health and other uses of water. This chapter seeks to inform the process by addressing the question of *what we need to assess* in order to determine whether a proposed bioenergy development would have a positive, negative or neutral effect on the state of water resources in a given area. To this end, we identify some key considerations for quantifying the water intensity of an activity, but leave the detailed discussion of analytical tools to other chapters in this report.[14]

In making or advising on decisions in this area, the following questions should guide our deliberations (Figure 3.1):

1. What do we need to know about the water intensity of an operation or activity that is proposed in a given region/watershed? How can we measure this?

[13] 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.
[14] Detailed discussion of the effect of bioenergy production on water quantity can be found in Chapter 2. Effects on water quality are discussed in Chapter 4.

2. What do we need to know about the state of water resources, as well as societal and environmental water needs, in the region or watershed? How can we measure this?
3. What important potential outcomes for water cannot be captured in these measurements? How can we characterize them?

This chapter seeks to answer these questions, offering an *assessment framework* that operators and policymakers can use as one component in their assessment of the sustainability of proposed activities.

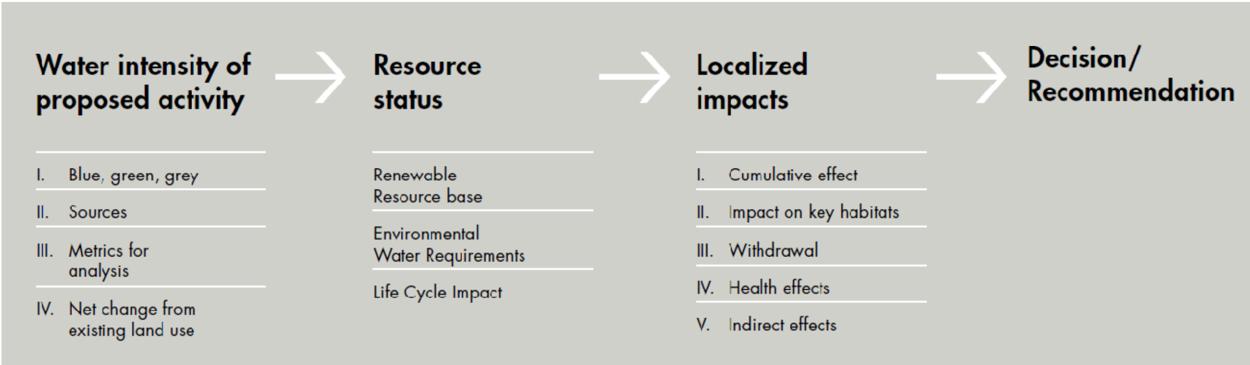


Figure 3.1: Assessment framework: key elements for ascertaining the impacts of bioenergy production on water resources.

The remainder of this chapter goes into detail concerning the questions, metrics, data needs and tools involved in the steps of this assessment framework. Because the issue is relatively new, a number of important questions remain to be answered. We focus here not on the research issues that could and will inform these decisions in the future, but on the current state of knowledge and the existing analytical approaches available to decision makers in this area.

3.4 Measuring water intensity

This section lays out the types of water use that should be considered for a water footprint assessment, or in the analogous inventory phase of water LCA for bioenergy. The tools and approaches for quantifying these impacts are discussed in much more detail in Chapter 2 (consumption) and Chapter 4 (water quality).

Water is consumed at multiple points along the bioenergy supply chain. Figure 3.2 shows the major uses of water necessary for the agricultural and industrial phases of bioenergy production. A comprehensive life cycle inventory (LCI) would account for many or all of these flows, as well as any others specific to the supply chain in question.

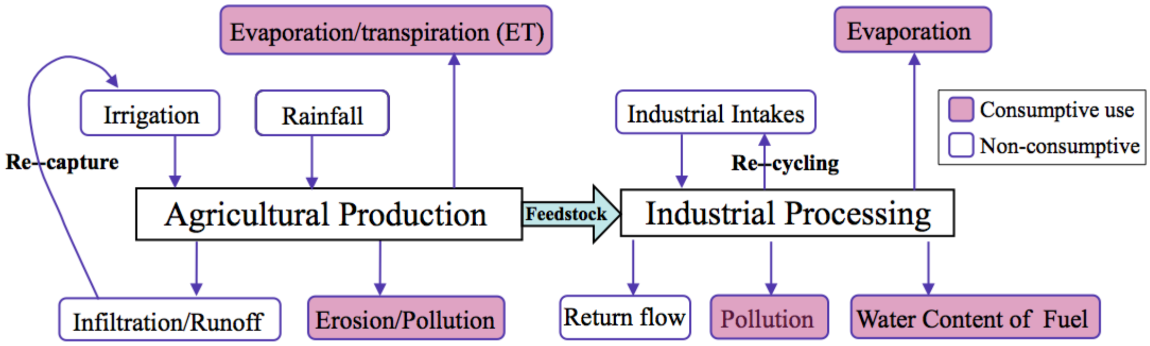


Figure 3.2: Schematic of water uses in the bioenergy life cycle. Flows of water both into and out of the bioenergy production and processing system are represented. Source: Fingerman et al. (2010)

Water resource use and impacts can defy easy quantification for a number of reasons:

1. A given activity can require vastly different amounts of water in different locations, and at different times, due to climatic differences and other factors.
2. Different water sources are not easily comparable. Withdrawals of freshwater from surface flows will have a different effect than groundwater pumping, rainfall, or the use of brackish water.
3. Even where the same resource type (e.g. river flow) is used or polluted, the impact of that activity can vary widely depending on the context of that use, where and when it occurs, and the current status of the affected resource base.

3.4.1 Types of consumption

Early studies of the water impact of bioenergy production focused only on the consumption of *blue water* at the bioenergy feedstock conversion facility (Keeney and Muller, 2006). Later, attention turned more towards irrigation, as further research indicated that the bulk of water use in most bioenergy supply chains occurs due to feedstock cultivation (King and Webber, 2008; Chiu et al., 2009; Dominguez-Faus et al., 2009; RSB, 2010). Recognizing that much of the water transpired by plants is *green water*, some researchers have focused on total evapotranspiration (ET) in characterizing water demand for bioenergy (Berndes, 2002; Berndes, 2008; De Fraiture et al., 2008; Gerbens-Leenes et al., 2009; Wu et al., 2009; Fingerman et al., 2010).

3.4.2 Pollution

Pollution can be considered a consumptive use of water (also called *grey water*) since it removes a certain volume of water from later being used productively. Some studies have made an effort to quantify the fertilizer intensity of bioenergy supply chains (Mubako and Lant, 2008; Dominguez-Faus et al., 2009; Fingerman et al., 2009), as well as to assess the macro-scale environmental effects of fertilizer use for bioenergy expansion (Donner and Kucharik, 2008).

3.4.3 Sources

The impact of a given amount of water consumption or pollution will depend primarily upon the resource base being affected. For example, the implications of pumping renewable groundwater are different from those of extracting fossil groundwater, diverting water from a river, or diverting it from an irrigation canal, although each would be termed "blue water" use. For this reason, any accounting method should disaggregate to the extent possible between different sources. Similarly, impact will vary greatly depending on when and where water is consumed and returned to the source. It is essential, therefore, that analysis be performed at the greatest feasible spatial and temporal resolution.

3.4.4 Metrics for analysis

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 still be misleading. LCAs are generally built around a single “functional unit” in which the impacts in question are measured. Choice of this functional unit for analysis can greatly alter the perceived patterns of impact. In a case study of California ethanol production, Fingerman et al. (2010) found that very different patterns emerge depending on whether water impact is quantified per litre of fuel produced or per hectare devoted to feedstock production (Figure 3.3).

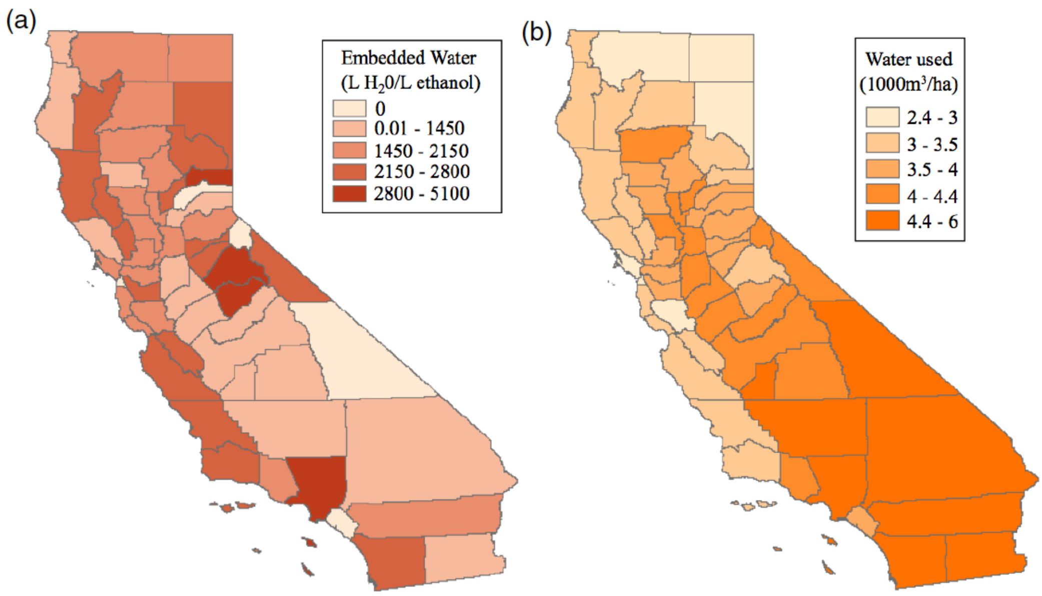


Figure 3.3: In California, USA: (a) water consumption (as total evapotranspiration) for ethanol from low-yield biomass feedstock; (b) annual per hectare water consumption for cultivation of low-yield biomass feedstock. Source: Fingerman et al. (2010)

Optimum water productivity from a megajoule per litre (MJ/L) standpoint would be achieved if bioenergy feedstock production were focused in the hot and arid reaches of Southern California. However, if decision makers are concerned with the equity of resource distribution, with maximizing the utility of naturally available rainwater, or with the energy intensity of pumping vast amounts of water hundreds of miles into the desert, they may want to focus on production in the north of the state.

3.4.5 Getting to “impact”

A variety of impacts can result from the consumption or degradation of freshwater resources. These can include diminished ecosystem functioning from reduced natural flows, as well as impacts on human health and well-being due to poor water quality or quantity or to lack of access (Milà i Canals et al., 2009). However, these impacts do not depend solely upon the absolute quantity of water consumed or degraded by an activity. More important is *net consumption*, taking into account the water intensity of any activities or land uses affected or displaced by the project in question (also see case study 2.4)

Even having conducted a comprehensive, disaggregated and spatially detailed life cycle inventory (accounting for considerations described above), the impacts of the activity in question will not have been adequately characterized. Life cycle impact assessment (LCIA) relates the LCI data to "the potential human health and environmental impacts of the environmental resources and releases identified during the LCI" (ISO, 1998). For water, it is impossible to understand these impacts without assessing the current state of the resource base in which the expected change would occur.

3.5 Characterizing the local water resource base

Characterization of impacts reflects the significant complexities to be found in natural resource systems and their use by society. Values placed on different potential uses and functions, perceptions of significance, and changing water use priorities are individually and culturally subjective. At the core of understanding impacts in water resource systems is recognition of this complexity, and an effort to characterize impacts within local physical and social contexts. Some ecological and social conditions can become impaired at very low levels of water resource disturbance, while others may remain undisturbed until water conditions have been altered significantly.

Individual water LCI or WF results are essentially incommensurable, as the impact of water consumption varies greatly depending on what resource base is affected, the previous state of that resource, and the location and timing of the use in question. In life cycle impact assessment (LCIA), characterization (or weighting) factors are derived whereby these different consumption values can be summed and compared across resource bases and locations. In the case of greenhouse gas LCA, global warming potential (GWP) is often used as a characterization factor to normalize across different types of GHG emissions. The most useful characterization factors for water LCA are derived from metrics of strain on the water resource base. A review of the literature reveals a set of approaches for assessing the status of a local water resource base.

3.5.1 Characterizing scarcity

Perhaps the most basic metric for evaluating water scarcity is that of water resources per capita (WRPC). WRPC values have been used to set annual threshold values for *water stress* – less than 1 667 (or 1 700) m^3 per capita; *water scarcity* – less than 1 000 m^3 per capita; and *absolute water scarcity* – less than 500 m^3 per capita (Falkenmark, 1986). Although it is a standard indicator of water scarcity, common applications of WRPC have not considered intra-annual variation of water availability, differences in water use patterns between countries, or any in-stream uses (Raskin et al., 1997).

From an environmental perspective, the water use per resource (WUPR = total withdrawal/total renewable resource base) indicator (Raskin et al., 1997) is more useful since it includes all human water withdrawals and reports them as a proportion of the total renewable resource base. Where

WRPC captures only the amount of water available to each person independent of any activities, WUPR begins to account for how human extraction has strained resources.

Another metric, drawing on the WUPR approach, is the Water Stress Index (WSI)[15] presented by Pfister et al. (2009). The WSI(Pfister) was introduced as a characterization (or weighting) factor for life cycle impact assessment and has been used to incorporate impact assessment into the traditional WF analyses (Pfister et al., 2009; Ridoutt and Pfister, 2010). That approach adapts LCA tools to water impacts by characterizing effects in three areas: human health, ecosystem quality, and resources. Pfister et al. (2009) innovate by inserting some local nuance into their calculated WUPR, which they refer to as "withdrawal to availability" or WTA. They apply a variation factor to the metric, accounting for climate variability and for storage and flow regulation in managed watersheds. Furthermore, the authors recognize that water stress does not occur linearly with increased WUPR; low levels of withdrawal might not generate much stress, and in highly stressed watersheds further withdrawal may not have much marginal effect. To account for this, they apply a logistic function or **S** curve to translate WUPR values to their Water Stress Index.

The WSI(Pfister) and other common WUPR metrics use withdrawal as their gauge of water use. Withdrawal, however, is not an adequate proxy for consumption. For instance, use of water for thermoelectric generation consumes very little (~2%) of the water withdrawn, whereas irrigation use typically consumes 40-50% (Solley et al., 1998). This means that WUPR-based tools, as commonly applied, can produce highly misleading results. Furthermore, to be useful as an indicator of freshwater ecosystem health, an LCA tool must account for environmental flow requirements. None of the above metrics incorporates this at present.

3.5.2 Environmental flows

Based on principles of ecosystem science and integrated water resources management (IWRM) (e.g. Gleick, 2000), the concept of "environmental flows" has emerged – 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". This concept recognizes that there is a limit to human alteration of natural hydrologic conditions, beyond which a water resource suffers unacceptable (and possibly irreversible) damage to its ecosystem functions. Maintenance of environmental flows should be viewed as both a goal and a primary measure of sustainability in river basins (Dyson et al., 2003; Hirji et al., 2009; Richter, 2010).

Water movement and its variation in time are key drivers of the ecology of rivers and associated floodplain wetlands. Every river and its tributaries express a unique flow regime, produced by climatic, geologic and land cover controls on precipitation and run-off. Because these controlling factors vary geographically, even within the same river basin, flow regimes vary spatially as well. Each of these characteristics has its own (as well as interactive) influences on the shape, size and complexity of river channels, the structure of aquatic habitats, key ecological processes, and the

[15] Some confusion has emerged from the fact that both this metric, and another similar one called the Water Stress *Indicator* (Smakhtin et al., 2004), are abbreviated as "WSI." To distinguish between them, they will henceforth be referred to as WSI(Pfister) and WSI(Smakhtin). The Smakhtin et al. approach is discussed in detail in Section 3.5.3.

ecosystem services[16] the river provides to humans (Bunn and Arthington, 2002; Poff and Zimmerman, 2010).

While bioenergy currently accounts for a small percentage of total water use, its expansion has been implicated in water-related environmental impacts ranging from streamflow reduction to changes in soil-level vapour processes (De Fraiture and Berndes, 2009). Withdrawals from surface and groundwater resources may lead to reduced streamflows in rivers, groundwater decline, and wetland drainage. Other impacts include eutrophication and toxicity effects that can result from the application of fertilizers and agro-chemicals (Smeets et al., 2009). Conversely, biomass can be cultivated in such a way as to offer benefits from a water resource perspective. Some plants can be cultivated as vegetation filters for treatment of nutrient-bearing water, e.g. pre-treated wastewater from households and run-off from farmlands. (Bioenergy-related water quality impacts are discussed in detail in Chapter 4.) Groundcovers and vegetation strips can be used to limit erosion, reduce evaporation of surface run-off, trap sediment, enhance infiltration, and reduce the risks of shallow landslides.

On larger scales, changes in land use and cover – such as reforestation of sparsely vegetated lands to provide carbon sinks or produce biomass for energy – may also affect watershed-scale hydrology, causing shifts in evapotranspiration, run-off dynamics and other hydrologic attributes and potentially altering local climate (Brauman et al., 2007; Uhlenbrook, 2007).

An array of analytical methods and approaches has been developed to assess environmental water requirements (EWR) for specific rivers or throughout a region. The methods vary in their complexity, their data requirements, and the financial and human resources needed for analysis. The type of approach most appropriate for use depends on the resources available and the objectives of the environmental flow assessment.

At the most fundamental level, and in the absence of detailed ecological data, the sustainability boundary approach (SBA) presented by Richter (2010) provides a framework for defining the desirable variability to be maintained for rivers, lakes and groundwater. Using this approach, human-induced changes to hydrologic flows are managed within specified boundaries (Figure 3.4). Richter et al. (in review) subsequently suggested that a sustainability boundary of up to 20% augmentation or depletion from the natural condition would generally maintain good-to-excellent ecological health. These boundaries should be dynamic, reflecting changing societal needs, local ecology, or priorities for resource protection and development.

This type of analysis can be an important first order assessment, especially where data or resources are not available for more in-depth study. At the opposite end of the spectrum lie data and time-intensive approaches incorporating river-specific hydrology, geomorphology, and field ecological study to define environmental water requirements for specific rivers (Tharme, 2003; Richter et al., 2006; King and Brown, 2010). Such detailed analysis will be warranted in the case of politically or socially contentious water allocation decision-making.

[16] Intact aquatic ecosystems can provide humans with a variety of critical services, including water purification, flood and drought mitigation, groundwater recharge, and habitat creation.

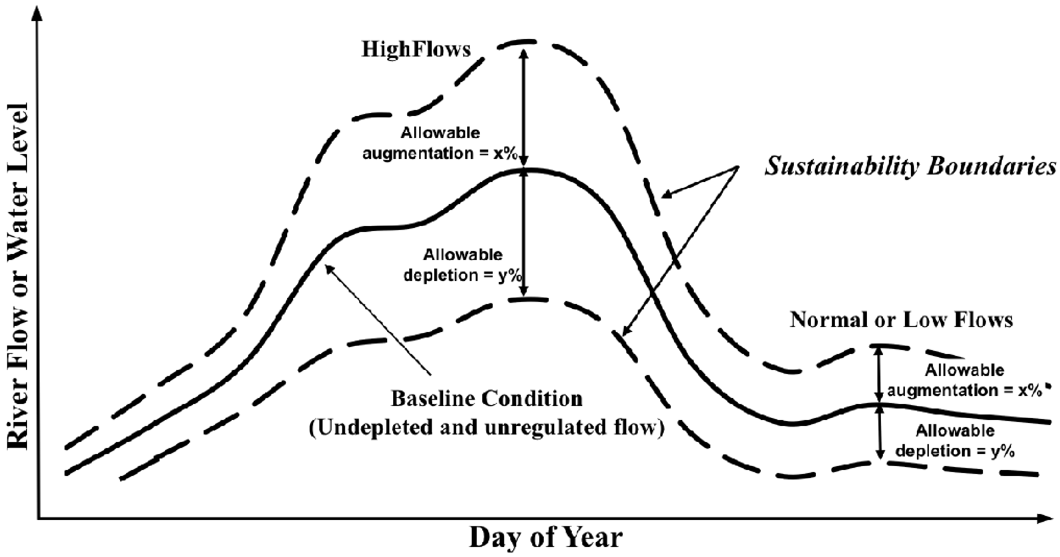


Figure 3.4: Illustration of the sustainability boundary approach (SBA) to maintaining environmental flows. This approach suggests that human-induced flow alterations beyond a certain percentage will likely cause ecological impacts. By managing within sustainability boundaries, ecological impacts can be avoided or minimized. Source: Adapted from Richter (2010)

The recently developed ELOHA (Ecological Limits Of Hydrologic Alteration) framework (Puff et al., 2010) offers a compromise between the need for local nuance and the need for an efficient and broadly applicable system. ELOHA analysis involves a number of steps, briefly outlined here:

1. The first step in the ELOHA process calls for building a hydrologic database to characterize both natural or "baseline" hydrologic conditions and "developed conditions" (i.e. current conditions). These baseline and developed hydrographs can be generated using measured field data and hydrologic modelling.
2. The hydrologic database is then used to calculate the degree of hydrologic alteration that has transpired for each river, or for individual segments of rivers, defined as the percent difference between baseline and developed conditions for a number of ecologically relevant hydrologic metrics.
3. The baseline hydrologic conditions are used to classify each river or river segment into "river types" that are similar in terms of hydrologic, geomorphic, and other environmental features.
4. For each river type, "flow-ecology curves" are developed to describe how ecological conditions are expected to change with increasing degrees and types of hydrologic alteration, using available biological data and the "developed condition" hydrologic data from the hydrologic database.
5. The flow-ecology curves inform decision-making about the environmental flow standards to be set for each river type.

Managing for environmental flows involves setting agreed-upon precautionary boundaries, or benchmarks, beyond which hydrologic regimes should not be altered. The degree of acceptable risk is likely to reflect the balance between the perceived value of the ecological goals and the scientific uncertainties in projected ecological responses to flow alteration (Poff and Zimmerman, 2010). Analysis of environmental water requirements (EWR) should inform policy and business decisions at the bioenergy-water nexus. It can be combined with the WUPR-type approaches described above to characterize a basin, assess risk and project impact.

3.5.3 Incorporating environmental water requirements (EWR)

The Water Stress Indicator (WSI) of Smakhtin et al. (2004) made a first attempt to estimate environmental water requirements for all of the world's river basins and, using this, to characterize risk. EWR and all other water uses were subtracted from the available water resources to derive a water stress indicator at the river basin level (Equation 1). This is a WUPR-style indicator, which better captures the resources available for human use by considering the available resource base to be only the water left over after "reserving" the necessary flows for ecosystems.

$$(1) \qquad WSI(Smakhtin) = \frac{U}{R - EWR}$$

where:

WSI (Smakhtin)	=	*Water stress indicator*
U	=	*Withdrawal for human use in area of interest* $[m^3\ year^{-1}]$
R	=	*Renewable water resource in area of interest* $[m^3\ year^{-1}]$
EWR	=	*Environmental water requirements*

The WSI(Smakhtin) suffers from the same shortcoming as the rest of the WUPR-based indices in employing only withdrawal as its metric of usage, although it could be adapted to apply to consumptive use as well. Hoekstra et al. (2009) resolve this problem by approaching scarcity from the net consumption framing of the water footprint (Equation 2). Their "water scarcity" metric can be applied at any temporal scale, and is designed to be used separately for blue and green water.

$$(2) \qquad WS[x,t] = \frac{WF[x,t]}{R - EWR}$$

where:

WS	=	*Water scarcity (blue or green)*
WF	=	*Total catchment-level water footprint (blue or green)*
x	=	*Watershed of interest*
t	=	*Timescale of interest*
EWR	=	*Environmental water requirements*

The *levels* of environmental water requirements suggested by Smakhtin have been broadly criticized by the ecological science community as being so low as to "…almost certainly cause profound ecological degradation, based on current scientific knowledge" (Arthington et al., 2006). These critiques could be addressed by simply increasing the EWR value as a precaution considering uncertainties involved, or by applying a more comprehensive EWR assessment such as the ELOHA method detailed above. Furthermore, a more robust analysis using the WSI(Smakhtin) or the blue and green water scarcity metric as a characterization factor for LCIA could employ the variation factor and the logistic curve fitting techniques introduced by Pfister et al. (2009) to account for climate variability and non-linearity of stress effects.

3.5.4 Assessing the impacts

Tools such as the WSI(Smakhtin) or Hoekstra's blue and green "water scarcity" metric could be used to sort basins, watersheds or regions into stress classes to evaluate risk or the need for further study. In this vein, Hoekstra et al. (2009) propose characterization of "water footprint hotspots" based on an activity's spatially and temporally explicit water footprint. A green water footprint hotspot occurs "when in the catchment re-allocation of the green evaporative flow from natural to productive vegetation takes place at the cost of biodiversity beyond a certain acceptable level." A blue water footprint hotspot occurs when extraction level fails to provide for environmental water requirements. Lastly, a grey water footprint hotspot occurs when pollution violates agreed-upon water quality standards in a catchment.

These tools can also be used directly as characterization factors to give more weight to consumption where strain is greater. This approach has been suggested by Hoekstra et al. (2009) in the form of "water footprint impact indices" generated separately for blue, green and grey water impact. More sophisticated characterization factors could account for climatic variability, watershed management, and the non-linear relationships between consumption and impact. Weighted consumption values can then be used to examine specific impacts of greatest concern, such as Freshwater Ecosystem Impact (FEI) and Freshwater Depletion (FD) (Milà i Canals et al., 2009), or human health effects, resource depletion and ecosystem change (Pfister et al., 2009).

3.6 Evaluating other impacts

The quantitative analytical approaches discussed in this chapter were designed to be broadly applicable, and so may at times fail to capture some location-specific impacts of concern. In evaluating a policy or an investment related to bioenergy expansion, decision makers should consider some of the following location-specific concerns and should work to avoid or to alleviate them where relevant:

- While individual projects may have water impacts well below established thresholds, the cumulative effect might become problematic in regions undergoing rapid change or expansion of energy infrastructure.
- Localized effects may be deceptive. Water consumption for biomass conversion represents less than 1% of the total water footprint for many types of bioenergy (Fingerman et al., 2010). Because refining takes place in a concentrated area, however, it might have a larger local effect 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.
- The impact on key habitats such as aquifer recharge zones, wetlands and floodplains can have a large effect throughout a watershed. This local impact might be missed in watershed-scale evaluation (Alliance for Water Stewardship, 2009).
- 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 for the life cycle GHG impact of bioenergy (Searchinger et al., 2008; Hertel et al., 2010). Similarly, perturbation of global commodity markets due to bioenergy production could lead to a detrimental impact on

water resources 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 instead be due to social realities such as equity of access, barriers to entry, poor infrastructure, institutional failure, and other considerations that may be affected by bioenergy expansion.
- Water scarcity does not have the same effect in all places. Affected populations vary in their ability to adapt to scarcity through altered lifestyles, development of new resources, and imports of "virtual water".

3.7 Conclusions

Bioenergy expansion can have significant implications for the state of water resources in the region where it occurs. Business, policy and resource management decisions related to bioenergy should take this critical consideration into account. Bioenergy systems need to be analyzed from a comprehensive socio-ecological perspective, with consideration given to underlying ecological functions in agricultural and natural landscapes and 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 the development of sustainable land and water use.

Water resource impacts can defy easy quantification. Water consumption varies spatially and temporally, different water sources are not necessarily commensurable, and impact depends on the state of the resource base that is drawn upon. In order to describe impacts, a life cycle inventory (LCI) must be comprehensive, accounting for both blue and green water use as well as for pollution effects, varying sources, and the spatial heterogeneity of usage. Furthermore, where possible, the LCI should quantify the *net effect* of activities, accounting for the consumption associated with any prior or displaced land uses rather than only quantifying consumption in absolute terms.

A nuanced and disaggregated LCI is an essential component of impact assessment, but does not in itself serve to sufficiently characterize impact. Unlike greenhouse gases, which have a functionally uniform impact wherever or whenever they are emitted, water consumption has implications that vary depending on context. While there is no universally suitable quantitative tool with which to characterize the impact 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 sufficient environmental flows need to remain intact to maintain a stable ecosystem.

This nuanced and comprehensive analysis can require detailed data that may not always be widely available. However, most of the 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 the human and financial resources may be available to gather detailed information *in situ*.

Life cycle impact assessment (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 that reason, localized concerns including cumulative effects, impacts on key habitats, indirect effects, social realities, and resilience to scarcity should be investigated carefully as a complement to this type of quantitative analysis.

The increasing demand for bioenergy is a challenge from the perspective of water resources, but it is important to address this challenge based on a holistic approach that considers the pressure placed on water by all competing uses. There is considerable scope in many regions of the world for improving water productivity, reducing the amount of water needed for crop production, and leaving 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 development of biomass supply systems as a new element in the landscape.

Impact assessment using the tools described can be an important first step towards optimizing opportunities from bioenergy production while minimizing any detrimental effects on water resources. 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 for capturing opportunities and avoiding or mitigating detrimental effects on water resources.

Finally, most of 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 implement Best Management Practices where they may not otherwise occur.

4 Bioenergy-related water quality issues

Water quality is a measurement of the physical, chemical and biological characteristics of water against certain standards that can be ecological or specifically related to human needs. The production of bioenergy feedstocks and their conversion to solid, liquid and gaseous biofuels for heating, power and transport can drastically affect water quality in aquatic ecosystems, with impacts on biodiversity and human health. Depending on how a bioenergy system is located and managed, it can lead to deterioration or improvements in water quality. This chapter focuses on the impacts of bioenergy production on water quality, and how to measure and reduce these impacts.

4.1 Sources of water pollution in bioenergy production

Water quality needs to be considered in an integrated manner. According to Perry and Vanderklein (1996), it should be seen as part of a wider picture, including hydrology, chemistry, biology, geology, land use, demographics, public attitude and policy. Water quality may be affected by physical, chemical, biological and thermal pollution of aquatic systems from bioenergy production. It may also be affected by natural events (e.g. volcanic eruptions) and by human activities. The following sections review these impacts, from agricultural and forestry practices to the processes used in bioenergy feedstock production and conversion.

4.1.1 Agricultural inputs and impacts on water quality

The impacts on water quality of cultivating conventional crops as feedstock for first generation biofuels are the same as those of cultivating other farm crops. Direct impacts on water quality arise from pollution owing to run-off from intensive agricultural production employing pesticides (e.g. herbicides, insecticides, fungicides) and fertilizers, together with other undesirable agricultural practices such as tillage of unsuitable soils.

a) Pesticides

Pesticides can have a profound effect on aquatic life and water quality. As pesticide residues are carried to ponds, rivers, lakes and other water bodies by surface run-off or spray drift, they can cause acute poisoning (e.g. fish kills) as well as chronic poisoning when wildlife is exposed to pesticide levels that are not immediately lethal. Negative effects on fish that receive repeated sub-lethal doses of pesticides include reduced fish egg production and hatching, lower resistance to disease, decreased body weight and reduced avoidance of predators. The overall consequence can be lowered population abundance. There are also risks of secondary poisoning when predators consume prey that contain pesticides. This can be a particular concern in relation to persistent chemicals that bioaccumulate and move up the food chain. Indirect effects may also occur when habitats or food chains are modified, for instance when insecticides diminish insect populations fed on by fish and other aquatic animals.

Pesticides stored in sub-standard conditions pose a threat to both human health and the environment, particularly when they are stored in urban areas or near water bodies. Farmers with insufficient knowledge of pesticide management commonly use older, more toxic and environmentally persistent chemicals (Ecobichon, 2001). This may be a particular problem in some developing countries. Absence of stringent regulations, or lack of enforcement of existing regulations, contribute to the problem (Eddlestoon et al., 2002).

b) Fertilizers

Fertilizers are used to increase agricultural yields. In particular, nitrogen and phosphorous may end up in waterways and aquifers, where they can have significant impacts on the quality of river water and groundwater and result in eutrophication of wetlands and water bodies (Ongley, 1996). High nutrient concentrations stimulate growth of algae, leading to imbalanced aquatic ecosystems. These ecosystems may experience phytoplankton blooms, production of excess organic matter and increased oxygen consumption, leading to oxygen depletion and the death of benthic organisms that live on or near the bottom in aquatic habitats.

For example, the Baltic Sea[17] is surrounded by nine countries. Five more countries are in its drainage basin, but do not border on it. Fertilizer run-off to the Baltic Sea from surrounding agricultural land contributes to a large nutrient load, primarily via river discharges[18]. This run-off has changed it from an oligotrophic clear-water sea into a eutrophic marine environment experiencing summertime algal blooms. Blue-green algae that are potentially toxic to humans and animals are a particular problem (Figure 4.1). Similarly, nitrogen run-off to the Mississippi River has resulted in algal blooms and an anoxic “dead zone” in the Gulf of Mexico[19] (Bianchi et al., 2000; Finni et al., 2001). The Black Sea[20], which is an inland sea, provides a third example of the occurrence of large annual phytoplankton blooms. During the last decades, increased nutrient loads from human sources, together with other forms of pollution and over-harvesting of fisheries, have caused a sharp decline in water quality in the Black Sea.

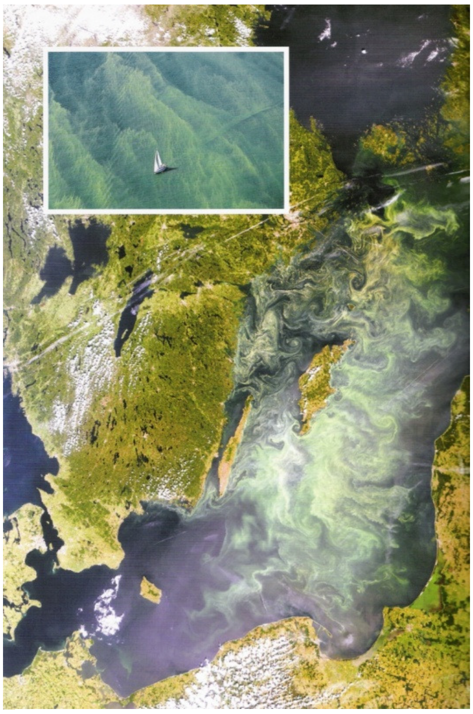


Figure 4.1: Algal blooms in the Baltic Sea. Photo credit: SMHI, Sweden.

c) Manure and sludge from wastewater treatment

Wastewater treatment can be a valuable source of nutrients and contribute to maintaining/improving soil carbon content and productivity. Nevertheless, especially when spreading takes place on frozen ground, high nutrient run-off can result in high levels of contamination of receiving waters by pathogens, metals, nitrogen and phosphorus. Groundwater may also be polluted, specifically by nitrogen.

[17] The Baltic Sea is not a freshwater body as defined in Chapter 1, footnote 1

[18] All sources of pollution of the Baltic Sea were made subject to the Convention on the Protection of the Marine Environment of the Baltic Sea Area (the Helsinki Convention), which was signed in 1974 and entered into force in 1980. A new Helsinki Convention, signed in 1992 by all bordering states and the European Union, entered into force in 2000.

[19] The Gulf of Mexico is not a freshwater body as defined in Chapter 1, footnote 1

[20] The Black Sea is not a freshwater body as defined in Chapter 1, footnote 1

d) *Irrigation*

The impacts of irrigation include run-off of salts (leading to salinization of surface waters), run-off of pesticides and fertilizers to surface waters (causing ecological damage), and bioaccumulation of hazardous substances in edible fish species (Ongley, 1996). Box 4.1 presents a case study from the Republic of Senegal, where the irrigation of thousands of hectares of sugarcane fields requires millions of cubic metres of water per year (pumped directly from the Senegal River and Lake Gouiers) with environmentally harmful effects.

e) Tillage

Unsustainable agricultural practices such as the tillage of unsuitable soils can lead to sediment run-off to water bodies, causing physical impacts (e.g. water turbidity and siltation of river beds) as well as chemical ones (e.g. through the absorption of organic chemicals like phosphorus, and of pesticides, on sediment particles) and consequently loss of habitats including spawning grounds (Ongley, 1996). These impacts should also be considered in regard to harvest residue extraction for bioenergy production, which encourages erosion (Section 4.1.2).

Box 4.1: Sugarcane production in Senegal

The Senegalese Sugar Company (Compagnie Sucrière Sénégalaise, or CSS) is located in northern Senegal on the Senegal River. The largest agro-industrial unit operating in the Senegal River basin, it has a production potential of more than 8 000 hectares of sugarcane with an average yield of 120 tonnes/hectare, using water from the river and Lake Guiers. The company employs 3 000 permanent workers and 2 000 seasonal ones. In 2008, it inaugurated a new bioethanol plant with an annual production capacity of 10 to 12 million litres of ethanol from the distillation of molasses. Ethanol production covers the company's energy consumption and supplies the Senegalese market with clean fuel as an alternative energy source for households and sectors such as pharmaceuticals, alcohol and alcoholic drinks.

Irrigating some 8 000 hectares of sugarcane fields requires approximately 188 million m^3 of water per year, which is pumped directly from the river and Lake Guiers. The lake, the country's largest reserve of surface freshwater, is connected to the Senegal River by a canal. Its hydrological regime was subject to fluvial rising, but is now regulated by dams on the river. The lake's main uses include irrigation of sugarcane and drinking water supply. In the future, Lake Guiers could be the starting point for a 250-kilometre canal to Dakar, the capital, which would supply the city with water. From the Ngnith station pumps, the lake already provides Dakar with over 100 000 m^3 of drinking water per day.

Irrigation using water from the lake and river has environmentally harmful impacts. Those associated with sugarcane production involve the use of chemicals, especially mineral fertilizers and pesticides. Studies have been conducted to assess water pollution of the river and lake (in terms of quantity and quality) due to sugarcane production. Effluent quality has been measured at different points, upstream and downstream of the receptor point and of the surface near where water is pumped, in order to take the diffusion of water pollution into account. Concentrations of nutrients from fertilizers (e.g. nitrogen and phosphorous) appear to be low. The lake is more polluted than the river, where water is moving. However, the deeper lake water is less polluted than that at the surface.

Source: Cogels, 1994; OMVS, 2002.

4.1.2 Forestry inputs and impacts on water quality

In addition to impacts associated with cultivation, other practices related to bioenergy feedstock production (e.g. harvest residue extraction) can lead to negative impacts, including soil erosion (causing sedimentation of water bodies) and reduced ability of precipitation to penetrate the soil and replenish groundwater supplies.

Increased demand for lignocellulosic biomass can change the way bioenergy production affects water quality. Although removing lignocellulosic harvest residues may have negative impacts, some positive impacts on water quality can be expected if increased demand for this biomass leads to shifts in land use towards a larger share of perennial herbaceous plants and woody plants (e.g. willow, poplar, eucalyptus) being grown in multi-year rotations. Such short rotation coppice plantings are generally considered more beneficial for water quality in a given area due to less intensive management practices (e.g. use of weed control only during the establishment phase, tillage only before the establishment phase, and lower inorganic fertilization than in the case of conventional food/feed crops) (Box 4.2).

Box 4.2: Water quality impacts of cultivating short rotation coppice (SRC) plants

Most studies of the impacts on water quality of cultivating short rotation coppice (SRC) plants have been concerned with nitrogen and phosphorous leaching to groundwater. Reports of considerable differences in nitrogen leaching between SRC and conventional food/feed crops can, in some cases, be attributed to the smaller amount of fertilizer applied to SRC plantings. However, results for SRC plantings intensively irrigated with nutrient-rich wastewater (usually nitrogen, but also phosphorous) suggest that in general nitrogen leaching from these plantings in comparison with that of arable crops is significantly lower and a shift from arable crops to SRC can lead to improvement of groundwater quality and, consequently, of surface water quality in a certain area. Similarly, results from experiments involving applications of municipal sewage sludge to willow and poplar can provide insights into the effects of SRC on phosphorous leaching.

Today, application of sludge to SRC is a common practice in Sweden and the United Kingdom, where it compensates phosphorous losses in newly harvested fields (Sagoo, 2004; Dimitriou and Aronsson, 2005). Here, studies also point to low phosphorous concentrations in drainage water when there is a relatively high phosphorous input. Phosphorous is usually bound to soil particles. Its leaching patterns differ from those of nitrogen, which in most cases are related to water drainage. However, future phosphorous leaching cannot be excluded if sewage sludge is applied over a number of years at high rates.

Source: Dimitriou et al. (2011).

Energy production from wood has a life cycle that produces environmental burdens and impacts on hydrologic systems at various stages (Malkki et al., 2001; Neary, 2002). Most concerns have been focused on forest operations, including road networks, site preparation, herbicide use, fertilization, harvesting, ash recycling and regenerated site preparation (Ranney and Mann, 1994). These operations are transitory and are generally well-dispersed throughout watersheds. They can affect hydrological processes and pollute water directly or indirectly through the use of pesticides and fertilizers, among other activities. Their impacts include:

a) Hydrological processes

Hydrological processes can be affected, for instance, by harvesting. The hydrological cycle quantifies interactions between the atmosphere, geosphere, biosphere and hydrosphere (Table 4.1). Since water is a primary driving force in ecosystem processes and fluxes, water quality reflects the net effects of those processes and disturbances that occur in watersheds.

A generalized breakdown of the inputs, fluxes and outputs in undisturbed forested watersheds in humid regions was described by Hewlett (1982) and Neary (2002). The percentage distribution of water movement changes somewhat depending on whether arid shrub, grassland or woodland ecosystems are being studied, and it can vary considerably in watersheds disturbed by climate change, harvesting, burning, insect defoliation, windthrow, land use conversions, mining and agriculture. Precipitation inputs consist of rain, snow and sleet. Fluxes, or the movement pathways of water within watersheds, consist of interception, evaporation, transpiration, stemflow, throughfall, infiltration, surface run-off, interflow, baseflow and stormflow. They convey variable amounts of dissolved or suspended solids, which constitute the physical component of water quality (Swank, 1988).

Table 4.1: Changes in hydrological processes in forests after harvesting. Source: Adapted from Neary and Hornbeck (1994) and Neary (2002)

Hydrologic process	Type of change	Specific effects
1. Interception	Reduced	Moisture storage smaller Greater run-off in small storms Increased water yield
2. Throughfall	Increased	Baseflow increase Soil moisture increase
3. Evaporation	Increased	Baseflow decrease Soil moisture decrease
	Decreased	Baseflow increase Soil moisture increase
4. Litter storage	Litter reduced	Less water stored (0.5 mm cm^{-1})
	Litter not affected	No change
	Litter increased	Storage increase
5. Transpiration	Temporary Elimination	Baseflow increase Soil moisture increase
6. Infiltration	Reduced	Overland flow increase Stormflow increase
	Increased	Overland flow decrease Baseflow increase
7. Streamflow	Changed	Increase in most ecosystems Decrease in snow systems Decrease in fog-drip systems Decrease depending on conversion process
8. Baseflow	Changed	Decrease with less infiltration Increase with less transpiration Summer low flows (+ and -)
9. Stormflow	Increased	Volume greater Peakflows greater Time to peakflow shorter
10. Snowpack	Changed	Cuts <4 ha, increase in snowpack Cuts > 4 ha, decrease in snowpack Snowmelt rate increase Evaporation/sublimation greater

b) Erosion and peakflows

When a watershed is in good condition, rainfall infiltrates the soil and baseflows are sustained between storms. Well-vegetated watersheds in good condition generally do not suffer from damaging peakflows (flash floods). The term “watershed condition” describes the ability of a watershed system to receive, route, store and transport precipitation without ecosystem degradation (Brooks et al., 2007).

In some regions of the world destructive streamflows are common irrespective of watershed condition. Nevertheless, severe fires, poor harvesting practices, over-grazing, conversion to agriculture and urban uses, and other disturbances may alter the watershed condition, reducing it to a moderate or poor level. In the case of poor watershed condition, the percentage of infiltrated rainfall is reduced significantly and the result may be erosion and flooding. Moreover, sometimes the loss of organic material through severe burning, harvesting, respiration, oxidation, site preparation or other disturbances can bring about adverse changes in hydrologic conditions.

c) Chemical pollution

A number of studies have examined the effects of forest harvesting on water quality (Bosch and Hewlett, 1982; Neary and Hornbeck, 1994; Neary, 2002; Andreassian, 2004; Bruijnzeel et al., 2004). The water quality parameters typically examined by these studies are nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total nitrogen (N), total phosphorus (P) and orthophosphate (PO_4-P), cations such as sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg), micronutrients, sediment and temperature. These parameters are of concern for streams being used as water supplies, and for their potential impact on aquatic biota, particularly threatened and endangered species.

The changes in water quality parameters discussed here are mostly taken from studies treating entire watersheds uniformly. These studies have rarely examined situations in which forest harvesting was carried out within much larger catchments, so that most of the area could not be treated at the same time. Due to dilution effects, water quality effects are usually attenuated as the untreated area increases.

d) Nutrients

Nitrate-nitrogen (NO_3-N) levels are often used as an indicator of watershed health and water quality. This is a good integrator and indicator of disturbance (Swank, 1988), as well as a critical water quality parameter for human health. For the most part, large increases in NO_3-N levels have not been observed in streams draining harvested watersheds. The greatest increases in NO_3-N levels reported in the literature (Pierce et al., 1970) were measured where herbicides had been specifically applied to suppress vegetation regrowth, and also where nitrogenous fertilizers had been applied during forest regeneration (Neary and Hornbeck, 1994) or where nitrogen saturation of ecosystems had reached a critical level due to atmospheric deposition (Aber et al., 1989). Severe fire can cause similar nutrient release (DeBano et al., 1998).

e) Fertilizers and wood ash

Compared to agricultural land, even managed forests have much higher water quality. Certainly fertilizer use in the forest bioenergy life cycle is not expected to cause water quality problems, especially when Best Management Practices (BMPs) are used (Aust and Blinn, 2004). Inter-rotation forest fertilization programmes can be a source of additional nutrient inputs to streams, but mitigation practices may limit those inputs (Neary and Leonard, 1978).

A review by Pitman (2006) cautioned that environmental problems associated with wood ash use are less likely to derive from its heavy metal content, which can be partly removed at source when it is burned, and are more likely to be associated with the tree species and type, the nature of the burn process and conditions at the site. The application of the incorrect wood ash may result in higher soil pH, increasing microbial populations, and potential mobilization of nitrogen. Although higher soil pH is potentially beneficial to tree growth on acidic or nutrient-poor soils, it can be accompanied by changes in the ecology and functioning of forest ecosystems.

f) Pesticides

Herbicides and insecticides are sometimes used in the establishment of bioenergy feedstock plantations to reduce weed competition or deal with insect infestations. Analyses conducted in regional environmental impact statements indicate that the low concentrations and short persistence of forestry pesticides in surface and groundwater do not pose a significant risk to water quality, aquatic biota or human health (Neary and Michael, 1996).

g) Sediment increase

Sediment increase during and after forest harvesting is highly variable, depending on factors such as soils, climate, topography, ground cover and watershed condition. Although sediment levels increase after harvesting as a result of the physical disturbance of soil, they are usually transient due to vegetation regrowth. The largest increases documented in the literature have been associated with post-harvest mechanical site preparation, slope instability, road construction, or soils that are naturally highly erosive. The cumulative effects of erosion and sedimentation that occurred centuries ago as a result of agriculture or forestry can present forest managers with many challenges (Terrene Institute, 1993).

Sediment is an important water quality parameter since it can harm aquatic organisms and habitats, as well as rendering water unacceptable for drinking water supply or recreational purposes. The natural variability of sediment regimes in bioenergy forests must be understood before judgements are made concerning the effects of harvesting. Use of appropriate BMPs and carefully planned harvesting can result in minimal or no additions to stream sediments (Neary et al., 2010) (Table 4.2). BMPs are most effective in minimizing sediment inputs to streams or lakes when they are properly planned and implemented prior to, during and after harvesting (Aust and Blinn, 2004).

Table 4.2: Sediment increases due to forest harvesting and related disturbances. Source: Neary and Hornbeck (1994), Neary and Michael (1996), Neary (2002)

Forest type	Location	Treatment	Sediment increase	Sediment increase
			%	mg ha^{-1} yr^{-1}
Harvesting alone				
Northern hardwoods	New Hampshire, USA	Clearcut	769	0.323
Mixed hardwoods	West Virginia, USA	Clearcut	0	0.000
Loblolly pine	South Carolina, USA	Clearcut	655	0.131
Mixed hardwoods	Georgia, USA	Clearcut	154	0.103
Upland hardwoods	Tennessee, USA	Clearcut	2 020	10.600
Loblolly pine	Arkansas, USA	Clearcut	1 875	0.225
Loblolly/shortleaf pine	Arkansas, USA	Clearcut	6 500	0.260

Lodgepole pine	Montana, USA	Clearcut	661	0.119
Douglas fir	Oregon, USA	Clearcut	8 182	0.202
Mixed conifer	Arizona, USA	Clearcut	38	0.003
Beech-podocarp	New Zealand	Clearcut	42	0.182
Beech-podocarp	New Zealand	Clearcut	700	3.003
Beech-podocarp	New Zealand	Clearcut	2 100	2.100
Harvesting and site preparation				
Loblolly pine	Mississippi, USA	Clearcut, bed	2 198	13.630
Slash pine	Florida, USA	Clearcut, windrow	1 100	0.033
Loblolly pine	North Carolina, USA	Clearcut, blade	1 939	9.695
Loblolly pine	Arkansas	Clearcut, shear	653	0.464
Shortleaf pine	Arkansas	Clearcut, windrow	1 926	0.578
Loblolly pine	Texas, USA	Clearcut, shear	750	0.170
Roads				
Mixed hardwoods	North Carolina, USA	Roads	11 900	1.190
Loblolly pine	Georgia, USA	Roads	96 700	3.868
Douglas fir	Oregon, USA	Roads	175	0.930
Mixed conifer	Arizona, USA	Roads	1 012	0.081

h) Water temperature

Water temperature is a water quality parameter that affects stream biota in temperate forests. Forest vegetation shades stream channels from solar radiation, producing stream temperatures that are cooler and less variable than in the case of unshaded sites (Neary and Hornbeck, 1994; Neary, 2002). Temperature increases that result from canopy removal or thinning during forest harvesting temporarily affect physical, chemical and biological processes. The impact on aquatic biota varies considerably, depending on whether individual species are eurythermic and the degree to which stream temperature is controlled by solar heating or stream baseflow.

Adverse changes in stream temperature can be buffered by using streamside management zones as a form of BMP. Cumulative effects of stream temperature increases are often moderated as the streamflow from harvested areas merges with that from larger, uncut areas. In some ecosystems, stream temperatures are primarily controlled by the temperature of baseflow inputs. Canopy removal by thinning or whole tree harvesting therefore has little impact on temperature.

4.2 Biomass conversion and impacts on water quality

From a water quality perspective, the biomass production phase represents a diffuse and distributed source of pollution (non-point source pollution). In contrast, the conversion phase can be considered a point source of pollution.

Impacts on water quality associated with *discharges* from conversion plants – the main focus of this section – are caused by chemical, biological and thermal pollution of aquatic systems. Some of the impacts associated with the conversion of bioenergy feedstocks include:

a) Industrial effluents (chemical and physical effects): impacts on rivers, lakes and land of uncontrolled discharges. For example, in Brazil the process of producing ethanol from sugarcane is highly efficient and there is control of discharges. (See Section 4.2.1 below and case study 2.1 in Chapter 2).

b) Application of wastewater in agriculture. Sugarcane vinasse is used as a fertilizer in Brazil and other sugarcane producing countries. This practice needs to be controlled to avoid soil saturation.

c) Wastewater can be a substantial contributor to *greenhouse gas (GHG) emissions.* For instance, palm oil mill effluent (POME) from processing the fruits of oil palm is generated mainly from oil extraction, washing and cleaning. As water quality discharge guidelines and regulations have been implemented (see Chapter 5), POME is now frequently discharged first into open lagoons (without methane capture) where the wastewater is treated. Biological oxygen demand (BOD) is the key measurable parameter of water quality. Microbial activity in anaerobic conditions, a natural process that reduces the BOD, also produces methane (CH_4), a greenhouse gas around 25 times more effective than CO_2 in trapping heat in the atmosphere, according to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (Chalmers and Warden, 2009).

Without the capture of these methane emissions, this stage in the wastewater treatment process is a substantial contributor to GHG emissions. A comprehensive study of emissions associated with various biofuels (JEC, 2008) has calculated that biofuel production saves only 44% of GHG emissions when compared to a fossil diesel if POME emissions are not captured. If the POME emissions are captured and used, GHG savings will be 72%.[21] Methane capture from wastewater treatment for use as a process energy source (e.g. the methane can be used as a gas in boilers) would represent a significant step towards reducing GHG emissions associated with biofuels, and specifically with wastewater.

Some of these impacts are better explained by referring to the different feedstocks and production systems used. The following section focuses on the use of sugarcane for ethanol production in Brazil and the harvesting of feedstock (forestry) in Australia, including some of the impacts mentioned above.

4.2.1 Case study: Use of sugarcane for ethanol production in Brazil

In Brazil, recovery and treatment of industrial effluents from sugar mills and distilleries basically consists in the application of preventive internal controls. Reuse and recycling of effluents to reduce pollution (discharge and physico-chemical parameters), and reduction of water use, have long been carried out in industrial plants. Techniques include recirculation, wastewater reuse, more efficient equipment, less polluting processes, and crop fertigation. The advantages of implementing these techniques include: less use of power and water pumping; better use of raw materials; lower costs; and better management of nutrients (nitrogen, phosphorous and potassium) and organic matter in agriculture, resulting in better yields and soil improvement.

Treatment systems in the sugarcane industry include:

- water washing of the cane: 180-500 mg/litre of BOD_5 and high concentrations of solids. Treatment in sedimentation and stabilization ponds for release to water bodies. For reuse, treatment consists of settling and correction to a pH between 9 and 10;

[21] This assumes a fossil fuel reference of 86 g CO_2 eq/MJ.

- water-cooled multijets and barometric condensers in sugar mills: low pollution potential (10-40 mg/litre BOD_5) and high temperature (~50°C). Treatment by spray ponds or cooling towers before recirculation or release;

- water cooling of fermentation and distillation: high temperature (~50°C). Treatment by spray ponds or cooling towers before recirculation or release;

- use of effluent gas scrubber to treat flue gas from the bagasse-fired boiler in order to retain particulate matter (PM), with low potential for organic matter (range 100-150 mg BOD_5/litre and 200-300 mg/litre COD) and high temperature, reaching 80°C. Treatment is usually by sedimentation-flotation systems for recirculating the gas of the scrubber system. Sludge, containing a great deal of solid (generally referred to as "soot"), is sent to the fields as solid waste;

- stillage (vinasse or spentwash): large volume, ranging from 11 to 12 litres/litre of ethanol, with high organic load (25 000-40 000 mg/litre of COD). The stillage is applied to sugarcane fields with or without wastewater (from washing of floors, purging of closed circuits, excess condensate), promoting fertigation with the use of nutrients.

Table 4.3 summarizes the types of wastewater generated, with its volumes and main features. The characteristics of these effluents and the availability of simple treatment systems allow immediate reuse. The more recalcitrant wastewater – such as stillage (vinasse or spentwash) and purges of reuse systems, with high levels of organic matter and salts – is reused in fertigation of sugarcane.

Table 4.3: Summary of characteristics of wastewater from sugar-ethanol sugarcane mills. Source: Elia Neto and Shintaku (2009)

Wastewater		Physico-chemical characteristics						
		Flow	pH	Temperature (°C)	Settleable solids (mL/L)	COD (mg/L)	BOD (mg/L)	Oil and grease (mg/L)
Sugarcane washing		2-5 m^3/tonne cane	5-6	room	5-10	280-700	180-500	0
Cooling equipment (mills, turbines and turbo generators)		0.665 m^3/tonne cane	7	< 30	< 0.5	0	0	-
Cooling condensers/multijets evaporation and cookers		70-100 L/kg sugar	6-7	50	< 0.2	20-80	10-40	0
Cooling distillery for	Sugarcane juice	30 L/L ethanol	7	< 45	0	0	0	0
	Fermentation	60-80 L/L ethanol	7	< 35	0	0	0	0
	Ethanol condenser	80-120 L/L ethanol	7	50-60	0	0	0	0
	Subtotal	200 L/L ethanol	7	50	0	0	0	0
Effluent gas scrubber, flue gas from bagasse-fired boiler		2 L/kg steam	8	80	50-100	200-300	100-150	-

Condensate of	Steam escape	40-50 L/kg sugar	7	80	0	0	0	0
	Steam juice	50-60 L/kg sugar	5-6	60-80	0	600-1 500	300-800	0
Cleaning of floors and equipment		50 L/tonne cane	5-6	room	< 0.5	1 000-3 000	800-1 500	> 20
Domestic sewage		70 L/person /day	6-7	room	5-20	600	300	-
Stillage (vinasse or spentwash) and flegmass[22]		12-18 L/L ethanol	4-4.5	80	3-5	25 000-40 000	15 000-20 000	8

Note: L = litre

A number of solutions are available to mitigate negative impacts from the different types of wastewater. For example, processing water can be treated and recirculated for further use in the conversion plant, or it can be returned to water bodies. For more information on mitigation strategies, see Section 4.4.

For more information on sugarcane ethanol production, see case study 2.1. in Chapter 2.

4.2.2 Case study: Evaluation of the water quality benefits of Best Management Practices during tree harvesting in Australia

A study conducted in northwest Tasmania, Australia, evaluated the water quality benefits of Best Management Practices during tree harvesting in a streamside management zone typical of tree farming (Neary et al., 2010). A 20-year-old *Eucalyptus nitensm*, growing in a pulpwood plantation along an intermittent stream, was cut according to the Tasmanian State Code of Forest Practice. A machinery exclusion zone immediately adjacent to the stream limited machinery traffic, but tracked harvesters were used to cut and extract tree stems without entering the exclusion zone (Figure 4.2). Ground cover and water quality pre- and post-harvesting were measured to identify major sources of sediment in this headwater catchment, and to determine the effect of tree harvesting.

Figure 4.2: Tigercat tracked harvester delimbing and topping a felled *Eucalyptus nitens* stem during a streamside harvesting study on the effectiveness of Best Management Practices. Note the slash coverage remaining in the harvested area. Photo credit: Daniel G. Neary

[22] Flegmass is a by-product obtained from the rectifying column of phlegm during the process of alcohol production.

The study demonstrated that post-harvesting turbidity levels in streamflow were similar to pre-harvest levels (< 2.5 nephelometric turbidity units, or NTUs) in streamflow exiting the catchment. A road, a dam (accessible to cattle) and a cultivated paddock were much more significant sources of sediment. These sources led to turbidities of about 300 NTUs in Dam 10 immediately below the road, in paddocks, and above the harvested stream reach during a storm in late June 2009 and subsequent winter storms through October 2009. At Dam 13, below the harvesting areas, stream turbidities were mostly below 10 NTUs. The in-stream dams functioned as very effective sediment traps. This study demonstrated how BMPs can be effective in limiting adverse impacts on water quality. It shows that bioenergy-related forest harvesting operations can be carried out without increasing stream turbidity if existing BMPs are followed.

4.3 Key indicators to measure water quality related to bioenergy production

Indicators to measure water quality refer to the chemical, physical and biological characteristics of the water and to its final purpose. 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. For this purpose, a number of regulations and international standards and agreements exist, such as the Stockholm Convention on Persistent Organic Pollutants (POPs),[23] the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal,[24] the World Bank EHS guidelines,[25] and the Global Reporting Initiative[26] reporting guidelines on water use and pollution (Smeets et al., 2006).

Water quality indicators can be classified as those concerning drinking water, bathing water, water pollution, and, depending on other uses, agricultural and industrial uses.

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

- BOD (biochemical oxygen demand), to determine the 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 are harmful to water fauna.

The United States Environmental Protection Agency has set some standards for water pollution with regard to best available technologies (Smeets et al., 2006) (Table 4.4).

Other indicators include conductivity and oxygen reduction potential (ORP). Indicators will vary according to the goal or standard of the measurement, and will include physical, environmental and chemical characteristics.

[23] For information on POPs, see: http://chm.pops.int/
[24] For information on the Basel Convention, see: http://www.basel.int/
[25] For information on the World Bank Environmental, Health, and Safety Guidelines (known as the "EHS Guidelines"), see: http://www.ifc.org/ifcext/sustainability.nsf/Content/EHSGuidelines
[26] For information on the Global Reporting Initiative, see: http://www.globalreporting.org

Standards and regulations vary among regions and countries. In the European Union their use is regulated by different directives and rules, including the EU Water Directive (EC, 2000).

Table 4.4: United States Environmental Protection Agency (US EPA) standards for water pollution. Source: Smeets et al. (2006)

	BOD	Volume of suspended solids (indicator)	pH
Raw sugar factory	kg/tonne cane	kg/tonne cane	(-)
Maximim daily value	0.10	0.24	
30-day			6.0-6.9
mean	0.05	0.08	
White sugar factory	kg/tonne raw syrup	kg/tonne raw syrup	(-)
30-day			6.0-6.9
mean	0.09	0.035	
Liquid sugar factory	kg/tonne raw syrup	kg/tonne raw syrup	(-)
Maximum daily value	0.30	0.09	
30-day			6.0-6.9
mean	0.15	0.03	

There are many possible metrics. In the United States, the National Research Council (NRC, 2008) 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. Of the bioenergy feedstocks, corn (maize) has the highest application rates per hectare of both fertilizers and pesticides. Per unit of energy obtained, biodiesel requires just 2% of the nitrogen and 8% of the phosphorous needed for corn ethanol. Pesticide use differs similarly. Using this metric, low-input, high-diversity prairie biomass and other native species would also compare favourably to corn (maize).

NRC (2008) has reported that soil erosion from tillage is another source of water quality impacts. Soil erosion moves both sediments and agricultural pollutants into waterways. Various farming methods can help reduce soil erosion. However, if bioenergy production expands the cultivated area, especially on marginal land that is more prone to soil erosion, erosion problems could increase. An exception would be the use of native grasses such as switchgrass, which can reduce erosion on marginal lands.

The index proposed by NRC (2008), building on inputs of fertilizers and pesticides per unit of the net energy gain captured in a biofuel, requires calculation of the biofuel's net energy balance (i.e. its energy content divided by the total fossil energy used throughout the full life cycle of the production of the feedstock, its conversion to biofuel, and transport). This calculation has been made for ethanol produced from corn (maize) in the United States (NRC, 2008).

Smeets et al. (2006), reporting on the sustainability of biofuel production in Brazil, stated that the emission standards used to monitor water pollution in that country are different to international ones in most cases, as some have been implemented especially for Brazil. This is the case for BOD and pH standards. The US EPA standards for pH differ from those of Brazil and the World Bank, which have different parameters. (These standards are explained in detail in Chapter 5.) Some certification and standardization schemes also consider the use of agro-chemicals and pesticides linked to water pollution. Examples are GLOBALG.A.P[27] and the Forest Stewardship Council (FSC) (Chapter 6).

Another approach to assessing impacts on water quality is to use the grey water footprint (Box 2.1, Chapters 2 and 3).

4.3.1 Energy and water links with ecosystem services and the Millennium Development Goals

The UNEP Water Quality Outlook (GEMS/Water, 2007) states that water quality management contributes to meeting the Millennium Development Goals (MDGs), particularly Goal 7 on ensuring environmental sustainability, by helping to:

- integrate the principles of sustainable development into countries' policies and programmes and reversing the loss of environmental resources;
- halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation;
- significantly reduce biodiversity loss; and
- achieve significant improvements in the lives of at least 100 million slum dwellers by 2020.

Use of water quality indicators is one way to demonstrate progress towards achieving the MDGs. GEMS/Water (2007) emphasizes that the link between human health and aquatic systems is determined by water's physical, chemical and biological composition.

In the case of bioenergy projects, lack of water availability is probably the most obvious way that achievement of the MDGS could be jeopardized at local level if water is deviated solely for the production of bioenergy crops. Nevertheless, proper land management and use of resources for different agricultural products can contribute to more efficient use of water to produce food and bioenergy crops. Better management of resources, including water, can contribute in general to better ecosystem services.

The possibilities of new bioenergy projects with respect to developing infrastructure at the local level could also contribute to improvements in local water access and quality.

4.3.2 How to measure bioenergy-specific social and economic impacts

One overall challenge in assessing social and economic impacts is that the socio-economic environment is difficult to describe and quantify, and that it is generally a very complex composite of numerous (directly or indirectly) inter-related factors. Several of these factors are poorly understood. Social processes also have feedbacks that are commonly difficult to recognize clearly and to express with an acceptable level of confidence. Identification and assessment of bioenergy-specific impacts

[27] GLOBALG.A.P is a private sector body that sets voluntary standards for the certification of production processes of agricultural (including aquaculture) products around the globe. The GLOBALG.A.P standard is primarily designed to reassure consumers about how food is produced on the farm by minimizing detrimental environmental impacts of farming operations, reducing the use of chemical inputs and ensuring a responsible approach to worker health and safety as well as animal welfare. GLOBALG.A.P serves as a practical manual for Good Agricultural Practice (G.A.P.) anywhere in the world on the basis of an equal partnership of agricultural producers and retailers who wish to establish efficient certification standards and procedures. The GLOBALG.A.P website (http://www.globalgap.org) is a comprehensive knowledge base for all interested parties: producers, suppliers, retailers, journalists and consumers.

adds to the challenge by requiring separation of these impacts, while bioenergy feedstock production can be more or less integrated with other land uses and industrial activities.

4.4 Mitigation strategies

A commonly expressed precondition for large-scale bioenergy production is that the agricultural sector should improve land use efficiency drastically, so as to require less land for meeting demand for food. Nevertheless, increasing yield levels can have negative impacts where further intensification depends on large inputs of nutrients, freshwater and pesticides. Even so, significant potential exists 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 selection of drought-adapted crops), and employment of best practices involving, for instance, mulching, low tillage, contour ploughing, terracing, rainwater harvesting and supplementary irrigation, crop rotation, and reduction of the length of time land lies fallow (Keys, 2005; Badgley et al., 2007; Rockström et al., 2007; Rockström et al., 2010).

Conservation agriculture and mixed production systems (double cropping, combining crops with livestock and/or crops with forestry) have the potential to sustainably increase land and water productivity as well as carbon sequestration, and to improve food security (Kumar et al., 2006; Heggenstaller, 2008; Herrero et al., 2010). Integrated approaches can also be based on combining bioenergy feedstock production with conversion, for instance by producing animal feed that can replace cultivated fodder such as soy and corn (maize) (Dale et al., 2009; Dale et al., 2010) and reduce grazing requirements (Sparovek et al., 2007). Multifunctional systems that provide multiple ecosystem services represent alternative options for production of bioenergy 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.

Examples include systems established to provide specific environmental services, such as trees that form a windbreak to reduce wind erosion or, where integrated into the landscape, reduce water erosion and mitigate flooding (Box 4.4). Plantations of suitable species can also be used to remove cadmium and other heavy metals from cropland soils (Berndes et al., 2004). For instance, certain Salix clones are very efficient at accumulating heavy metals – notably cadmium, but to some degree zinc, as well – which are then removed from the field with the harvest. Other systems provide environmental services of a more general nature, such as soil carbon accumulation leading to improved soil fertility and enhanced climate benefit (Berndes et al., 2008).

4.4.1 Mitigation measures along the supply chain

Mitigation measures for water quality can be incorporated at different stages of the supply chain, from the production of bioenergy feedstock to its conversion.

a) Mitigation measures in feedstock production

Planting short rotation coppice (SRC) for bioenergy development is likely to reduce the problem of nutrient pollution loads since biomass plantations commonly use smaller amounts of inputs. Based on that observation, integration of SRC into the agricultural landscape has been proposed as a strategy to meet the water quality objectives of the EU Water Framework Directive (Jørgensen and

Mortensen, 2000; EEA, 2008; Eppler et al., 2008). On good land, SRC is likely to increase water quality compared with the use of agricultural crops because of its lower agro-chemical requirements. There is some evidence that, in particular locations, nitrate leaching could be a problem due to applications of fertilizers and sewage sludge. However, it has also been suggested that mixtures of trees and grasses used as energy crops could be cultivated along waterways to act as a buffer to prevent nutrient run-off from agricultural land (Hall, 2003). It should be noted that, similarly to when plantations are established to meet feedstock demand for other agricultural and forestry products, the outcomes for water quality can be very different.

Box 4.3. Potential benefits of establishing SRC with poplar and willow in northwestern Germany

The Fuhrberg catchment is situated about 30 km north of the city of Hannover in northwestern Germany. It serves as an aquifer supplying about 90% of Hannover's annual water demand. As in most drinking water catchments, groundwater protection is a major priority and concern about the negative impacts of agricultural land use on groundwater quality has resulted in several measures being taken. These include: *(i)* voluntary agreements with farmers to reduce fertilizer applications to a minimum; *(ii)* initiatives to increase the portion of deciduous forests in the catchment; and *(iii)* set-aside of arable land to reduce nitrate leaching from soils. However, it has proven difficult to keep nitrate concentrations at catchment level below the legal threshold value (50 mg NO_3/litre). Reduced N inputs result in yield losses, but do not greatly decrease nitrate seepage concentrations (Köhler et al., 2006). Even on set-aside land, seepage concentrations above the limit can occur.

The explanation is to be found in the history of water and land use here. Since 1960, provision of drinking water for Hannover has lowered the groundwater table, making wet grasslands drier. Large grassland areas containing high levels of soil organic carbon (SOC) were shifted to arable land between 1960 and 1970. The resulting SOC mineralisation has resulted in both CO_2 emissions to the atmosphere and nitrate leaching to groundwater, which still influences groundwater quality since it takes 50 to 100 years for soils to achieve a new equilibrium under present conditions (Springob and Mohnke, 1995; Springob et al., 2001).

Köhler et al. (2006) concluded that setting aside land does not have the desired effect on nitrate concentration levels, and that the only way to reduce N output to groundwater is to convert arable land containing high SOC into forest or continuous grassland. A promising strategy combining groundwater protection and agricultural reactivation of such fallow land might be the establishment of short rotation coppice (SRC) with willow and poplar (Lamersdorf, 2008). These bioenergy production systems might even improve groundwater quality compared to that in fallow areas. SRC with willow and poplar can contribute to groundwater protection, especially through its high fixing potential for nutrients. High biomass production associated with a high fixing rate for nitrogen can reduce the nitrate leaching potential of soils (e.g. see Berthelot et al., 2000 and Aronsson et al., 2000). The establishment of SRC on soils with high nitrate leaching potentials is therefore a promising option for arable land that is about to be set aside for purposes of groundwater protection and compensation.

Source: Paul Schmidt-Walter and Norbert Lamersdorf, Göttingen, Germany (2010)

This section includes two case studies of how bioenergy demand can contribute to water quality improvements through new land use practices. The first one is in Germany (Box 4.3.), and the second in Sweden (Box 4.4). In the Swedish example, there is a shift from conventional food/feed crops to increased production of perennial herbaceous plants and short rotation woody ones 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. Expanding these types of irrigated or non-irrigated biomass production systems can help address problems of eutrophication of aquatic ecosystems due to nutrient losses in agriculture.

Box 4.4: Willow vegetation filters for removal of nutrients from pre-treated wastewater in Sweden

In Enköping, central Sweden, which has 20 000 inhabitants, a 75 hectare willow plantation treats and utilizes decanted water from the dewatering of sewage sludge. The water contains approximately 25% of the nitrogen entering the wastewater treatment plant, but less than 1% of the water volume. By treating the water separately, instead of pumping it back into the treatment plant, the total nitrogen load is reduced by 25%.

The relatively limited water volume (around 15 000 m^3 per year, containing some 20 000 kg nitrogen and 600 kg phosphorous) enables storage in ponds during the winter, which is also required in order to reduce the level of pathogens. Between May and September, the water is used to irrigate the adjacent willow plantation using drip pipes laid in double rows, so that harvesting will not be obstructed. To stimulate growth and further improve the wastewater treatment plant's overall nitrogen treatment efficiency, the system is designed so that conventionally treated wastewater is added through the irrigation system. The irrigation load is approximately 250 mm per year, resulting in a load of some 200 kg nitrogen and 10 kg phosphorus per hectare. Ongoing monitoring thus far has shown low nitrogen leaching losses. Thus, the system is apparently capable of transforming the large quantities of added nitrogen.

The municipality covered all costs of the storage ponds, pumps, automatic filters and irrigation pipes (which were lower than the estimated costs of improved conventional nitrogen treatment), whereas the farmer/landowner planted the willows and is responsible for maintenance of the irrigation pipes. The biomass produced is used in the local district heating plant, contributing to the local supply of heat and electricity. Ash from the boiler is recycled back to the willow plantation. This treatment system is therefore an excellent example of how treatment and recycling of society's waste products can be combined with the production of biomass for energy (Figure 4.3).

Figure 4.3: View of the Enköping municipal wastewater plant in Sweden, showing water storage ponds and willows used as vegetation filters

Swedish quality requirements for sewage sludge recycling in agriculture are among the strictest in the world. Nevertheless, most sludge in Sweden is allowed to be used in agriculture. High quality has been obtained through effective and persistent work with, for example, controls on industrial wastewater connected to sewerage, and disconnection of polluted stormwater and landfill leachates. Still, demand for sewage sludge for use in conventional farming is very low. Utilization of the sludge in willow plantations has considerably higher acceptance. The main reasons it is utilized in willow plantations are:

- Willows are not included in food production – they are not eaten;
- Existing routines and equipment for sludge management can be used – it is just another crop;
- To a large extent, sewage sludge replaces commercial fertilizers, especially phosphorus, and increases the soil content of organic material.

Source: Pär Aronsson, Swedish University of Agricultural Sciences, Sweden

Furthermore, more efficient irrigation systems – such as drip irrigation – can help to prevent water pollution and consequent negative impacts on ecosystems caused by the run-off of salts as well as fertilizers and pesticides to surface waters. Figure 4.4 shows examples of such irrigation systems.

Figure 4.4: Drip irrigation pipes (left) and an irrigated poplar plantation (right) in Chile. Photo credit: Dimitriou et al. (2011)

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 in river water quality due to the suspended load that accompanies flood waters (formed mostly by run-off).

A specific case of water quality problems, where certain biomass plantations can offer mitigation, is the replacement of forests with pastures or other vegetation types that have lower evapotranspiration rates than the forests, where this results in productivity losses due to soil salinity induced by rising water tables. In such cases, biomass plantations with high water usage can be planted to intercept water moving through the soil and reduce groundwater recharge. When planted up-slope of salt-prone areas, plantations with a high evapotranspiration capacity can contribute to the prevention of salinity by reducing the amount of water reaching recharge zones. When planted within salt-prone areas, plantations can lower the water table and also reduce evaporation losses by providing ground cover.

b) Mitigation measures at the conversion stage

Cleaner production approaches can be very good for business, as they focus attention on maximizing output, minimizing wasted resources of any kind, and recycling and reusing all by-products. Technology change is only one aspect of this approach, and it may be better managed if it is part of a voluntary programme than if it is dictated by legislation. Many actions can be taken to protect the environment and save water resources, such as developing an environmental policies framework (Chapter 5) and minimizing pollution.

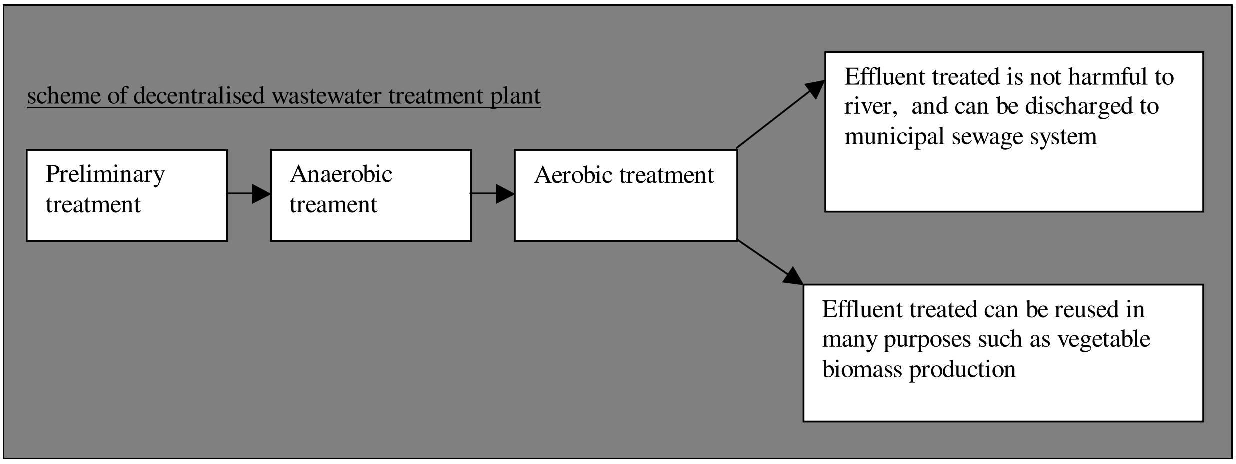
The high organic load and low concentration of chemical products (e.g. sulphate, sodium, copper, iron, zinc) in industrial wastewater justify its use in biogas production (Table 4.5).

Table 4.5: Results of experience with the use of industrial wastewater in biogas production

Type of substrates	Temperature (°C)	Loading rate of volatile solids (kg/m^3/day)	Retention time (days)	Gas yield per kg of COD (m^3/kg)
Sugar refinery waste	35	1.5	5.1	0.76
Molasses stillage	35			0.35
	37	2.2	10	0.12
		5.4	4.1	0.04
		7.5	3	0.02
Rum distillery waste	35	10.4	12-15	0.28-0.29
		8.8	8-10	0.27-0.29
Palm oil mill effluent	35		11-20	0.24
	55		7-13	0.42

Fermentation of wastewater from bioenergy conversion facilities, integrated in a sewage treatment system, is well-developed. However, a conventional type of wastewater treatment plant widely used in developing countries is different, with an anaerobic system of liquid waste treatment (Figure 4.5).

Figure 4.5: Decentralized wastewater treatment plant



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 treating and reusing water effluent;
- to define the necessary reduction;
- to develop reduction options.

Wastewater characteristics have already been addressed in this chapter. The objective of treating or reusing effluent is to discharge the effluent to surface water without any damage to the environment, to discharge it to the municipal sewage system, or to reuse it in irrigation.

The goal of preliminary treatment is to adjust pH and temperature following flow equalization, and to remove large, heavy solids through collecting, screening and degritting. In anaerobic treatment, where effluent is fermented, about 85% of suspended solids and BOD/COD is removed. At this level, the digester widely used is the UASB (Upflow Anaerobic Sludge Blanket) reactor, which is applied successfully in the municipal and industrial sector. Several advantages are associated with anaerobic treatment, including *(i)* low energy requirement, *(ii)* little sludge produced, and *(iii)* production of methane gas as an energy source. Generally, anaerobic processes are followed by an aerobic second stage that can use conventional activated sludge, extended aeration and rotating biological contactors. With aerobic treatment, organic loads continue to decrease and nutrients such as nitrogen and phosphorus are removed. An aerobic treatment system may consist of one to three oxidation ponds.

Following this treatment, wastewater is no longer harmful to the environment and can be discharged to a municipal sewerage system (if the capacity to do so exists) with the approval of the relevant authority and at the lowest cost to industry. It is important to note that, in wastewater treatment, the first step is “primary treatment” and the combination of anaerobic and aerobic treatment is “secondary treatment”.

Advanced or “tertiary treatment” can be applied in the case of liquid waste disposal. A natural system for wastewater treatment, such as constructed wetlands, may be used in tertiary treatment. Constructed wetlands, regarded as an emerging technology 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.). Natural systems can provide a huge quantity of vegetable 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.

Finally, in addition to considering technical mitigation measures, water resources management is a way to promote the development of alternatives for bioenergy production. It should be multidimensional and have a sustainable development point of view. Management needs to include: *(i)* an understanding of the resource condition (e.g. levels and types of pollution); *(ii)* goals of the society/community, and/or the decision-maker; and *(iii)* appropriate physical and institutional mechanisms to accomplish these goals. Therefore, the implications of water resources management in terms of policymaking are significant mainly for larger geographical areas and decisions on development and/or regulations (e.g. land use areas with better possibilities for production of bioenergy crops). Failure of water resources management plans has been related to lack of a clear definition of goals, and to ignoring the geological, hydrological and biological realities of water resources (Perry and Vanderklein, 1996).

4.5 Conclusions and recommendations

Water quality related to the production of bioenergy feedstocks and their conversion to solid, liquid and gaseous fuels for heating, power and transport is associated, in particular, with agricultural and forestry activities. The main sources of pollution are clearly related to the use of pesticides and fertilizers, but also to certain co-products (e.g. vinasse) from the industrial pathways of some feedstocks. The impacts of these co-products on water quality depend upon several natural factors, as well as on the severity of the impacts and their effects, including indirect and cumulative ones.

Although the main impacts originate to a great extent from agriculture and forestry, it is not possible to attribute impacts on water quality solely to the production of bioenergy crops.

Innovative forms of integrated production will prove the best way to avoid and mitigate impacts. Water use in processing also contributes to GHG emissions, for example in wastewater treatment in the palm oil industry. Future technologies, probably associated with biorefineries, could incorporate better water quality management.

One of the main constraints in some areas is lack of current data for developing countries, the importance of which is shown, for example, in the case study on water quality in Senegal. Monitoring should be conducted on a regular basis, whereas it may not occur often enough to comply with regulations or with the aim of sustainable production.

Several case studies and examples of research demonstrate that good practices and standards are already available, including affordable measures that can be taken to avoid or mitigate impacts. Examples are provided by the case studies on ethanol production from sugarcane in Brazil; harvesting of short rotation coppice (SRC) in Australia; the potential for using SRC to improve groundwater quality in Germany; and use of willow vegetation filter for wastewater treatment in Sweden.

Finally, considering water resources management as part of policymaking and decision-making can contribute to the mitigation of harmful impacts on water quality and promote better practices with regard to the production of bioenergy feedstock and its conversion to biofuel.

5 Policy instruments related to water use in bioenergy production

Growing water scarcity and pollution call for enhanced water resources management to assess and balance water supplies and demands from different sectors. Bioenergy is a relatively new water-using sector, adding pressure on available supplies. Hence, bioenergy development needs to take into account sustainable management of water resources as a precondition for ensuring its long-term sustainability without compromising its potential benefits.

This chapter reviews policy instruments that can influence how bioenergy production affects water availability and water use, either directly or indirectly. Following an overview of policy instruments relevant to the use of water in general, policy instruments that address water use more specifically associated with bioenergy development are discussed in greater depth. Consideration is given both to biomass production and to subsequent conversion to solid/liquid/gaseous fuels and to electricity. Several case studies illustrate existing experience.

5.1 Overview of policy instruments affecting water use

In the past, investments to increase the *supply* of water were a common strategy to manage water resources. However, in economies characterized by growing water scarcity (Randall, 1981) and water transfers (in scale and amount), managing *demand* for water is becoming critical. The challenge for water demand and water resources management is to generate physical and economic savings by increasing output per unit of *evaporative loss of water*, reducing *water pollution*, and reducing *non-beneficial water uses* (see the preceding chapters).

5.1.1 Types and scales of policy instruments used in water resources management

Based on Bhatia et al. (1995), for the purpose of this report the authors differentiate between four types of policy instruments that can be used in water resources management:

- *Enabling* conditions, that is, changes in the institutional and legal environment in which water is supplied and used. They may include the creation of institutions or processes, such as mechanisms for exercising water rights and for taking collective action (e.g. water user associations that manage water allocation within irrigation systems as a group), but also the privatization of utilities;
- *Market-based incentives*, which directly influence the behaviour of water users by providing incentives to conserve water, including water pricing, water markets (e.g. tradable water use rights and, more recently, water pollution trading), effluent charges and other types of taxes, and subsidies;
- *Non-market instruments* or *command-and-control approaches*, such as water quotas, licenses and pollution controls (e.g. water standards); and
- *Direct interventions*, such as investments in efficiency or conservation programmes, including rehabilitation and restoration of water infrastructure in all sectors.

Command-and-control approaches are the policy instruments most often used to directly address an environmental problem. Market-based approaches have been introduced to increase flexibility in policy application and to minimize implementation costs. Each instrument has benefits, but also presents challenges in terms of effectiveness and efficiency, and in most cases a mix of policy instruments is used for water resources management. The specific set of policy instruments used will vary from one location to another, depending on factors such as the status of economic development, level of water scarcity, historical development and institutional capability, among others. Besides conceptual differences, all instruments face implementation barriers, which may vary greatly.

All of these instruments are applicable to water management more broadly, but are also of relevance to water management specifically associated with bioenergy production.

5.1.2 Water rights – the key enabling conditions

Water rights are the *key enabling conditions* of policies aimed at making the use of water in bioenergy production (and other uses) more sustainable. If well-defined rights are established, water users can benefit from investing in water-saving technology; and when water is expropriated or transferred to other uses, rights holders can claim compensation on the basis of these rights.

Although some customary or statutory water rights systems operate in virtually any setting where water is scarce, systems not firmly grounded in formal or statutory law are likely to be more vulnerable to expropriation.

When property rights are difficult to define or enforce (e.g. in the case of common pool resources, such as small reservoirs), collective action may be needed to achieve sustainable water management (Ostrom, 1990). While scarcity and the need for access to markets may drive the emergence of collective action and/or the assertion of property rights, appropriate institutions are needed to support collective action and administer property rights. If property rights to water or land have not been established by statutory means, or if customary rights are not recognized by government authorities, local water users may lose out when biofuel plantations are established through government sales or concessions (Songwe and Deininger, 2009; Mann and Smaller, 2010).

5.1.3 Levels of implementation

Implementing water policy instruments is highly complex, given 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 uses, and the existence of consumptive and non-consumptive uses. Thus, water policies are implemented at different levels ranging from local to district, national, regional and up to the global level. While most water policies with a statutory basis are generated at the national level, an increasing number of countries are trying to determine the best level of intervention, which has resulted in the actual responsibility for implementation being transferred to lower levels of authority, particularly the provincial or district level – providing both new opportunities and new challenges. In Indonesia, for example, the central government assigned virtually complete responsibility for urban and rural infrastructure services to local governments almost overnight. Local authorities are now in charge of most of the government's development budgets, while provincial (and national) oversight was decreased. As a result, accountability to the local citizenry has increased and the perception of corruption has declined (Peterson and Muzzini, 2005).

Global level agreements, such as those on climate change negotiated within the United Nations Framework Convention on Climate Change (UNFCCC), and assessments including those carried out by the Intergovernmental Panel on Climate Change (IPCC), also concern water, inform and influence policymakers, and have an impact on water policy. Moreover, some water policies consider customary use rights, generally on a small scale, while others are based on statutory laws and regulations. Thus, multiple legal and normative frameworks may coexist, while the dynamics between customary water rights and statutory water policies are subject to change (see also the literature on legal pluralism, e.g. Bruns and Meinzen-Dick, 2000; Meinzen-Dick and Pradhan, 2001 and 2002; Wiber, 2005; Cotula et al., 2008).

5.1.4 The multisectoral nature of water policies

Reflecting the crucial role of water in many sectors, policies relevant to water are developed and implemented by different agencies or ministries, including those focusing on the environment, agriculture, fisheries, public health, construction and energy and on water proper, such as a Ministry of Water Resources. Besides this fragmentation across institutions, management of the water resources themselves (e.g. surface water and groundwater resources) is often fragmented across different actors and legal systems. For bioenergy production, water policies in the environmental, agricultural, forestry, energy and industrial sectors are relevant. In several countries bioenergy policy and research related to the conversion stage of bioenergy production, as well as overall development strategies, are housed with the ministry responsible for (renewable) energy, while the ministry responsible for agriculture often funds and manages research and extension services (including trial fields) related to the agricultural stage of bioenergy production.

The EU Water Framework Directive, whose purpose is to ensure sustainable development of all water resources in the EU, is one example of how policies and regulations in the area of water can affect bioenergy production and use (case study 5.1).

Case study 5.1: The EU Water Framework Directive and water use for bioenergy

The EU Water Framework Directive (WFD) was adopted in October 2000. Its key objectives are general protection of aquatic ecosystems, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water.

The scope of water protection in the WFD covers both surface and groundwater. The Directive includes deadlines with respect to reaching “good ecological status” for all water in all EU Member States. It uses a river basin approach, with supporting river basin plans to be introduced in all Member States. Moreover, it sets emission limits and quality standards. These limits and standards imply strong pressures for changes in the agricultural sector, a major source of water pollution in many EU countries. Successful implementation of the WFD strongly depends on the development of agriculture and land use, which is influenced by the EU’s Common Agricultural Policy (CAP) and bioenergy-related policies.

The Rural Development Regulation (for the period 2007-2013) directly supports the objectives of the Directive by providing financial support for the implementation of WFD objectives that offer the ability to protect and enhance natural water resources (e.g. agro-environmental and agro-forestry payments, use of advisory services, and farm investment support to improve the environmental status of agricultural holdings).

Based on the observation that replacing arable crops with perennial herbaceous and short rotation woody plants can lead to improved water quality, the integration of such plants into the agricultural landscape has been proposed as a strategy to meet WFD water quality objectives, while also providing biomass for energy to help meet the objectives of climate change mitigation and improved energy security. Thus, the WFD supports some bioenergy development. However, implementation of the Directive strongly varies among Member States.

Source: Berndes, G., 2010 (personal communication)

5.1.5 Influence of other sectoral policies

In addition to water policies that affect bioenergy production directly, water policy and water use related to bioenergy production are impacted by macroeconomic and trade policies, input and output price support policies (subsidies), investment strategies for infrastructure and foreign direct investment (FDI), agricultural research, climate change and energy policies, and demographic changes (including migration), among others (Ringler et al., 2010). For example, given the international scope of bioenergy development, the liberalization of trade in environmental goods under the World Trade Organization (WTO) has potential impacts on developing countries' water security.

Furthermore, biofuel targets and mandates enacted in an increasing number of countries have been driving bioenergy development, opening up opportunities and challenges for production, particularly in the developing world. Along with changes in climate change policies and energy prices, this will influence demand for bioenergy, with direct impacts on water quantity and quality. Trade, agricultural and food security policies can also introduce bioenergy to (or eliminate it from) national energy portfolios. For example, in 2007 China was the world's third largest bioethanol producer after the United States and Brazil, with annual production of 1.35 million tonnes. Due to increasing food security concerns, the government subsequently prohibited bioethanol production using maize and wheat as feedstock, except at four plants that were allowed to maintain their output but not to expand (Qiu et al., 2010).

On the other hand, energy policy and price developments, as well as climate change, have not only been the major underlying causes of increased bioenergy feedstock production, but have also helped improve water and (bio)energy use efficiency and have led to the use of new integrated approaches such as biorefineries.

5.1.6 International and multilateral approaches

International governance arrangements and codes of conduct would also be useful to support rural dwellers in developing countries (who often do not have secure property rights to land or water) in avoiding potential expropriation as a result of foreign direct investment (FDI) in land for feedstock plantations. This issue has received attention during the last several years in the context of investment in farmland by large-scale investors (see, among others, Cotula et al., 2009; FAO, 2009; von Braun and Meinzen-Dick, 2009; Borras and Franco, 2010; FAO et al., 2010; Kiene, 2010; Deinenger et al., 2011; FAO/OECD, 2011). [28]

[28] As part of the work of the United Nations Committee on World Food Security (CFS) (http://www.fao.org/cfs/en/), Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests have been under

Several codes of conduct have been developed to help ensure sustainable bioenergy production, including the Cramer Commission Criteria in the Netherlands, the Renewable Transport Fuels Obligation (RTFO) in the United Kingdom, and the Global Bioenergy Partnership (GBEP) criteria and indicators (Section 5.2.7).

Such codes of conduct should include an assessment not only of the impact of FDI on local inhabitants, but also of the natural resources they depend on, chiefly land and water. For example, Principle 7 of the FAO, IFAD, UNCTAD and World Bank Group *Principles for Responsible Agricultural Investment that Respects Rights, Livelihoods and Resources,* which addresses environmental sustainability, includes the requirement that "environmental impacts due to a project are quantified and measures taken to encourage sustainable resource use while minimizing the risk/magnitude of negative impacts and mitigating them" (FAO et al., 2010).

5.2 Specific policy instruments addressing water implications of bioenergy production

Policy instruments need to address potential impacts at all stages of the bioenergy life cycle (i.e. those related to feedstock production and those related to conversion, as discussed in the preceding chapters). For many of the environmental impacts during the agricultural production and refining phases, technical solutions are available but have not yet been adopted. Policy instruments can encourage their adoption by economic actors. Such encouragement should be given in a manner that avoids, as far as possible, adverse impacts on the competiveness of bioenergy producers.

Moreover, new policy instruments should be integrated with existing ones to achieve policy coherence and synergies. Table 5.1 lists examples of policy instruments that can be used to reduce negative impacts of the bioenergy sector on water.

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

Policy instrument	Example	Description/goal	Examples of application	Evaluation	
				Advantages	Disadvantages
Enabling conditions	Statutory water use right	Government-defined bundles of rights related to access to and use of water	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
Enabling conditions	Intellectual property rights	Creations of the mind for which property rights are recognized	Can support development of water-conserving feedstock	Helps support R&D investments in water-efficient crops	Can reduce access to new feedstocks in countries that cannot afford new technologies
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	Quotas, water rights, discharge permits and effluent-based water quality standards	*(i)* Ease of implementation and policing *(ii)* 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

development. The draft guidelines aim at providing broad governance principles, founded on transparency and the accountability of governments and private actors, to guide the acquisition of land and natural resources.

		quality of water resources			maximum allowed effluent concentrations), 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 to the same extent as those for which the cost is lower
Command-and-control approaches*	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	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)
Command-and-control approaches*	Ambient-based water standards	Establish allowable ambient-based quantity and quality standards, which can be for a basin or reservoir, usually with multiple users/The purpose is also to ensure adequate quantity and quality levels for water bodies. In this case, neither the technology nor reduction levels per user have been established	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 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 producers' costs to reduce pollution differ
Market-based instruments*	Charges	Rates charged according to quantity and/or quality of water used/Social costs of water resources use assigned	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 lowest 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 (does not ensure allocative efficiency) *(ii)* Distributive implications related to higher prices of products that use water as raw material, unemployment, etc. *(iii)* Increase in enforcement costs (prevention of illegal use of the water resources)
Market-based instruments*	Subsidies	Payment or concession of tax reduction to provide conditions for economic activities to reduce impact on water resources/ Internalization of social benefits due to non-use or pollution of water resources	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, which is generally very costly
Market-based instruments*	Payment system per land reservation	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	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 supervision costs	The identification of reimbursement values compatible with activities' opportunity costs that lead to environmental impact can take some time for adjustment, therefore incurring costs for society without the desired benefits
Market-based instruments*	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 waters are established, whereas the market will establish the price	Tradable permits, water tradable quality permits or water quality trading/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 reflect the amount of 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 respect 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)* Risk of 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
Direct interventions	Awareness campaign	To increase the knowledge of the general public with respect to certain topics	Water pollution awareness campaign to explain how point and non-point source pollution affects health and the environment	*(i)* Can have considerable impacts *(ii)* Can be inexpensive	It is often difficult to remain neutral, i.e. campaigns often advocate only one point of view/perspective
Direct interventions	Efficiency-enhancing water infrastructure investments	Investments to improve the functioning of government services in various sectors	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 developments

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

Effective policy instruments need to be developed based on sound bioenergy strategies and national programmes. A process for sound bioenergy strategy and policy development is described in the *Decision Support Tool for Sustainable Bioenergy*[29] prepared by FAO and UNEP under the framework

[29] The *Decision Support Tool for Sustainable Bioenergy* is targeted at decision makers to assist them in developing robust bioenergy policy and strategies. For further information, go to: http://www.bioenergydecisiontool.org

of UN-Energy.[30] It identifies as key elements land use planning and, particularly, agro-ecological zoning. Agro-ecological zoning consists of matching climatic, soil, water and other biophysical conditions with crops and agricultural management systems.

Box 5.1: The online decision support tool WaterWorld

WaterWorld incorporates detailed global spatial datasets at 1 km^2 and 1 hectare resolution, spatial models of biophysical and hydrological processes, and scenarios for climate and land use change. The model, developed for policy analysts and scientists, allows users with little specialized training to assess the consequences of different policy and land use decisions (e.g. those related to feedstock production). The effects of these decisions can be traced through the biophysical systems, allowing users to incorporate the results into decision-making processes and potentially avoid unintended impacts on local or downstream hydrological resources from, for example, policies that encourage biofuel feedstock production (*http://www.waterworldmodel.org/, http://www.policysupport.org/links/waterworld)*

One sample analysis was done to assess the hydrological impacts of the cultivation of oil palm on plantations in northern Colombia. In this scenario, users are able to convert the existing vegetation cover to oil palm (*Elaeis guineensis*) in areas of moderate to high suitability, as determined by oil palm suitability maps, based on broad-scale current climate information and a set of crop-specific climatic and biophysical threshold requirements yielding a coarse-scale, spatially explicit profile of areas of potential suitability (Hewson et al., in preparation). In the example, conversion of the mixed tree, grassland and bare areas identified as potentially suitable for oil palm cultivation to oil palm plantations leads to an increase in evapotranspiration of up to 200 mm/year. Since some of the areas converted receive significant inputs of fog, the extra tree cover leads to extra fog inputs of up to 50 mm/year. Overall, the water balance of the converted areas decreases by 0-200 mm/year, with the greatest change occurring in lowland areas where potential evapotranspiration is greatest. Such a reduction would not only have real consequences in the watershed, concerning both its use by local populations and its use for other economic activities requiring water, but would also potentially fail to meet roundtable standards (see Chapter 6) prohibiting reductions in water availability and flow.

Source: Honzák, M., Mulligan, M., Hewson, J., Ashkenazi, E., Dragisic, C., and Portela, R., 2010 (personal communication).

Furthermore, Module 9 of the UN-Energy *Bioenergy Decision Support Tool* contains a list of tools and resources which can be useful for decision makers and planners looking at bioenergy strategies and projects. Some of these tools and resources concern the hydrological impacts of bioenergy development. Therefore, they allow decision makers to evaluate the potential effects of different production scenarios on water resources, and to take this information into account in planning and managing production schemes. They address not only the recognition, by forward-thinking private and public sector planners, that water impacts should be addressed from the earliest stages of planning, but also the requirements of emerging industry standards such as those of the Roundtable on Sustainable Biofuels, Roundtable on Sustainable Palm Oil, Round Table on Responsible Soy, and Better Sugarcane Initiative (Chapter 6). WaterWorld, a web-accessible model developed by King's

[30] UN-Energy (http://esa.un.org/un-energy) was established to help ensure coherence in the UN system's multi-disciplinary response to the World Summit on Sustainable Development (WSSD) and to ensure the effective engagement of non-UN stakeholders in implementing WSSD energy-related decisions. It aims to promote system-wide collaboration in the area of energy with a coherent and consistent approach, as there is no entity in the UN system with primary responsibility for energy.

College London, in collaboration with a number of organizations including Conservation International, is such a decision support tool (Box 5.1).

5.2.1 Policy instruments that address water quantity

Negative impacts on water availability associated with bioenergy production can be mitigated by *choosing the appropriate bioenergy feedstock,* suited to specific rainfall and other biophysical conditions in the region where it is to be grown, as well as by *rational and efficient use of water resources* and *good agricultural practices and technologies.* However, the costs associated with using water resources efficiently could make biofuel production in some areas unviable (National Research Council, 2008). Taking spatial and temporal variations in water resources into account is related not only to irrigation, but also to changes in total crop evapotranspiration (ET). It is therefore important, in the planning of biofuel plantations, to consider the ET associated with previous land use and with alternative farming options.

A number of indicators provide information about the relative water intensity of different bioenergy options, as well as variations in water intensity across these options, which depend on both biophysical conditions related to the biomass production (e.g. evaporative demand) and the technologies used in converting biomass to the end product. However, policymaking requires a broader set of criteria and indicators, also reflecting, for instance, local/regional water availability as well as water quality aspects (Chapter 2). In addition, whether more or less water-intensive bioenergy options are attractive will depend on the consequences of not using the water for bioenergy, i.e. on alternative water uses (including for environmental flow requirements) and on alternative ways to meet energy demand (Göran Berndes, personal communication).

5.2.2 Policy instruments that address water quantity during feedstock production

The cultivation of bioenergy feedstocks consumes by far the most water during the biofuel production process. Cultivating bioenergy crops that are less “thirsty” could save large amounts of water. In addition, water use varies not only from one crop to another but also with location and production method, i.e. according to whether crops are irrigated and the type of irrigation technology is used. Policies could therefore influence feedstock choices and land use choices (Box 5.1).

Moreover, given that globally most of the water used in agriculture is from precipitation, and that most investments have focused on blue water alone (Chapter 2), investments and policies promoting rain-fed feedstock production will be important in many regions, particularly Sub-Saharan Africa. Such policies include *incentives for enhanced measures to conserve soil moisture, including rainfall capture, conservation tillage and precision agriculture* (Berndes, 2002; Sulser et al., 2009). If implemented appropriately, such investments and policies can reduce pressure associated with generally more costly blue water developments.

Converting cropland or grassland to bioenergy feedstock production generally changes total annual ET and/or shifts its seasonal distribution, subsequently changing soil moisture and possibly affecting the regional climate over the long term. Thus, to avoid increasing local or seasonal water shortages resulting from biomass production, regulations need to be stipulated and/or incentives provided to ensure that the varieties chosen either reflect or reduce current ET levels.

Direct investments in agricultural research and development have been crucial for reducing crop water use through changes in cultivation practices and crop varieties. Such changes include:

- increasing the share of water taken up by plant roots;
- reducing the share of non-beneficial evaporation from the soil; and
- improving transpiration efficiency (the ratio of the mass of CO_2 taken up by plant photosynthesis and the amount of water transpired), biomass efficiency (the ratio of crop biomass to the CO_2 assimilated by photosynthesis) and yield efficiency or the harvest index (the ratio of harvested yield to the crop biomass produced) (Hsiao et al., 2007).

Some of these water conservation options are also available for rain-fed agriculture, and are thus important for biomass produced on rain-fed land (Cai et al., 2008).

Box 5.2: New feedstocks, cultivation practices and advanced biofuels

Further advances with respect to *lignocellulosic bioenergy crops* offer considerable potential to reduce the impacts of feedstock production on water quantity and quality. This is because, in general, these crops are more tolerant to dry weather and dry periods. It is expected that negative impacts will be reduced and benefits increased, especially in degraded areas (marginal lands), if adequate biomass cultivation systems are established. Still, it should be noted that the lower productivity of marginal lands implies that more land is needed to supply a given amount of biomass, and less productive lands may contain relatively biodiverse ecosystems and might well be the only option allowing for subsistence farming (or extensive herding) by landless people. In this regard, mapping of "go" and "no-go" areas for bioenergy development, particularly with respect to defining and mapping biodiversity and degraded lands, has been identified as an important measure. Such mapping needs to be based on common definitions of terms, as well as a mix of a top-down approach via GIS mapping and a bottom-up approach involving local stakeholders in the identification of areas of high conservation value and degraded lands.[31]

Similarly to the conventional crops used as biofuel feedstock today, advanced biofuel crops – if not cultivated sustainably – could also increase soil erosion or deplete already fragile natural resources, particularly nutrients and green water. Policies to encourage the production of biofuels from lignocellulosic biomass are already in place. For example, one aim of the 2006 EU strategy for biofuels[32] was to support research into advanced biofuels, while the 2009 EU Renewable Energy Directive implements explicit "double counting" for lignocellulose-based biofuels towards the 2020 renewable transport target,[33] the 2010 US Biomass Multi-Year Program Plan refers to a focus on developing, demonstrating and deploying cellulosic ethanol,[34] and the 2007 US Energy Independence and Security Act establishes mandatory targets for cellulosic ethanol.[35] Comprehensive assessment of

[31] In 2008, UNEP, Oeko Institut and the Roundtable on Sustainable Biofuels (RSB), in collaboration with Conservation International, IUCN, FAO and WWF, organized a first workshop, "Bioenergy and Biodiversity: Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands". In July 2009, the "2nd Joint International Workshop on Bioenergy, Biodiversity Mapping and Degraded Lands" was held in Paris, bringing together leading experts and organizations to discuss definitions, tools, data sources and methods for sustainable bioenergy planning. Further information and background documents are available on http://www.unep.fr/energy/activities/mapping/

[32] http://www.biofuelstp.eu/downloads/An_EU_Strategy_for_Biofuels_2006.pdf

[33] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

[34] http://www1.eere.energy.gov/biomass/pdfs/mypp.pdf

[35] http://energy.senate.gov/public/_files/getdoc1.pdf

the full impacts of large-scale production of lignocellulosic biomass on water resources is needed in order to support the development of policy frameworks that promote sustainable implementation of such technologies, as existing studies either use aggregated data or assume still speculative improvements regarding yields and water use efficiency (see detailed discussion in NRC, 2008; Ecologic/Alterra, 2009; US-GAO, 2009; Wu et al., 2009).

To obtain effective water use reductions, it is important to consider regional differences related to water needs.[36] The design of policy instruments that encourage lignocellulosic feedstock production must therefore also incorporate specific regional conditions. Moreover, not only crop type, management and previous land use but also physical characteristics of the land (e.g. soil, climate and topography), crop location in relation to other land uses, and the amount of land used affect water availability (Graham, 2008). Thus, the impacts of commercial-scale lignocellulosic feedstock cultivation on hydrology, as well as the ET values of these crops on marginal lands, remain uncertain (US-GAO, 2009). There is concern that lignocellulosic crops will use more water since they are bred for higher biomass than the main types of vegetation found on natural prairies (McIsaac, 2009). However, there are still insufficient data to determine whether perennials for biomass harvest will consume more water than native plants on natural prairies (see also Box 5.2).

Using agricultural *residues as raw materials* would very likely reduce water use by feedstock, as residues are a by-product that would not require additional water. However, 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 from overexploiting crop residues for use as biofuels. Furthermore, complete removal of agricultural residues results in erosion and nutrient run-off into the water supply, as well as soil impoverishment requiring the application of nutrients for future crops.

Because of possibly excessive ET from crops or other vegetation, the National Water Act of South Africa (NWA) (DWA, 1998) has established the concept of a "stream flow reduction activity" (SFRA), which uses the regulation of land use changes that can affect water availability as an instrument to manage water resources. Under the NWA, it is necessary to assess the potential water use and likely impact of potential biofuel feedstock production before permission is granted for production, in which case a water use license may be required even for dryland production (Jewitt et al., 2009). In addition, the Department of Water Affairs (DWA) of South Africa takes the position that production of biofuel crops under irrigation should not be supported (case study 5.2).

Case study 5.2: Policy instruments affecting water use for biofuel crops in South Africa

In South Africa, production of biofuels is guided by the Biofuels Industrial Strategy of South Africa (NBIS), a policy document from the Department of Minerals and Energy (DME) (DME, 2008). The South African strategy is generally considered to be conservative, with a pragmatic approach towards a goal of 2% biofuel penetration within five years. There is a focus on production of bioethanol from sugarcane and sugarbeet, and of biodiesel from sunflower, canola and soya beans. Citing food security concerns, maize (corn) is specifically excluded. Jatropha is also excluded because of fears that it could possibly behave as an invasive alien plant.

[36] For instance, see Wu et al. (2009): "In its native habitat, switchgrass can yield 4.5 to 8 dry tonnes per acre (Downing et al., 1995; Ocumpaugh et al., 2002; Taliaferro, 2002) without irrigation … If switchgrass were grown in regions where it is not native, irrigation would be needed (Fransen and Collins, 2008)."

Impacts on water resources are a major concern with respect to production of biofuels. In South Africa, the impacts of land use and land use change on the hydrological cycle and their potential impact on water resources are well known. Principle 18 in the preamble to the National Water Act of South Africa (DWA, 1998) states: “Since many land uses have a significant impact upon the water cycle, the regulation of land use shall, where appropriate, be used as an instrument to manage water resources within the broader integrated framework of land use management.” This principle has been given effect in legislation by Section 36(2) of the National Water Act of 1998 through the concept of a “stream flow reduction activity” or SFRA, defined as “… any activity (including the cultivation of any particular crop or other vegetation) … [that] … is likely to reduce the availability of water in a watercourse to the Reserve, to meet international obligations, or to other water users significantly.”

Thus, in terms of the NWA, it is necessary to assess the potential water use and likely impact of potential biofuel feedstock production in South Africa before permission is granted for production, in which case a water use license may be required even for dryland production (Jewitt et al., 2009).

Second, production of biofuel crops under irrigation is not supported by the Department of Minerals and Energy: “The production of feedstock under irrigation will only be allowed in exceptional circumstances and a detailed motivation will have to be provided” (DME, 2008). Moreover, the Department of Water Affairs (DWA) has taken the position that “South Africa is a water scarce country which can ill afford the use of current or potential irrigation water for fuel production rather than growing crops for food.” Under current legislation, the DWA cannot prevent farmers with existing water use licenses from converting their farming practices from food/fodder crop production to biofuel feedstock production, but it relies on the DME to ensure that license applications for biofuel processing plants will not be approved if the plants are to receive irrigated feedstock.

Furthermore, if the DWA becomes aware of farmers supplying irrigated feedstock to biofuel processing plants, it intends to impose an appropriate industrial water tariff on the irrigated water used to produce the crop, effectively charging much more for this water than the usual subsidized agricultural tariff. The policy of not permitting irrigated feedstock for biofuel production may severely limit investment in the biofuels industry.

Source: Jewitt et al., 2009

In many areas that lack sufficient rainfall for agricultural purposes, irrigation is practised. However, many regions are already overusing irrigation water and thereby draining water resources, further contributing to water scarcity. For example, in India more than 60% of cereal crops grown for consumption are irrigated and this figure rises to nearly 70% in China (Rosegrant et al., 2002). According to the same authors, extensive irrigation in northern China and in northern and western India has caused considerable groundwater depletion. The ratio of groundwater pumping to recharge was as high as 0.85 in the Hai River Basin in northern China, and in excess of 0.80 in several river basins in northern and western India.

In countries where crops or feedstocks are irrigated, it has been difficult to reduce water applications through water pricing even if increasing water shortages can be traced back to irrigation (see, for example, Perry, 2001 and Rosegrant et al., 2000). In the State of São Paulo, Brazil, where sugarcane production currently is mainly rain-fed, irrigation will likely need to increase in the future in dryer areas due to projected increases in sugarcane production. Current fees charged for the use of irrigation water in the State of São Paulo are unlikely to reflect the water’s full scarcity value. Anecdotal information even indicates that, under pressure from the agricultural sector, there are cases where the price of water has been set at a level that does not affect or hardly affects the economic performance of crop production (Smeets et al., 2008)[37]

Around 20% of the corn (maize) currently grown in the midwestern United States is irrigated (USDA, 2010). However, because of climate change it is likely that this percentage will increase, causing greater blue water consumption (Cai et al., 2009). Alternatively, different crops could be grown, or different corn (maize) varieties that would require less irrigation, or biofuels could be imported from areas that have abundant water resources (the "virtual water trade" concept), instead of using scarce water supplies for domestic biofuel production (Schneider, 2010).

The impact of water use related to biofuel production can be assessed using water modelling tools that support decision makers in formulating policies. One such tool, WEAP (the Water Evaluation and Planning System),[38] has been used in the Chira-Piura system of Peru to assess the impact of introducing bioenergy crops on the availability of water resources (case study 5.3).

Case study 5.3: Assessing the impact of introducing bioenergy crops on the availability of water resources in the Chira-Piura system, Peru

Management of land and water resources is especially important in semi-arid regions, where conflict over water is already a reality. In the Piura department of northern Peru, which has around 960 000 inhabitants, low water availability due to the loss of storage capacity of the Poechos Reservoir, and growing water demand in the Chira and Piura Valleys, require an integrated resources management approach to ensure the sustainability of the valley's resources and a secure supply of agricultural products to the people who live there.

In the last decades, local water resources management bodies have systematically implemented hydraulic use and control of water resources with state investment. However, this constitutes only a partial solution since the efficiency of water use is low. At the same time, the main part of the system, the Poechos Dam, is progressively losing usable storage volume due to high rates of sediment transport in the Chira River. Sedimentation has already resulted in the loss of half the reservoir's designed capacity of 840 cubic hectometres (84 km^3).

Water scarcity consequently threatens this area. In the Chira and Piura Valleys, water resources are already significantly constrained due to growing competition among agricultural, urban and industrial users. In this context, water demand for biofuel crop production will increase competition with traditional users.

A study evaluated the sustainability of water resources for the expansion of farming (agricultural water demand) due to the incorporation of energy crops for biofuel production (bioethanol) in the Chira Valley. The evaluation was based on four scenarios, which fundamentally varied demand and water availability in the valley of the Chira River. These scenarios were described and assessed with respect to impacts from the standpoint of system reliability, coverage of the application, and system vulnerability. They were: Scenario 1 – with reference to the current situation; Scenario 2 – with increasing areas of sugarcane; Scenario 3 – with increasing areas of sorghum; and Scenario 4 – with increasing areas of sugarcane and of farmers' crops.

System simulation and reliability assessment were conducted using the WEAP (Water Evaluation and Planning System) model. The analysis used an integrated approach, looking at both supply of and demand for water. It provided a basis for evaluating the allocation of limited water resources among agricultural, municipal, industrial and environmental uses.

[37] The São Paulo State water law 7.633 (1991) provides the basis for legislation (2000, bill 676) that promotes efficient water use based upon the "user pays" and "polluter pays" principles. The amount paid by users and polluters depends on the amount and quality of the water collected and released.

[38] WEAP can be applied at several levels, ranging from a sub-basin to more complex systems. The data structure and level of detail may be customized to meet the requirements of a particular analysis and to reflect the limits imposed by restricted data (Yates et al., 2005) (http://www.weap21.org).

The simulation results were assessed and evaluated using supply reliability and demand coverage as assessment criteria. The analysis considered an average 75% supply reliability as the acceptable level of water demand. The percentage coverage for each development scenario was determined. A sustainability analysis was carried out to assess the impact of each development scenario on the reliability of the system.

The results for scenarios 2, 3 and 4 indicated reduced reliability, resulting in a decrease in water demand served. The latter fell from 90% (baseline) to 84, 89 and 85% respectively for water availability to farmers and from 80% to 60, 74 and 52% respectively for water available to energy crops.

In conclusion, under current conditions of water provision, there was *not* found to be enough water available to support the introduction of a projected additional 23 976 ha for sugarcane production in the Chira Valley for bioethanol production. The current supply of water would only be adequate to support an additional 10 000 ha for sugarcane production in the valley.

The results demonstrated the urgent need for land and water resources management for the Chira and Piura Valleys. In addition, improvement in water productivity (0.7 kg of rice per m^3 of water, current situation, and 1.34 per kg of all crops in the valley) would be possible, enabling an increase in food production with the same volume of water and the same cultivated area.

Source: Bioenergía y seguridad alimentaria "BEFS" El análisis de BEFS para el Perú Compendio técnico – Volumen I, Resultados y conclusiones y Compendio técnico – Volumen II, Metodologías (FAO, 2010)

Results show that land use planning and water resources management are urgently needed to support balanced growth in areas where food crops and biomass are planted. While such analyses help to assess the potential impacts of bioenergy feedstock production on water availability, they need to be complemented by studies that incorporate aspects of integrated management, such as water quality, ecosystem preservation, economic efficiency, and direct and indirect economic impacts, as well as reuse and allocation, among others.

Hence, integration of economic, agronomic, environmental and hydrological aspects is needed to support efficient water use. This is aligned with the concept of integrated water resources management (IWRM). According to the GWP (Global Water Partnership) definition, IWRM is "a process which promotes the coordinated 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."[39]

Environmental policy instruments, whether they are *market-based tools or command-and-control regulations,* can be effective not only in changing crop or feedstock varieties and types to those more suitable to a specific region, but also in stimulating the adoption of agricultural practices such as precision agriculture and advanced irrigation technologies.

The use of one and/or another approach will depend on a series of factors, especially: *i)* the legal environment and restrictions; *ii)* the state of economic development; *iii)* characteristics of the impacts on water resources; and *iv)* the market context (Thomas and Callan, 2010).

Policy formulation should be supported by data and models, as feasible, particularly economic modelling[40] and criteria for allocative and technical efficiency. The allocative efficiency of an

[39] http://www.gwp.org

[40] More specifically, hydro-economic models represent spatially distributed water resource systems, infrastructure, management options and economic values in an integrated manner. In these tools water allocations and management are either driven by the economic value of water or economically evaluated to provide policy insights and reveal opportunities for better management (Harou et al, 2009).

instrument requires that the resulting allocation among sectors be economically optimal, i.e. each sector derives the same utility from the last unit of resource allocated. However, such a principle is difficult to implement in practice and does not always hold for complex environmental models (Harou et al, 2009). Instruments can also be evaluated according to the cost-effectiveness criterion (the second best criterion, also known as the "technical efficiency criterion"), i.e. maximum production at available resources (Thomas and Callan, 2010).

Although some command-and-control regulations can also meet the technical efficiency criterion (Table 5.1), it is mainly market-based tools that can achieve cost-effective solutions. They support producers in choosing the most cost-efficient individual strategies. For example, several studies have shown that water markets, which have been successfully used in Australia, Chile and the United States, have induced farmers to adopt cost-effective, water-saving irrigation technologies while overall water use has declined (Rosegrant and Binswanger, 1994; Rosegrant et al., 1995; National Research Council, 2008).

5.2.3 Policy instruments that address water quantity during feedstock conversion

Bioenergy conversion generally has smaller impacts on water availability than does feedstock production, but this relation may change depending on local characteristics.[41] Water consumption by biomass conversion facilities depends on the conversion process used as well as on the biomass itself.[42]

Yet, again in the case of bioenergy conversion, water should be used as efficiently as possible, particularly in water-scarce regions. Water use efficiency will vary by feedstock and conversion technology used. While data are generally available on conventional feedstocks and conversion processes, water use and water use efficiency have yet to be comprehensively assessed for advanced technologies.[43] Given that water use generally represents only a small share of total production costs, it is unlikely that industries will significantly increase their efficiency unless *regulations or other measures promote* such improvements. The design of any *environmental policy instruments,* to be effective, must be based on reliable data and models.

Two of the world's major bioethanol producers, Brazil and the United States, show trends of declining water consumption following the evolution and maturing of diverse new technologies. The American Midwest, where most of the country's bioethanol plants are located,[44] faces significant water supply concerns (Phillips et al., 2007). According to Keeney et al. (2006), water availability in

[41] For instance, 2003 data for sugarcane production in the State of São Paulo, Brazil, show that ethanol-producing industries used 4% of total water consumed in that year whereas sugarcane irrigation used 1% (Smeets et al., 2008).

[42] "For example, a 100-million gal/yr conventional dry-mill ethanol plant typically uses 300 to 600 million gallons of water per year, with average water consumption currently about 4 gallons of water consumed per gallon of ethanol produced. Wet-mill processing uses somewhat more water per gallon of ethanol produced. The current state of the art with corn stover falls within the range of 10-11 gallons of water per gallon of ethanol (Pate et al., 2007).

[43] "Lignocellulosic ethanol production processes are still being developed and water use and consumption for commercial operations has not been established. Target projections are for commercialized enzymatic biochemical ethanol production to use on the order of 6 gallons of water per gallon of ethanol produced. Current projections are that thermochemical approaches using water based cooling systems will require twice as much water, with the 2012 water-use target with wood feedstock to be about 12 gallons per gallon of ethanol" (Pate et al., 2007).

[44] Ethanol plants in the United States are examples of today's biorefineries. Their products include ethanol, corn syrup, corn gluten meal, corn oil, and, as co-products, DDGS, fibre, steep water and corn gluten feed (Eric Andersen, personal communication, 2010). Another example is the Brazilian sugarcane-ethanol factories that use the process by-product bagasse for the cogeneration of process heat and electricity.

this region is a local (rather than regional) phenomenon and varies over time.[45] Furthermore, the effects of biomass conversion facilities on groundwater withdrawals[46] vary locally, but there is already evidence that development opportunities for the rural Midwest from this emerging industry would only be sustainable if options for reducing bioethanol's water consumption were adopted (Keeney et al. 2006).

In the United States, water consumption reductions were achieved through *technological improvements*[47] promoted through regulatory measures, triggered by water scarcity,[48] and *cost-saving measures* due to high electricity prices. Data from the NRDC, cited by Pate et al. (2007), attest to the importance of energy use for water consumption.[49] Theoretical economic models (e.g. Zilberman et al., 2008) suggest that rising energy prices alter water allocation and use for irrigated agriculture because of costly water extraction and conveyance, and that higher prices induce the development of technologies to extract water more cheaply and transport it more efficiently. However, without water allocation mechanisms that consider environmental costs, the adoption of such innovations can worsen over-extraction problems. For this reason, efficient water allocation mechanisms will become increasingly important.[50] Moreover, anecdotal evidence confirms that higher energy prices in the mid-2000s have already led to reduced groundwater use in parts of India and the United States (Tushaar Shah and John Sadler, respectively, personal communications).

Higher total water extraction as a result of advanced technologies (as described by Zilberman et al., 2008) could also occur in the bioenergy conversion stage. Thus, the proper design and permanent evaluation of environmental policy instruments are needed to reflect the true economic value of water, in order to induce water efficiency in all sectors and prevent upstream efforts from being lost downstream. As water is not valued in the same way as energy, autonomous water use efficiency is unlikely (Keeney et al., 2006).

In Brazil, reduction of water consumption of bioethanol production plants in the State of São Paulo has not been an isolated phenomenon. Industrial water use has been declining across the sector as a result of greater awareness of the need to save water and the indications of future legal and

[45] "The region has shown significant areas of water stress during the growing season in parts of the Midwest and Great Plains although it appears rainfall is returning to normal levels. However, drought is a recurring issue in the Midwest and Great Plains. The distribution of groundwater availability and sustainability is not uniform, nor is the distribution of demand. Rural industries, especially livestock production, consume considerable water. Crop irrigation, while not widespread in the rain fed Corn Belt east of the Missouri River, is necessary in Great Plains states" (Keeney et al., 2006).

[46] According to Phillips et al. (2007), ethanol plants often use well water from local aquifers that are not necessarily easily rechargeable. This is driven by the need for high-quality water in the boiler system (Phillips et al., 2007).

[47] In the United States, there is a high degree of recycling at today's dry mill ethanol plants. Many plants use what is known as a "zero discharge" design, where no process water is discharged to wastewater treatment. The use of centrifuges and evaporators enables recycling of process water. Therefore, much of the consumptive water demand of an ethanol plant is due to evaporative losses from the cooling tower and utility systems (Phillips et al., 2007).

[48] Lack of water has already curtailed some ethanol plant permits in the Midwest. One of the first was a proposed plant in Pipestone, Minnesota, by Cargill, Inc. The Lincoln-Pipestone Rural Water System could not provide the 350 million gallons of water per year needed by the proposed 100 million gallon per year ethanol plant (Keeney et al., 2006).

[49] Nationwide, about 3% of power generation in the United States is currently used for water supply and treatment, which is comparable to several other industrial sectors. Electricity represents 75% of the cost of municipal water processing and distribution. In California, where water is conveyed long distances by the State Water Project, 5% of the state's electricity consumption is for water supply and treatment. In locations dependent on groundwater, the energy required to supply water (excluding treatment) increases as water levels decline, from about 540 kWh per acre-foot at 120 feet to 2 000 kWh per acre-foot at 400 feet (NRDC, 2004).

[50] According to Zilberman et al. (2008), incentives need to be aligned. In particular, the external costs of energy and water use need to be internalized to encourage conservation.

regulatory action in this direction (Macedo et al., 2005). *Water use legislation* in the State of São Paulo, as well as federal laws and a few committee resolutions, mandate billing of water use (water pricing) and level-based water standards: *regulations on the volume and quality of water supply* and return flows. *Water prices* have been introduced in some basins, where they are determined by committees that include representatives of all users.

The above mentioned environmental legislation and technological advances will help achieving the Brazilian water efficiency goal of 1.0 m^3 per tonne of cane. Technological advances can be achieved by increasing the water recycling rate or replacing wet by dry cane washing (case study 2.1 in Chapter 2 and Smeets et al., 2008). However, the effect on overall water depletion will depend upon integrated water allocation strategies associated with bioenergy feedstock production (see the section on bioenergy feedstock production above), given projected increases in bioethanol production[51] and the consequent pressure on dryer production areas that need irrigation (e.g. the western part of the State of São Paulo)[52] (case study 2.1).

5.2.4 Policy instruments that address water quality

In addition to policies that mainly address water *quantity*, the water *quality* aspects of bioenergy production require increased policy attention.

5.2.5 Policy instruments that address water quality during feedstock production (non-point source pollution)

The main pollution concerns associated with bioenergy feedstock production relate to sediment and to additional nutrient loadings of water bodies, resulting from soil erosion (National Research Council, 2008) and from the application of fertilizers and pesticides. According to Simpson et al. (2009), large increases in both nitrogen and phosphorus levels are of particular importance as they stimulate primary production in downstream riverine, lake, estuarine and coastal waters. Nutrient-enhanced primary production (eutrophication) is a key cause of oxygen depletion (hypoxia).[53]

Agricultural policies that discourage the use of highly erosive land, and policy instruments and investments that encourage better nutrient use efficiency, along with incentives to change tilling practices, are already being implemented, mainly in developed countries.

[51] There are projections of a doubling of ethanol production between 2005 and 2015 (IEA, 2006).
[52] Brazil's irrigated areas are relatively small (1.2% of the world's total irrigated area) and use efficiency (defined as water reaching crops as a share of water withdrawn) is relatively low, at 61% on average (Moreira, 2007).
[53] Nitrogen fertilizer run-off in the Mississippi River system is the major cause of the oxygen-starved "dead zone" in the Gulf of Mexico (Section 4.1.1).

In the last few decades, developed and emerging countries have made considerable progress in controlling non-point source pollution using both non-market-based (or command-and-control, e.g. *standards, quotas*) and market-based tools (e.g. *subsidies*). In the United States, for example, farmers receive subsidies for adopting *Best Management Practices (BMPs),* i.e. specific agricultural practices whose purpose is to improve water quality by reducing non-point source pollution related to soil erosion and to fertilizer and pesticide use.[54] Two examples of forestry good practice codes related to water quality, from Australia and New Zealand, are presented in Box 5.3

Box 5.3: Two forestry good practice codes related to water quality: Australia and New Zealand

Example 1 – Australia. In a plantation cycle, most concerns about potential effects on water quality arise during establishment, harvesting or tending operations that include major soil disturbance or the application of fertilizers or pesticides. Hence, these operations are foci within codes of practice. For example, in the Tasmanian code in relation to reforestation of pastures (Forest Practices Board, 2000; currently being revised) plantation establishment in streamside reserves is permitted subject to:

- no establishment within 2 metres of a stream bank;
- machinery exclusion provisions;
- restrictions on cultivation;
- restrictions on the use of chemicals; and
- prohibition of tree harvesting within 10 metres of a bank of a permanent stream.

Example 2 – New Zealand. The principal statute determining the rules and regulations relating to forestry practices in streamside management zones (SMZs) is the New Zealand Resource Management Act (New Zealand Government, 1991). Regional plans usually allow the harvesting of historical plantation plantings up to the stream edge, but specify planting set-back distances usually of 5 metres and up to a maximum of 20 metres from a water body. Therefore, in many parts of New Zealand, farmers wanting to plant in SMZs for timber purposes will need to do so outside these "no planting" zones. Some water quality rules in regional plans for permitted forestry activities in New Zealand include management of the discharge. In addition to the Resource Management Act of 1991, a number of other key agreements and codes of practice influence farm forestry practices in SMZs in New Zealand. As an Organisation of Economic Cooperation and Development (OECD) member, New Zealand also participates in the development of its agri-environmental indicators (Manderson et al., 2007). Consequently, in New Zealand there is a strong emphasis on the management of SMZs in the agricultural landscape for mitigating nutrient and sediment run-off and for protection and conservation purposes using indigenous plant species. Whether exotic or indigenous species are planted for timber purposes is generally not a priority consideration (Cornell, 2003), although in appropriate areas non-indigenous plants can be established more cost-effectively than indigenous ones.

Source: Dan Neary, United States Department of Agriculture Forest Service, personal communication, 2010

There are also general principles for Best Management Practices in forest bioenergy programmes for the protection of water quality, as well as Codes of Practice for forest land management activities.[55] These incorporate practices to protect soil productivity, water quality, and biodiversity values. The Codes are usually based on the objectives of the regulating entity and the best available science.

[54] For the United States, also see the Conservation Reserve Program (CRP) established by the 1985 Farm Bill; the Environmental Quality Incentives Program (EQIP) established by the 1986 Farm Bill; and the Conservation Security Program (CSP) established by the 2002 Farm Bill (US Environmental Protection Agency, 2006). According to Dominguez-Faus et al. (2009), in 2007 an area of more than 14 million ha was enrolled in the CRP, resulting in significant reductions in pollutant loads to surface water in the United States, including reductions of 187 million tonnes of sediment erosion, 218 000 tonnes of nitrogen and 23 000 tonnes of phosphorous.

[55] Dan Neary, USDA Forest Service, personal communication 2010.

They should be dynamic in nature, and subject to periodic review in order to use the most recent research and address emerging problems.

Nevertheless, according to Segerson (1988), "the suggestion that Best Management Practices be required to reduce non-point surface pollution does not allow for flexibility and cost-minimum abatement strategies unless applied on a site-specific basis, which is generally impractical." This means BMP incentives do not necessarily favour the use of pollutant reduction strategies at minimum cost to the producers.

Attempts to complement instruments such as BMPs with lower-cost approaches have been encouraged by the US Environmental Protection Agency's Office of Water in the form of *water quality trading*. Policy development, guidance, and financial and technical support have been provided to watershed-based trading efforts for almost a decade (US EPA, 2008). However, success to date has been limited due to a variety of economic and regulatory barriers and lack of integration across instruments already in use. For example, many farmers are already part of BMP programmes and are not interested in participating in nutrient trading.[56] Moreover**,** *subsidies* for bioenergy feedstock production, as well as higher agricultural commodity prices in recent years (partly as a result of biofuel policies and subsidies), have outstripped support payments for BMP. Enrolment in conservation programmes has therefore declined in the United States (Box 5.4).

Box 5.4: Support for conservation programmes in the United States

According to US Environmental Protection Agency data, resources for conservation programmes supported by the US Department of Agriculture (USDA) increased from US$3 billion in 1990 to US$5.6 billion in 2005. EQIP, a programme that received the highest proportion of resources allocated to protect water quality, increased from US$200 million in 1996, its first year, to US$1.3 billion in 2007 (US EPA, 2008). At the same time, the increase in biofuel crop prices in the United States – especially as a result of US energy policy – was associated with a drop in land re-enrolment in Conservation Reserve Program (CRP) contracts.

According to Dominguez-Faus et al. (2009), "In June 2008, the price of corn rose to nearly $314/t ($8/bu) and stabilized through 2008 to between $157-196/t ($4-5/bu) and … overall 2008 averaged just over $160/t ($4/bu). This puts 2008 … well above the stable average or peaks of the previous two decades before the Energy Independence and Security Act (EISA) mandate. Although CRP contracts are established on a 10-15 yr basis, enrolment in the program is already decreasing. CRP enrolment dropped by more than 840 000 ha in 2008 and another 410 000 ha as of January 2009. Due to the erodible and less-productive nature of most land enrolled in the CRP, removing land from the program for row crop production will likely lead to a nonlinear increase in erosion and nutrient loading to surface waters. One proposal to avert removal of land from the CRP program is to increase CRP payments, which totalled more than $1.6 billion 2007. However, some analysts suggest that even doubling the payments would not be sufficient to retain land in the CRP."

Reduced tillage has also been associated with Best Management Practices (BMPs) since it can reduce non-point source pollution related to soil erosion: "The effects of increasing reduced and no-till rates on water quality illustrate the importance of tying economic *incentives* for biofuels feedstock production to sustainable crops and management practices" (Ugarte et al., 2010). According to Boehmel et al. (2008), reduced tillage also reduces the rate of mineralization, leading to lower mineralized nitrogen content in the soil in the spring and thus to reduced nitrogen leaching (Harrach and Richter, 1992) and reduced erosion (Pekrun et al., 2003).

[56] Assessments of this instrument (US EPA, 2008) have shown that farmers were generally not inclined to forego existing subsidies for water quality trading.

As discussed earlier in this chapter, further advances with respect to *lignocellulosic bioenergy crops* offer considerable potential to reduce the impact of feedstock production in terms of water quality (Box 5.2). However, it is important to stress that – as in the case for any other kind of crop – large-scale adoption of these crops can still have negative impacts on the environment and that there are variations according to local conditions (soil type and farming methods). Hence, policy instruments encouraging the use of lignocellulosic feedstock production need to consider local conditions and should continue to encourage the adoption of BMPs to reduce non-point pollution.

Other developed countries face similar problems to those described above in the United States (Novotny and Chesters, 1981), while most developing countries have yet to address non-point source pollution.

According to Segerson (1988), who developed a pioneering model for studying economic *incentives* to control non-point source pollution, controlling this type of pollution is challenging because it is not possible to observe (without prohibitive costs) the level of discharge of a potential polluter or to infer discharges from the levels of observable pollution in the environment. In the case of non-point agricultural pollution that contributes to the deterioration of water quality, according to Dzikiewics (2000) the difficulty of traceability results from the dispersion of agricultural products (sediments, fertilizers, pesticides, manure, and other sources of inorganic and organic matter) due to stochastic factors as well as to the watershed's own unique characteristics.

Thus, there is no observable direct relationship between individual emissions and levels of environmental pollution. Only combined effects are observable. The focus, in this case, should be on mechanisms to control levels of pollutants in the environment (emitted by multiple polluters), as opposed to mechanisms to control individual emissions. Regulations such as those specifying Total Maximum Daily Load (TMDL),[57] approved in 1992 by the US EPA, as well as the development and use of models (e.g. SWAT and MONERIS) to support the determination of these maximum amounts, have been of fundamental importance for the control of non-point source pollution. Where applied, the TMDL regulation has been shifting[58] the focus of water quality management from effluent-based to ambient-based water quality standards.[59]

In addition to the identification of ambient-based water quality standards, putting non-point source pollution control into practice would benefit from a series of characteristics suggested by Segerson (1988), including:

- increasing the probability that pollutant levels in the environment are below ambient-based water quality standards;

[57] TMDL is the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards.
[58] For the United States, see the National Research Council (2001): "… over the last 30 years, water quality management has been driven by the control of point sources of pollution and the use of effluent-based water quality standards. Under this paradigm, the quality of the nation's lakes, rivers, reservoirs, groundwater, and coastal waters has generally improved as wastewater treatment plants and industrial dischargers (point sources) have responded to regulations promulgated under authority of the 1972 Clean Water Act. These regulations have required dischargers to comply with effluent-based standards for criteria pollutants, as specified in National Pollutant Discharge Elimination System (NPDES) permits issued by the states and approved by the U.S. Environmental Protection Agency (EPA)."
[59] In the document that reviews the reasons for limited gains in water quality trading programmes in the United States, there is an evaluation by those interviewed (agents): "The most common economic barrier identified in this category was lack of regulatory drivers for trading such as nutrient criteria, but especially lack of a TMDL in the targeted waterbody. Interviewees from the majority of programs indicated that TMDLs are a prerequisite for trading" (US Environmental Protection Agency, 2006).

- minimum government interference in polluters' day-to-day business, so as to achieve lowest-cost pollution reduction;[60]
- a focus on environmental quality, i.e. monitoring of pollutants, not emissions;
- having defined parameter values, in such a way as to ensure that emission reduction levels are socially optimal;[61]
- eliminating free-riding in the case of multiple pollutants;
- avoiding an excessive burden on the polluting sector in the short term; and
- ensuring the long-term efficiency of the polluting sector.

5.2.6 Policy instruments that address water quality during feedstock conversion (point and non-point source pollution)

The major challenge with respect to water pollution from bioenergy conversion[62] is potential chemical and thermal pollution through the discharge of effluents, and the fate of waste or co-products from today's refineries in aquatic systems (Berndes, 2008). These effluents, and waste or co-products, are by-products of the conversion process that require some form of disposal, which can result in adverse environmental impacts on water and other natural resources (Chapter 4).

Better utilization of by-products, with consequently less impact on water quality, generally requires *strict regulation*[63] as well as the existence of a market and a return to by-products or recoverable (e.g. stillage).[64] The biorefining industry is continuing its research to improve the use of by-products[65] and avoid a market collapse due to over-supply.[66] In the face of biofuel production growth projections and related "losses", *policies and non-market and market-based instruments* to address the water implications of bioenergy feedstock conversion need to focus on by-product handling options associated with adverse water quality impacts, e.g. from stillage originated from molasses and sugar-based fermentation (Chapter 4 and case studies 5.4 and 5.5 in this chapter).

[60] This characteristic is proposed based on polluters being in a better position to determine more effective emission reduction techniques.

[61] The necessary estimates would include emission reduction costs, economic measures for related environmental damage, and ways to measure how reductions of each pollutant affect environmental pollution levels.

[62] On the feedstock production side, the main concern is non-point source pollution, while on the bioenergy conversion side it is generally point source pollution, unless by-products are returned to fields through land disposal.

[63] In Brazil they were discharged to waterways (sometimes with lagoon treatment) until this practice was forbidden. Stillage then began to be used as a fertilizer in cane fields (land disposal), with potentially adverse effects on water bodies. According to Smeets et al. (2008), technical standards were adopted in the State of São Paulo in 2005 regarding fertigation. Use of fertigation in environmentally important areas is currently forbidden, and there are technical standards for the storage, processing and application of vinasse.

[64] DDGs (by-products without water quality impacts) are mainly used as a protein source, and their prices are highly correlated with those of grains and oilseeds (Taheripour et al., 2010). However, in the United States the price of DDG is currently almost the same as that of corn (maize) (non-processed product) (Hans Blaschek, personal communication, 2010).

[65] Some new research concerns the use of DDGs to add value to fibre-rich DG in order to develop new markets and enhance the value of DG by using various pre-treatments and enzymatic and chemical catalytic approaches to convert fibre into forms that are fermentable to ethanol and other bioproducts (Hans Blaschek, personal communication, 2010).

[66] Some industry experts predict that DDG production in the United States will reach up to 15 million metric tonnes in a few years. There are concerns that over-supply might lead to market collapse (Hans Blaschek, personal communication, 2010).

Case study 5.4: Disposal of vinasse in Brazil

According to Willington and Marten (1982), vinasse (stillage from molasses and sugar-based fermentation) has little nutrient value and contains large amounts of potassium, reducing its value as an animal feed. Industrial evaporation, which eliminates impacts on water quality, and involves not only capital costs but also the use of considerable electricity,[67] is not economically viable due to vinasse's low product value.[68] Therefore, vinasse is often used as fertilizer, with low to moderate water quality impacts (Willington and Marten, 1982).

Problems with land disposal of vinasse have become evident in Brazil despite the prohibition of stream discharges and lagoon treatments. Data for 1992 from the São Paulo State Environmental Protection Agency (CETESB) found BOD levels equivalent to those of a city of 2 million people, based on water quality measurements of 54 grams of BOD per day. Thus, despite the prohibition of effluent discharges after 1978, and the implementation of a number of measures to reduce emissions (Moreira, 2007), negative water quality impacts remain.[69] For example, according to Gunkel et al. (2007), all rivers in the coastal region of the State of Pernambuco in northeastern Brazil are impacted by sugarcane cultivation.[70] The effects are often magnified, as the rivers also supply cities and are generally heavily dammed for both urban water supply and electrical power generation. These reservoirs could also contribute to further water quality deterioration through eutrophication.

Fertigation is becoming increasingly important in Brazil, as demand for bioethanol from sugarcane has skyrocketed in recent years. Combined water quantity-quality modelling can provide important insights into trade-offs between the costs of reduced water quality compared with the benefits of increased vinasse application (Moraes et al., 2010).

Stricter regulations would likely reduce adverse impacts (Smeets et al., 2008). However, insufficient *enforcement capacity*, as well as the non-point source pollution characteristics of land disposal, make monitoring difficult. Therefore, the identification of new options (e.g. for energy production) needs to be encouraged.

As adverse water quality impacts from land disposal of stillage can also be considered non-point source pollution, policy instruments used on the feedstock production side are valid for addressing water quality implications on the bioenergy conversion side when the stillage is disposed of on cropland or other types of land. These include *standards, discharge permits or water quality trading* for the stillage to match TMDL levels. Moreover, similarly to water quality concerns associated with bioenergy feedstock production, the freedom of industries to choose how to reduce impact by observing legal limits, thus favouring cost-effectiveness, the avoidance of excessive burdens on the polluter in the short term, and long-term efficiency should be emphasized. The design of *environmental policy instruments* to address the latter two issues needs to directly influence the distillery investor's decision-making and should be continuously evaluated.

If improperly developed, these instruments can discourage investors (especially in less developed regions), thereby affecting the income of many people, as well as infrastructure investments by the

[67] Evaporation concentrates the stillage into a smaller volume, but requires significant energy (equivalent to 10% of the energy content of the ethanol) (Wilkie et al., 2000).
[68] Other methods used, cited in Willington and Marten (1982) and Wilkie et al. (2000), such as incineration that would reduce volume and has fertlizer as by-product (and would eliminate water quality problems), face the problem of the low product value of vinasse (stillage from molasses and sugar-based fermentation).
[69] Fertigation represents a hazard to surface water quality when nutrients and organic matter reach the water through diffuse pathways, or accidentally through direct pathways from stillage storage and transportation facilities (Gunkel et al., 2007). Elevated biochemical oxygen demand (BOD) promotes depletion of dissolved oxygen (DO) in the water and often causes hypoxia. High nutrient concentrations in these effluents also contribute to the problems by algal blooms and eutrophication of surface waters.
[70] Stillage fertigation has been practised in Pernambuco, northeast Brazil, since 1981 when a state law prohibiting direct disposal of sugarcane wastewater to surface waters was introduced (Gunkel et al., 2007).

government and the bioenergy goals of the region or country. Policies also need to be established to promote a balance between energy production and water quality maintenance, and they need to be part of Integrated Water Resources Management (IWRM).

Model-based evidence can be used to determine abatement cost estimates, estimates of damage from ambient pollution, economic benefits per polluter, and well-being functions, among others, in support of policy development and evaluation (Section 5.3). Case study 5.5 presents an example of an integrated economic-hydrologic basin model that has been used to assess the impacts of environmental policy instruments on non-point source pollution and water quality outcomes.

Case study 5.5: Joint water quantity-quality management in a biofuel production area, Pirapama River Basin, Brazil

The Pirapama River Basin of northeastern Brazil is affected by both water quantity and water quality constraints. This region is a significant sugarcane-based bioethanol production area, where controlled fertigation practices have potentially significant adverse impacts on the environment. The Pirapama is the most important water source for Recife, the capital of the State of Pernambuco. Along the length of the river, most currently monitored water quality standards (including BOD) cannot be met.

To resolve domestic water supply problems, two reservoirs are planned, one on the Águas Claras tributary and the other on the Pirapama itself. The latter is almost completed. While these reservoirs may reduce the incidence of dry spells, they could also contribute to further water quality deterioration through eutrophication if measures are not taken to control/mitigate the impact of upstream sugarcane and bioethanol production.

In order to assess sustainable water allocation in the basin, an integrated hydrologic-economic basin model has been developed to study water quantity and quality aspects. The model is capable of: *(i)* estimating direct economic impacts, such as production levels for goods and net benefits, as well as associated environmental impacts due to different water allocations; *(ii)* assessing different restrictive levels for water quality constituents, standard classes and ecological flow rate values; and *(iii)* obtaining shadow prices that can be used to infer the cost of pollution prevention and design measures or economic incentives, such as pollution taxes.

The modelling results for the water quantity part of the model show that without water quality constraints, almost all water demands can be met even during harvest months. If water quality restrictions are introduced, however, net benefits are reduced significantly for fertigation even in a normal hydrologic year. Model results further show that when quality standards required by current legislation are met, economic benefits for agro-industries decline while social costs increase. Most of the region's agro-industries no longer allocate all effluents to sugarcane areas to meet water quality standards. As a result, they face higher transportation costs. It is therefore economically viable for the agro-industries to investigate new forms of vinasse disposal. Net benefits also decline for other water users, as water quality restrictions require higher in-stream flows for flow dilution and increased reservoir storage to avoid eutrophication. In dry years the impacts of water quality constraints are more severe, as would be expected – another important concern in view of growing climate variability and climate change.

The model can be used to develop economic incentives based on estimates of non-point source pollution loadings from the cropland under fertigation, which can be compared to an even worse case, effluent discharge directly to the water bodies, and a better one: some form of treatment of the effluent discharge. To enforce water quality restrictions, the shadow price for maintaining water in the reservoir could be used to design economic incentives, such as a pollution tax for fertigated areas (which are currently not subject to pollution charges). New stillage handling options, such as anaerobic digestion and biogas production, are currently being added to the model for further analysis.

Fertigation is becoming increasingly important in Brazil, as demand for bioethanol from sugarcane has greatly increased in recent years. Combined water quantity-quality modelling can provide important insights into the trade-offs between the costs of reduced water quality and the benefits of increased vinasse application.

Source: Moraes et al, (2010)

5.2.7 Examples of sustainability criteria and indicators at national and regional levels

Criteria and indicators are one way to help formulate sustainable bioenergy policies and measures. This section presents some examples of regulatory schemes, defined by national and regional governmental and voluntary inter-governmental initiatives, using criteria and indicators for water stress and/or pollution in order to characterize sustainable bioenergy production.

As mentioned above, the **Cramer Commission Criteria** in the Netherlands are an example. In February 2007, the "Sustainable Production of Biomass" project group (under the chairmanship of Jacqueline Cramer) published and presented the "Assessment Framework for Sustainable Biomass," including the so-called "Cramer Criteria". The Cramer Criteria address six themes: GHG emissions, competition with food or other local applications, biodiversity, prosperity, social well-being and environment. Water is covered mainly under the theme "Environment" and Principle 6:

Principle 6: In the production and processing of biomass, ground and surface water must not be depleted and water quality must be maintained or improved.	
No violation of national laws and regulations applicable to water management.	*[Minimum requirement]* Compliance is ensured with relevant local and national laws and regulations with respect to: - use of water for irrigation - use of groundwater - use of water for agricultural purposes in catchment areas - water treatment - environmental impact assessment - company audits
In the production and processing of biomass, best practices must be applied to restrict use of water and to retain or improve ground and surface water quality.	*[Reporting]* The formulation and application of a strategy aimed at sustainable water management with respect to - efficient water use - responsible use of agro-chemicals
In the production and processing of biomass, no use must be made of water from non-renewable sources.	*[Minimum requirement]* Irrigation water or water for the processing industry must not originate from non-renewable sources.

Source: Cramer et al. (2007)

The **Renewable Transport Fuels Obligation (RTFO)** in the United Kingdom is another example of sustainability criteria. The Renewable Fuel Agency (RFA) has required suppliers to report on net greenhouse gas savings and on the sustainability of biofuels since 2007. For sustainability reporting, a meta-standard approach is used whereby existing agro-environmental schemes have been benchmarked against seven principles: five environmental principles (conservation of large above- or below-ground carbon stocks, biodiversity, no degradation, no contamination or depletion of water sources, and no air pollution) and two social principles (not adversely affecting workers' rights and working relationships, or their existing land rights and community relations) (RFA, 2008).

With respect to Principle 4, on not contaminating or depleting water sources, the following table summarizes what the RFA considered would be verified within the meta-standard. As other recommended indicators, the RFA also included records of annual measurements of agrochemical inputs such as fertilizers and pesticides, water sources used, and the BOD of water on and near biomass production and processing.

Principle 4: Sustainable water use	Biomass production does not lead to the contamination or depletion of water sources
4.1 Compliance with national laws and regulations relevant to contamination and depletion of water sources	Evidence of compliance with national and local laws and regulations, including environmental impact assessment (EIA), water and chemicals use (fertilizers and pesticides)
4.2 Application of good agricultural practices to reduce water usage and to maintain and improve water quality	Documentation of water management plan aimed at sustainable water use and prevention of water pollution

The **EU Renewable Energy Sources Directive** (2009/28/EC) contains legal requirements on water in Articles 17 and 18. Member States are called upon to require market operators to provide information on measures taken for soil, water and air protection and to avoid excessive water consumption in areas where water is scarce. They are also required to document these measures (European Commission, 2009).[19]

In accordance with Article 17, No. 6 of the Directive, protection of groundwater and surface water quality primarily depends on compliance with EU legislation on agriculture (cross-compliance), although this legislation is limited to Member States. The “spirit” of these provisions concerning a “good agricultural and environmental condition” should also be applied beyond the scope of EU standards. This primarily refers to an appropriate limitation of the quantity of fertilizers used.

Unlike the requirements focused on greenhouse gas emissions reduction, protection of areas of biodiversity and of high carbon content (Article 17, Nos. 2 through 5 of the Directive), the water-related requirements are not mandatory although there is a reporting obligation.

Further specifications and definitions of excessive water consumption and of water scarcity are still lacking. Member States are asked to provide practical frameworks for reporting by market actors. There is some likelihood that existing voluntary systems will be approved by Member States or the European Commission as schemes that cover the Directive’s requirements.

In addition to these national and regional initiatives to sustain water use for bioenergy through sustainability criteria, indicators and related regulation, an international initiative is under way through the **Global Bioenergy Partnership (GBEP).** According to GBEP, this initiative is the only one seeking to build consensus among a broad range of stakeholders - i.e. national governments and international institutions - on the sustainability of bioenergy.

The GBEP was established to implement the commitments made by the G8 countries in the 2005 Gleneagles Plan of Action to support “biomass and biofuels deployment, particularly in developing countries where biomass use is prevalent”. In addition to other topics, GBEP works with relevant stakeholders to develop sustainability indicators for bioenergy production and use. To this end, it initiated the Task Force on Sustainability in June 2008 “to provide relevant, practical, science-based, voluntary sustainability criteria[71] and indicators to guide any analysis undertaken of bioenergy at the domestic level. The indicators themselves, when made part of such analysis, should be used with a view to informing decision-making and facilitating the sustainable development of bioenergy and,

[71] Later in the process the Task Force agreed to change the term “criteria” to “themes”, noting that this better represented the nature of the 18 agreed category headings under which 24 indicators had been developed.

accordingly, shall not be applied so as to limit trade in bioenergy in a manner inconsistent with multilateral trade obligations." It is important to note that the indicators developed under GBEP are voluntary, and that their application is primarily up to governments "measuring" the level of sustainability of their bioenergy policies. The GBEP indicators are expected to provide a basis for a globally convergent understanding and assessment of the sustainable production of bioenergy.

On 20 May 2011, GBEP agreed a set of 24 relevant, practical, science-based, voluntary sustainability indicators for bioenergy, including two with respect to water that capture the two basic aspects of quantity and quality:

Water use and efficiency (Indicator 5):

- Water withdrawn from nationally determined watershed(s) for the production and processing of bioenergy feedstocks, expressed as the percentage of total actual renewable water resources (TARWR) and as the percentage of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources;

- Volume of water withdrawn from nationally determined watershed(s) used for the production and processing of bioenergy feedstocks per unit of useful bioenergy output, disaggregated into renewable and non-renewable water sources.

Water quality (Indicator 6):

- Pollutant loadings to waterways and bodies of water attributable to fertilizer and pesticide application for bioenergy feedstock cultivation, and expressed as a percentage of pollutant loadings from total agricultural production in the watershed;

- Pollutant loadings to waterways and bodies of water attributable to bioenergy processing effluents, and expressed as a percentage of pollutant loadings from total agricultural processing effluents in the watershed.

It is expected that, through the use of the above listed criteria and indicators, 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.

5.3 Approaches for assessing water use policy instruments related to bioenergy

Evaluating water use policy instruments related to bioenergy should not only focus on their relative effectiveness and efficiency insofar as the use and quality of water resources are concerned, but should also incorporate socio-economic costs and benefits. In this way, the assessment of water policy instruments becomes part of the process of Integrated Water Resources Management (IWRM), which can help support bioenergy production while promoting economic development and social well-being without compromising environmental sustainability.

Ideally, water policy instruments for bioenergy development should be part of an integrated intersectoral water allocation analysis to assess full costs and benefits, including the opportunity costs of using water. The relative effectiveness and efficiency of water use and quality policies are increasingly being modelled (see the hydro-economic models reviewed by Harou et al., 2009) and these models can also be applied to bioenergy. However, it is generally more difficult to assess water quantity and quality aspects using the same model, and assessing socio-economic (full costs and benefits) and environmental impacts (water quantity and quality)[72] is generally even more challenging (e.g. see WEAP applications;[73] and some hydroeconomic models such as in Cai, 2002; Bateman et al., 2006; Volk et al, 2008, and Moraes et al., 2009).

Given the large potential for scaling up of bioenergy development, and the related risks to both rural populations and the environment, it is particularly important to take into account the full cross-sectoral costs and benefits. According to Sudha and Ravindranath (1999) and Chum et al. (2011), while around 10% of energy used globally is supplied by bioenergy, in developing countries this share can reach up to 80% (mainly traditional forms of bioenergy). In most developing countries the collection and use of biomass is non-commercial, but this situation can change,[74] as has happened in Brazil.[75] Because biomass production takes place in rural areas and is generally labour-intensive, its expansion can lead to the creation of jobs and help stem urban migration. Moreover, generation of “clean” energy can trigger industrialization and development, as well as promoting improvements in quality of life in poorer areas and reducing the negative impacts of air pollution that result from burning traditional fuels, such as those on human health and the environment (Carpentieri et al., 1993; Sudha and Ravindranath, 1999; Henderick and Williams, 2000).

At the same time, the challenges related to the environmental impacts[76] of bioenergy production on water resources in these countries are considerable. Forward-looking studies (e.g. Berndes, 2002) have shown that in water-stressed countries like China and India, water shortages will 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, but it is likely that the water quality implications are considerable.

Bioenergy production can offer opportunities to regions with, for example, high unemployment, low per capita income and high poverty. It can create jobs along the supply chain and support not only local development, but also overall economic development and industrialization. If environmental and social concerns are addressed at the outset of bioenergy development, the jobs created throughout the supply chain could be classified as “green jobs”.[77]

[72] According to Harou et al. (2009), non-point source pollution from agriculture is fertile ground for a new generation of hydroeconomic modelling.

73 WEAP applications allow for the representation of simulated policies through scenarios which, in turn, are evaluated for water availability, costs and benefits, compatibility with environmental levels, etc. (see case study 5.3). WEAP (Water Evaluation and Planning) is an initiative of the Stockholm Environment Institute (http://www.weap21.org/)

[74] In rural Chinese villages, where direct burning of biomass or coal has been the dominant means of providing cooking and heating energy services, there is evidence of economic viability even for the poorest, with the use of technologies capable of providing clean energy services in a centralized way (Henderick and Williams, 2000)

75 “In Brazil, the evolution of biomass energy use since 1965 shows that essentially all growth in bioenergy consumption during this period has come in regard to large-scale industrial uses: all bagasse for industrial sector combined heat and electricity production, much of the charcoal for iron ore reduction in the steel industry, all of the ethanol for transport vehicle use and some of the fuelwood” (Carpentieri et al., 1993).

[76] A few of these countries’ environmental concerns besides water resources could be mentioned. In China, there are concerns about air pollution from burning of coal, biomass and crop residues (Henderick and Williams, 2000). According to Fargione et al. (2008), if Brazil is converting native ecosystems (the Cerrado) to sugarcane ethanol fields, it should generate large carbon debts. In India, as in other developing countries, the issue of land availability for biomass production is particularly relevant since it has high population growth rates and land shortages (Sudha and Ravindranath, 1999).

[77] According to UNEP (2008), green jobs include jobs that help to protect and restore ecosystems and biodiversity; reduce consumption of energy, materials and water through high efficiency strategies; de-carbonize the economy; and minimize or altogether avoid generation of all forms of waste and pollution. But green jobs also help to protect ecosystem services and

It is therefore very important that evaluations of water policies related to bioenergy production (in terms of both water quality and water quantity) consider direct and indirect economic impacts. Different water allocation values not only lead to different economic impacts, affecting all water users and uses, but also have backward and forward linkages associated with the inputs and outputs of the bioenergy life cycle. Moreover, impacts need to be differentiated according to different social strata to assess impacts on the most vulnerable and the poorest (Bhatia et al., 2006).

Economic models using the neoclassical concept of general equilibrium[78] have been used in theoretical exercises to assess the overall economic impact of environmental policy instruments (Fullerton, 2001 and 2009; Fullerton and Heutel, 2010). They can be the basis of practical water management policy decisions. Bhatia et al. (2006) built and calibrated an input-output model embedded in a social accounting matrix to simulate the total direct and indirect impacts of different water management policies on the economy of the State of Tamil Nadu, India. The results show that switching from command-and-control allocation methods to flexible procedures, such as a “willing seller/willing buyer” approach (or “water markets”), would have major environmental, economic and social benefits for Tamil Nadu. Compared with the current “fixed sector-based allocation” policy (water rights), a flexible allocation policy would result in smaller quantities of water being used and removed from aquifers, together with greater income for the state. Water would also be distributed more equally between the rich and the poor by 2020. The same modelling framework could be used to assess the water-related welfare effects of bioenergy production. Such analyses have been performed for the direct impacts of large-scale biofuel expansion, but without considering water (e.g. see Arndt et al., 2010).

Zhao et al. (2009) assessed the economic and hydrologic impacts of a regulatory framework applied in the Yellow River Basin: Unified Water Flow Regulation (UWFR). In their study, “with UWFR” and “without UWFR” scenarios were used through a holistic coupling of the hydrologic and economic components considered in the basin. Based on Yellow River data from 1999-2004, a “with-without” scenario analysis method was employed. The results showed that the UWFR increased GDP by about 2.5% per year while flow cut-off events were avoided. Using this approach, impacts on economic sectors could also be evaluated.

The question of measurements of indirect and sector-based economic impacts of water policies (the demand management side) is of particular importance, given the large and growing significance of these impacts. There is evidence that investments in water infrastructure generate indirect impacts in the order of 90-100% of the direct economic impacts (Bhatia et al., 2003). According to the same authors, this proportion varies according to the characteristics and interlinkages of the various economic sectors in which the water planning unit is inserted. To measure these connections, the concept of multipliers (Bhatia et al., 2007) has generally been used and is added to a social accounting matrix (SAM) (e.g. see Strzepek et al., 2008). Water policy impacts can also be compared in terms of impacts on job creation and welfare (Fullerton and Metcalf, 2001).

access to water and land as the basis for livelihood in many rural areas. In addition, green jobs need to be good jobs which offer adequate wages, safe working conditions, job security, reasonable career prospects, and worker rights.

[78] General equilibrium is a situation in which the aggregate social welfare is maximized. This would be achieved, using the neoclassical postulates and assumptions, through the unimpeded operation of the market.

Still difficult is the linking of water quality models with modelling frameworks that will allow overall economic impacts to be assessed.

5.4 Conclusions and recommendations

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 conversion, taking into account the potential trade-offs between the competing 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 relative effectiveness and efficiency of water use and quality policies.;
- models are applied that identify economically optimal water allocations to provide policy insights and reveal opportunities for better management, with a focus on how economics affects water resources management.
- models are applied that measure total direct and indirect impacts of different water management policies (in terms of both water quality and water quantity) on the entire economic system, with a focus on how water resource policies affect the economy as a whole.; 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.

The policy instrument options are similar to those for irrigation in the agricultural sector and for industrial water use.

Water policy instruments concerned with feedstock production should focus on ensuring efficient water use. Such instruments can induce changes in the feedstock crop selected, as well as supporting the adoption of, for example, sustainable land and water management practices and advanced irrigation systems to reduce the amount of water applied per unit of biomass produced. While command-and-control approaches, such as water quotas or technological and efficiency standards, focus on reaching specific water use levels, market-based tools can 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.

Water policy instruments concerned with the conversion of feedstocks into biofuels should focus on ways to optimize conversion technologies in order to increase water use efficiency.

Policy instruments that address water use efficiency in feedstock production should be consistent with those that address its efficiency in energy conversion, to ensure that efficiency is achieved throughout the entire production process.

Water quality issues, too, need to be addressed using policy instruments with respect to both feedstock production and conversion. While impacts during feedstock production are mainly related to fertilizer and pesticide applications, as well as to soil erosion, those during feedstock conversion are mainly related to effluents. Moreover, in some countries where industrial by-products are reused in feedstock production (e.g. the application of stillage from sugarcane refineries on sugarcane fields), policies need to address potentially adverse water impacts that link feedstock production and energy conversion technologies.

Importantly, in feedstock production the main concern is non-point source pollution while in bioenergy conversion it is generally point source pollution (unless by-products are returned to fields). Non-point source pollution, which is more complex to address, is generally the key bioenergy-related water management challenge in developed countries.

Identification, monitoring and enforcement of ambient-based water quality standards require significant data collection and generally benefit from modelling. Command-and-control approaches have had considerable success in this area in developed countries, but are more difficult to implement in developing countries that have weaker legal and enforcement systems. Market-based instruments, such as water quality trading, are also being tried in developed countries with a focus on achieving least-cost water quality improvements, but so far have had limited success.

Usually the mix of instruments used will depend on countries' needs and conditions.

It is also important to take into account the interlinkages between general water policies and those focusing on bioenergy production, which calls for policy coherence.

Furthermore, the impact of other policies that may affect bioenergy water use indirectly, such as climate change, energy and trade policies, should be considered. Given the potentially large impacts of biofuel expansion in and on developing countries, increasing attention is being given internationally to approaches to help ensure that the rural poor have secure property rights to land and water prior to biofuel development.

Solid planning processes are required to inform the design of policy instruments. This includes, for example, matching of feedstocks with local conditions. Important advances have been made with the development of sustainability indicators and certification schemes that are intended both to inform policymakers in the analysis of sustainable bioenergy potentials and to guide decision-making at the national level. Since certification schemes are relatively new, their effectiveness and practicability, especially in developing countries, remain to be tested.

Finally, simulation/optimization and economy-wide economic models, as well as combinations of these models can help allocate water resources and identify appropriate trade-offs between different uses that reflect the values and choices of society (Harou et al., 2009). Combining water quantity and quality and the overall socio-economic consequences of biofuel use should help support policy formulation for bioenergy development and reveal opportunities for better management. This would avoid potentially long-term adverse consequences on the poor from large-scale development.

6 The role of voluntary certification schemes for bioenergy-related water impacts

This chapter presents an overview of a number of voluntary certification schemes relevant to bioenergy-related water impacts. They include indicators and criteria for water stress and/or pollution that can be used to determine the sustainability of bioenergy production.

More information on some of these certification systems is presented in Annexes II-IV at the end of this report. Readers may also wish to visit the websites provided in this chapter.

6.1 Overview of certification schemes addressing bioenergy and water stress/pollution

6.1.1 RSB: Roundtable on Sustainable Biofuels (http://www.rsb.org/)

The Roundtable on Sustainable Biofuels is an international initiative that brings together a wide range of stakeholders. There are around 110 120 RSB members in about 30 countries, ranging from farmers to oil companies, NGOs to governments, and scientists to investors. The RSB Governance is composed of seven Chambers representing concerned sectors (three for the private sector, three for civil society, and one non-voting Chamber for governments and academics). Each Chamber elects two co-chairs and one alternate, who sit on the RSB Steering Board, the highest decision-making authority. The RSB Chambers represent all concerned sectors. All decisions are consensus-based.

The RSB standard

Through a multi-stakeholder consultation based on consensus among members, the RSB has developed a certification scheme for sustainable biofuels, based on sustainability requirements (RSB Principles & Criteria). These requirements, which make up the RSB Standard, ensure that certified biofuels deliver on their commitments related to climate change mitigation and rural development. In addition, biofuels should not create additional social or environmental impacts.

To address these impacts, the RSB Principles & Criteria are divided into 12 Principles, which are further developed as Criteria (with minimum and progress requirements) and Indicators that can be measured by auditors (RSB, 2010 a and b). The RSB Standard concerns stakeholder consultation, free prior informed consent, gender equity, and benefits sharing in the areas of operations. By complying with the RSB Standard, certified operators make sure their biofuels are not produced at the expense of valuable ecosystems, conservation values, ecological services, soil health or air quality. Finally, biofuel operations cannot threaten local food security.

The RSB Certification System allows feedstock producers and processors, biofuel producers and biofuel blenders/retailers to be audited against the RSB Principles & Criteria and certified. Certificates are delivered by third party auditors to avoid conflict of interest.

RSB requirements with respect to water issues

One principle of the RSB standard (*Principle 9*) is dedicated to water (see Annex II in this report). This principle is further developed into four criteria, which describe the operator's requirements to:

- identify and respect the existing water rights of the local population;

- implement a water management plan to reduce consumption and contamination;
- not contribute to the depletion of the water resources used for the operations;
- maintain water quality or enhance it wherever possible.

The main challenge of the RSB certification system is to combine a robust standard with the reality of operators in terms of access to technology and the cost of compliance. Furthermore, auditing costs may become a barrier if not reduced to the strictly necessary. The RSB tries to balance robustness and flexibility. Biofuel operators are not allowed to infringe on existing water rights (formal and customary), contribute to the withdrawal of water resources beyond replenishment capacity, or contribute to contaminating these resources. On the other hand, compliance is not assessed in the same way for small scale and non-small scale operators during the audit conducted by independent certification bodies. The RSB also uses a risk management approach (RSB, 2010b), which evaluates the risk class of operations based on implemented practices and the context of operations (e.g. high biodiversity, political instability, food insecurity). The risk class determines the frequency and stringency of audits.

Water-related risk factors take the hydrological situation into account, as well as the water requirements of the crop (in the case of feedstock producers). Ultimately, farmers growing rain-fed crops in regions with a low risk of drought will be assigned a low risk factor for water, whereas freshwater-intensive operations will be assigned a higher risk factor, especially in drought-prone regions. Certification and compliance costs will therefore be lower for farmers.

6.1.2 RSPO: Round Table on Sustainable Palm Oil (http://www.rspo.org/)

Background

Driven by ever increasing demand for edible oils, rapid expansion of palm oil production has occurred in the past few decades. From the 1990s to the present, the area under oil palm cultivation has increased by about 40%, mostly in Indonesia and Malaysia. Along with rapid expansion to eco-sensitive areas, other environmental pressures related to palm oil production have been recognized.

In 2001, WWF began to explore the possibilities for a Roundtable on Sustainable Palm Oil. The result was informal cooperation in 2002 among Aarhus United UK Ltd, Golden Hope Plantations Berhad, Migros, the Malaysian Palm Oil Association, Sainsbury’s and Unilever, together with WWF. These organizations formed a committee to organize the first Roundtable meeting, and to prepare the foundation for the organizational and governance structure for the formation of the RSPO.

The RSPO standard

The stated goal of the RSPO is “to promote the growth and use of sustainable palm oil through cooperation within the supply chain and open dialogue with its stakeholders”. For this purpose, principles and criteria were developed. These must be met in order for a company to have its product successfully certified.

RSPO requirements with respect to water issues

Two of eight principles address water-related issues:

- *Principle 4: Use of appropriate best practices by growers and mills*

- *Principle 7: Responsible development of new plantings*

The table below lists requirements directly focusing on water, defined in the key document *RSPO Principles and Criteria for Sustainable Palm Oil Production*, which was published in October 2007 (RSPO, 2007).

Criterion	**Indicators**
Criterion 4.4: Practices maintain the quality and availability of surface and ground water.	An implemented water management plan. Protection of watercourses and wetlands, including maintaining and restoring appropriate riparian buffer zones. Monitoring of effluent BOD (biological oxygen demand). Monitoring of mill water use per tonne of FFB (fresh fruit bunches).
Criterion 7.2: Soil surveys and topographic information are used for site planning in the establishment of new plantings, and the results are incorporated into plans and operations.	Soil suitability maps or soil surveys adequate to establish the long-term suitability of land for oil palm cultivation should be available. Topographic information adequate to guide the planning of drainage and irrigation systems, roads, and other infrastructure should be available.

Criteria and indicators indirectly focusing on water can be found in *Criteria 4.3, Practices minimize and control erosion and degradation of soils* (effective and documented water management programme) and *7.4*, *Extensive planting on steep terrain, and/or on marginal and fragile soils, is avoided.*

The RSPO started certifications in 2008. Water aspects of performed certification processes have mainly focused on effluent (and therefore water quality) aspects, as oil palm plantations are located in wet tropical zones where water scarcity is mostly not a regional issue.

6.1.3 RTRS: Roundtable on Responsible Soy (http://www.responsiblesoy.org/)

Background

In a situation similar to that of palm oil, the RTRS was initiated to develop and promote a standard of sustainability for production, processing, trading and use of soy. Founded in 2006, the RTRS currently has more than 100 members in over 20 countries. The wide range of stakeholders comes, for example, from the areas of production, processing and trade. Besides individual businesses and their associations, NGOs are represented.

The RTRS standard

The criteria comply with the internationally accepted rules of the ISEAL Alliance, a global association for social and environmental standards (http://www.isealalliance.org/). The central document is *RTRS Standard for Responsible Soy Production* (Version 1.0, June 2010) (RTRS, 2010).

Five principles cover the legal and good practice aspects of business activities, labour and community issues, environmental responsibility in general, and agriculture in particular. Under *Principle 5: Good Agricultural Practice,* the first criterion focuses on water: *Criterion 5.1: The quality and supply of surface and ground water is maintained or improved.*

RTRS requirements with respect to water issues

The concrete requirements/recommendations are listed as follows:

5.1.1 Good agricultural practices are implemented to minimize diffuse and localized impacts on surface and ground water quality from chemical residues, fertilizers, erosion or other sources and to promote aquifer recharge.
5.1.2 There is monitoring, appropriate to scale, to demonstrate that the practices are effective.
5.1.3 Any direct evidence of localized contamination of ground or surface water is reported to, and monitored in collaboration with, local authorities.
5.1.4 Where irrigation is used, there is a documented procedure in place for applying best practices and acting according to legislation and best practice guidance (where this exists), and for measurement of water utilization.

An additional note specifies:

"For group certification of small farms – Where irrigation is used for crops other than soy but is not done according to best practice, a plan is in place and is being implemented to improve practices. The group manager is responsible for documentation."

In Criterion 5.1, the following is stated:

5.1.2 Where appropriate there should be monitoring of parameters such as pH, temperature, dissolved oxygen, turbidity and electrical conductivity. Monitoring should be considered at watershed level.
5.1.2 Where there are wells these should be used to monitor ground water.
5.1.4 When using irrigation, attention should be paid to other potential uses such as household use or use by other food crops and if there is a lack of water priority should be given to human consumption.

Implementation of the RTRS has just begun. For the 2011 harvest season, it is assumed that it will be possible to obtain responsible soy on the international market through Chain of Custody options designed for the RTRS. Irrigation is a widespread issue in soy production. The large number of indicators addressing irrigation and monitoring of household water demonstrates the attention RTRS is giving this issue.

6.1.4 Bonsucro (formerly the Better Sugarcane Initiative, BSI) (http://www.bonsucro.com/)

Background

Similarly to the RSPO and RTRS, Bonsucro/the Better Sugarcane Initiative (BSI) is a global, multi-stakeholder, non-profit initiative dedicated to reducing the environmental and social impacts of sugarcane production. Its purpose is to improve the social, environmental and economic sustainability of sugarcane by promoting the use of a global metric standard, with the aim of continuously improving sugarcane production and downstream processing in order to contribute to a more sustainable future (BSI, 2011).

The Bonsucro/BSI standard

Bonsucro/BSI aims to achieve this with a standard that measures these impacts accurately, and through the development of a system to certify that sustainable practices are being adhered to. The principles and criteria presented in this synthesis come from the third version of Bonsucro/BSI and are currently under discussion, to enter into force in 2011.

The five principles that make up the Bonsucro/BSI standard cover legal compliance, respect for human rights and labour standards, enhancement of sustainability management, production and processing efficiencies, active management of biodiversity and ecosystem services, and continuous improvement in key areas of the business.

Bonsucro/BSI requirements with respect to water issues

Three of the principles defined in the Bonsucro/BSI standard cover aspects of *water quality and quantity*. Concrete requirements are formulated in four criteria:

Criterion 3.1:	To monitor production and process efficiency; to measure the impacts of production and processing so that improvements are made over time.
Criterion 4.1:	To assess impacts of sugarcane enterprises on biodiversity and ecosystems services.
Criterion 4.2:	To implement measures to mitigate adverse impacts where identified.
Criterion 5.2:	To continuously improve the status of soil and water resources.

The indicators associated with the four water-related criteria are briefly listed below:

- *Criterion 3.1* is related to sugarcane yield, with standard values depending on whether the plantation is rain-fed or irrigated.
- *Criterion 4.1* includes two agriculture indicators and one mill indicator, associated with *water quality.* One of the agriculture indicators is the amount of "*nitrogen and phosphorus fertilizer applied per hectare per year*", and the other the amount of "*herbicides and pesticides applied per hectare per year*". The mill indicator is "*aquatic oxygen demand per unit mass product*". For each of these indicators, a standard/maximum/benchmark value is defined.
- *Criterion 4.2* under the same principle is related to both water quality and water quantity. It comprises one agriculture and mill indicator associated with a "*Document plan and implementation of mitigation measures"*, that is, the existence of an Environmental Plan.
- *Criterion 5.2* is related specifically to water quantity, but its indicator, "*net water consumed per unit mass of product",* applies to both the agricultural system and the mill. In this case, water consumed is captured water. Again, a standard/maximum/benchmark value is defined.

The number of water-related criteria gives an idea of the significance of sugarcane production with respect to the use of water.

The first pilot certifications began in 2010. Thus, an evaluation of first experience can be provided in this report (see Annex III).

6.1.5 ISCC: International Sustainability and Carbon Certification (http://www.iscc-system.org/)

Background

The ISCC system is the outcome of a project funded by the German Ministry for Agriculture (BMELV). The project began in 2007, based on discussions in the Netherlands (Cramer Commission) and the United Kingdom (RTFO) and the upcoming consideration by the European Commission of regulatory sustainability requirements. The latter led to the Renewable Energy Directive (RED) (2009/28/EC). Therefore, it was decided that the ISCC standard would cover the RED requirements (and German sustainability ordinances) as a basis. In 2010, the ISCC System was approved by the German Authority BLE as the first certification system for sustainable biomass and biofuels under the German sustainability ordinances (Biokraft-NachV).

The main stakeholder groups targeted by the German-based ISCC Association are agricultural, conversion, trade and logistics businesses, biomass users, NGOs, social organizations and research institutions.

The ISCC standard

In terms of concrete certification requirements, the key document is *ISCC 202 – Sustainability Requirements for the Production of Biomass* (most recent available version: V 1.15 10-04-19) (ISCC, 2010). The principles and criteria listed below were taken from that document.

The first two of six general principles cover specific requirements ("Major and Minor Requirements") that address water issues in the environmental context.

ISCC requirements with respect to water issues

These requirements are closely linked with the RED requirements. Therefore, restrictions on the use of peatlands or wetlands are adopted taking carbon storage aspects into account. Basically, water-related criteria are captured in *Principle 2,* which states that:

> Biomass shall be produced in an environmentally responsible way. This includes the *protection of soil, water and air* and the application of good agricultural practices.

The corresponding criteria are specified in the key document cited above. They include, for instance:

> 4.2.2.1 Natural vegetation areas around springs and natural watercourses are maintained or re-established.
>
> 4.2.5.2 If groundwater is used for irrigation, the producer respects existing water rights, both formal and customary, and can justify the irrigation in light of accessibility of water for human consumption. Local legislation is followed.

Concerning water quality, the ISCC standards contain an extensive list of criteria and requirements for the prevention of contamination of surface and groundwater by fertilization, use of chemicals, tank washing, and storage as well as waste management.

Furthermore, a section is included that is indirectly related to water, e.g. through soil erosion control.

The ISCC system addresses water issues in a broad and detailed way. The requirements are highly elaborate and designed for practical application.

6.1.6 SAN Rainforest Alliance (http://www.rainforest-alliance.org/)

Background

In the early 1990s, a number of Latin American stakeholders started to develop principles for sustainable agriculture. After about a decade of testing in practice, a revision was carried out by the Rainforest Alliance (acting as the Secretariat of the consortium) and public consultations followed. Through several further updates and consultations, following among others the ISEAL Alliance's Code of Good Practice for Setting Social and Environmental Standards (http://www.isealalliance.org/), the Sustainable Agriculture Network (SAN) further developed a set of requirements that must be met by farms for their products to be eligible to carry a special label (Rainforest Alliance Certified™). The SAN today describes itself as "a coalition of independent non-profit conservation organizations that promote the social and environmental sustainability of agricultural activities by developing standards" (SAN, 2011).

The SAN standard

The requirements mentioned above are part of the SAN's *Sustainable Agriculture Standard*, whose stated objective is "to encourage farms to analyze and consequently mitigate environmental and social risks caused by agriculture activities through a process that motivates continual improvement". The standard consists of ten principles addressing environmental and social topics, as well as management issues of production systems. Each principle is specified in the form of criteria, some of which are designated as "critical". The criteria relating to water issues are summarized below, based on the standard version published in July 2010.

SAN requirements with respect to water issues

One of the ten principles has water (as a natural resource) as its direct focus: *4. Water conservation* (see Annex IV in this report). The specific criteria defined under it are the following, with one being classified as "critical":

4.1 The farm must have a water conservation program that ensures the rational use of water resources. The program activities must make use of the best available technology and resources.

4.2 All surface or underground water exploited by the farm for agricultural, domestic or processing purposes must have the respective concessions and permits from the corresponding legal or environmental authorities.

4.3 Farms that use irrigation must employ mechanisms to precisely determine and demonstrate that the volume of water applied and the duration of the application are not excessive or wasteful. The farm must demonstrate that the water quantity and the duration of the application are based on climatic information, available soil moisture, and soil properties and characteristics. The irrigation system must be well designed and maintained so that leakage is avoided.

4.4 The farm must have appropriate treatment systems for all wastewaters it generates. The treatment systems must comply with applicable local and national and local laws and have the respective operating permits. There must be operating procedures for industrial wastewater treatment systems. All packing plants must have waste traps that prevent the discharge of solids from washing and packing into canals and water bodies.

Water also plays a central role in the specifications of *Principle 2.Ecosystem conservation.* The two criteria listed under it directly address water protection, but neither of them is classified as "critical".

Erosion is also addressed under *Principle 9.Soil management and conservation*.

Wastewater treatment is covered under *Principle 10.Integrated waste management*. *Criterion 10.3* explicitly addresses the relation to water bodies, requiring that existing laws be followed: "The final or semi-permanent waste deposit areas on the farm must be designed and managed to reduce the risks of environmental contamination and damage to human health ….”

Storage and use of agro-chemicals is addressed under *Principle 6. Occupational health and safety.* The requirements focus primarily on avoiding impacts on human health, but issues such as the water-proofness of storage areas and a minimum distance from natural water bodies are also included.

Under *Principle 7. Community relations*, the following requirement is found in criterion 7.4: “The farm must contribute to the protection and conservation of community natural resources, collaborate with the development of the local economy, and contribute fairly towards the costs of the community infrastructure and local shared resources consumed…”. This includes water infrastructure.

Under *Principle 5. Fair treatment and good working conditions for workers,* drinking water is addressed. A criterion is included requiring non-family farms to perform a periodic drinking water monitoring and analysis programme in cases where water is obtained from farm sources.

The SAN standard covers water use comprehensively. The requirements are ambitious and touch on a wide range of the water-oriented impacts on the agricultural production site.

6.1.7 GGL: Green Gold Label (http://www.greengoldcertified.org/)

Background

The Green Gold Label was established in 2002 by the Dutch energy company Essent and Skall International (now Control Union Certifications) as a global certification of sustainable biomass for energy, power production and chemical purposes (GGL-S2, 2005). At the beginning, the company initiated several research programmes at the University of Utrecht in the Netherlands under the name “Fair Bio Trade”. These programmes investigated the technical, environmental and economic aspects of conversion of clean biomass into sustainable energy. GGL is registered and owned by the independent Green Gold Label Foundation. This Foundation is responsible for criteria and for communication with stakeholders.

Currently, over 25 biomass suppliers are certified producers, as verified by the accredited certification body Control Union Certifications. More than 5 million tonnes of biomass have reportedly been GGL certified.

The Green Gold Label programme consists of standards for specific activities in the biomass supply chain, as well as the supply chain as a whole. For a producer of raw materials, meeting either GGL Standards 2, 5 or 7, or one of the endorsed systems, is required. For a user of biomass for power generation, meeting GGL Standard 4 is required. For a power plant, meeting GGL Standard 6 is required. To qualify for compliance with greenhouse gas emission reduction targets, meeting GGL Standard 8 is required.

Water issues are mainly addressed in GGL-S2 (*Agricultural Source Criteria*).

GGL-S2 requirements with respect to water issues

Under *Principle 4*, agricultural management is required to ensure freshwater supply and quality for sustainable food production and sustainable rural development. The following criteria are defined:

4.1	Increased efficiency and productivity of agricultural water use for better utilization of limited water resources.
4.2	Monitoring of irrigation performance.
4.3	Proper disposal of sewage and waste from the farm and human settlements, and of manure produced by intensive life stock breeding.
4.4	Monitoring of water quality for biological, physical and chemical quality.
4.5	Measures to be taken to minimize soil run-off and sedimentation.
4.6	Irrigation to be planned in a long-term programme.
4.7	Long-term strategies and implementation programme to be developed on water use under conditions of scarcity.
4.8	Wastewater reuse to be part of the agricultural management system.

Water resources are also addressed under *Principle 2*, which states that an agricultural management system based on land-resource planning is required.

Similarly to SAN, the GGL-S2 standard considers water issues in a broad and detailed way.

6.1.8 Alliance for Water Stewardship (http://www.allianceforwaterstewardship.org/)

The Alliance for Water Stewardship (AWS) provides a standard model as a guiding framework for water stewardship standards, to be developed through a global multi-stakeholder process. The model builds on work carried out since 2007 by the Water Stewardship Initiative in Australia and the European Water Partnership (EWP). The AWS approach refers to activities by civil society organizations, public sector agencies, companies and water service providers to arrive at sustainable management practices in order to gain significant benefits at the watershed level (AWS, 2011).

The model is adaptive according to local or regional conditions. The concept is to determine a number of common principles and criteria, but allow for variation on indicators. Furthermore, individual certification should be carried out using a watershed-level standard at site level, while AWS's role should include advocacy at the catchment level in addition to technical cooperation.

AWS standards will codify management actions that managers can take to reach watershed level targets and maximize benefits for all the key stakeholder groups that have developed and support the system. Proposed management actions include: *management of water quantity*, *management of water quality, interaction with catchment governance, and management of habitat*.

According to Wenban-Smith (2010), the principles for a water stewardship standard might be summarized as:

- water flow;
- water quality;
- governance transparency;
- ecosystems and biodiversity.

The first principle might be to "achieve and maintain sustainable water abstraction in terms of water quantity", requiring the evaluation of water abstraction from all sources as well as evaluation of the effect of water abstraction on sources.

To get there, sustainable water management is necessary to achieve and maintain sustainable water abstraction from all sources, and maintain or restore environmental flow regime in all catchments where it has a significant influence. Abstraction and use of water from all sources should therefore be evaluated by the water manager.

6.2 Examples of water-related forest certification requirements

Forest certification was developed in response to growing concern about tropical deforestation in the late 1980s and early 1990s. Following the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, the Agenda 21 Forest Principles came into effect. These principles are a blueprint for tackling global forest issues, and an inspiration for the development of forest certification systems.

The **Forest Stewardship Council (FSC) (http://www.fsc.org)**, formed in 1993 by a number of prominent environmental NGOs, was the first group to develop a voluntary system of sustainable forest management (SFM) certification and labeling to evaluate the sustainability of forest management practices against a set of environmental, social and economic criteria. A second major non-governmental SFM certification body, the **Program for the Endorsement of Forest Certification (PEFC) (http://www.pefc.org)**, was developed in 1999. While the FSC provides its own international, national and regional standards in more than 50 countries, the PEFC is an umbrella organization that endorses previously independent certification standards, including 34 national standards in countries around the world. Together, the FSC and the PEFC provide or endorse over 140 international, national and sub-national SFM certification standards, collectively certifying over 366 million hectares of forests globally.

Forest certification schemes all contain some objectives or criteria to safeguard water resources, differing in scope and detail from one scheme to another. These schemes were developed to address issues that may arise from conventional harvesting, but are also applicable to biomass harvesting for bioenergy, as they cover basic principles of sustainability.

The following examples of forest certification criteria and indicators for the protection of water quality and quantity are taken from two prominent schemes: the Sustainable Forestry Initiative (SFI), a North American scheme endorsed by PEFC, and the FSC International Standard.

6.2.1 SFI: Sustainable Forestry Initiative (http://www.sfiprogram.org/)

The Sustainable Forestry Initiative requires that all forest managers have written plans to address 14 principles of sustainable forest management. Water resources are specifically addressed under *Principle 3. Protection of Water Resources – To protect water bodies and riparian zones, and to conform with Best Management Practices to protect water quality.* More specifically, plans should meet a number of objectives, which are evaluated by performance measures and corresponding indicators. The objectives, performance measures and indicators that directly address water issues are summarized below.

Objective	Performance measures and indicators
3. Protection and maintenance of *water resources.* To protect water quality in streams, lakes and other water bodies.	3.1. Programme participants shall meet or exceed all applicable…*water quality laws,* and meet or exceed Best Management Practices developed under [government] approved *water quality programmes*. [four corresponding indicators] 3.2. Programme participants shall have or develop, implement and document *riparian protection* measures based on [local conditions and harvesting practices]. [five corresponding indicators]
15. Forestry research, science and technology.	15.1. Programme participants [shall provide in-kind support or funding for forest research]. Indicator c: *Water quality* and/or effectiveness of BMPS Indicator f: *Ecological impacts of bioenergy feedstock removals on…water quality,* and other ecosystem functions.

Also relevant are provisions for the management of slash found in *Objective 7* (*Performance Measure 7.1, Indicator 1.a*) and *Objective 8* (*Performance Measure 8.1, Indicator e*), as the volume and distribution of slash are impacted by energy feedstock harvesting and can affect the hydrological regime of a site.

6.2.2 FSC: Forest Stewardship Council (http://www.fsc.org)

Under the FSC International Standard, water issues are largely addressed under *Principle 6: Environmental impact,* which states that "Forest management shall conserve biological diversity and its associated values, *water resources,* soils and unique and fragile ecosystems and landscapes and, by so doing, maintain the ecological functions and the integrity of the forest." Relevant *criteria* call for an assessment of environmental impacts (6.1), maintenance, enhancement or restoration of ecological functions and values (6.3), written guidelines to protect *water resources* and other values (6.5), and criteria for chemical use (6.6).

The FSC standard states that plantations shall not occur except in exceptional circumstances (6.10) and, where exceptional circumstances do allow for certified plantations, they must adhere to criteria under *Principle 10: Plantations.* This principle includes provisions for water protection, including *Criteria 10.6,* requiring plantation management techniques that "do not result in long-term adverse impacts on *water quality, quantity, or substantial deviation from stream course drainage patterns*, and *10.8*, requiring monitoring of various on- and off-site impacts including impacts to *water resources.*

Various regional FSC standards deal with issues in greater detail, based on regional conditions and requirements. For example, the FSC standard for the State of Mississippi in the United States requires written guidelines to *protect water* and other values (C 6.5), including prescriptions for streamside management zones (C 6.5.v) and requirements for meeting and exceeding state Best Management Practices (BMPs) (C 6.5.u). (Chapter 4)

6.3 Overview of schemes

This section presents an overview of the schemes using a tabular matrix (Table 6.1) for a synoptical characterization. It shows what the schemes cover, where they overlap, and where gaps can be identified.

Table 6.1: Synopsis of voluntary systems

Certification scheme	**RSB**	**RSPO**	**RTRS**	**Bonsucro/BSI**	**ISCC**	**SAN**	**GGL-S2**	**AWS**	**FSC**
Relation to bioenergy	Biofuels	Palm oil	Soybean Soybean oil	Sugarcane Ethanol from sugarcane	Biofuels	Agricultural products	Biomass	Generic	Wood Fuel wood
Water is addressed by	1 dedicated principle with 4 criteria	2 criteria with 2 generic principles	1 criterion with a generic principle	Diverse indicators with 4 generic criteria	2 criteria with a generic principle	1 dedicated principle with 9 criteria	1 dedicated principle with 4 criteria		2 criteria with a generic environmental principle
Water quantity	No depletion of surface/ groundwater resources beyond replenishment capacities; 7 indicators	Maintain availability of surface/ groundwater; 1 indicator	2 indicators: GAP and best irrigation practice	Report on used volumes	Minor requirement to maintain watercourses; requirements for irrigation	Farm must have water conservation programme, permits, best irrigation practice	Increased efficiency, monitoring of irrigation	Water is the genuine focus of AWS	Indirectly by protection of water resources (plantations: no adverse impacts from drainage)
Water quality	Enhancement or maintenance of surface water quality of surface/groundwater resources; 6 indicators	Maintain quality of surface/groundwater. 1 indicator	2 indicators: GAP and monitoring	Monitor efficiency, assess impact on ecosystems, mitigation measures, improvement	Extensive list of criteria regarding fertilizer, chemical use, storage, etc.	Appropriate wastewater treatment, threshold values	Sewage control (manure), water quality monitored	Water is the genuine focus of AWS	Protection of water resources, avoid chemical pesticides
Water management plan (WMP)	1 dedicated criterion for efficient use and quality enhancement; 11 detailed indicators	Implemented WMP is 1 of 4 indicators within the water criterion	No	Embedded in environmental management plan	No	Embedded in environmental and social management system	Embedded in agriculture management system	Water manage-ment on focus	No (forest management plan)

Certification scheme	RSB	RSPO	RTRS	Bonsucro/BSI	ISCC	SAN	GGL-S2	AWS	FSC
Monitoring of effects	Yes, according to management plan	Yes, consumption and effluents (BOD) of mills	Yes, effectiveness of practices, contamination	Yes, production efficiency	No	Yes, wastewater	Irrigation performance, water quality		Yes, within environmental effects
Watershed considered	Yes	No	Yes	Yes	No	Not directly addressed	Not directly addressed	Watershed is the basic unit	No
Water rights	1 dedicated criterion regarding formal, customary rights/ indigenous communities; 8 detailed indicators	No	No	No	Irrigation has to be justified	Not directly addressed	Not directly addressed	Implicit	No
Related aspects	Rural and social development, food security, buffer zones, soil erosion	Soil erosion, riparian buffer zones	Soil erosion	Soil erosion, riparian areas, wetlands	Good agricultural practice, IPM, riparian areas, waste management	Soil erosion, waste management	Diverse aspects of agricultural management system	All consequences of water impacts	Soil erosion, maintenance or enhancement of value as watershed
Addressed to	Market operators: biofuel production chain	Market operators: palm oil production chain	Market operators: soybean oil production chain	Market operators: sugarcane ethanol production chain	Market operators: biofuel production chain	Market operators: biofuel in general	Market operators: biofuel production chain and electricity producers	Policymakers, stakeholders, civil society, public sector, business	Forest owners, wood producers
Experience	Began in 2010	Began in 2009; 3 million tonnes oil capacity certified by end 2010	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

6.4 Summary of benefits and limitations of voluntary certification schemes

A number of voluntary certification schemes have been analyzed above, with respect to how effects on water are being addressed. Most of the analyzed schemes cover three key items: excessive water consumption, water scarcity, and protection of water quality. *Water quality,* in particular, is well-covered. Regarding effluents from processing processes, useful water quality indicators for customary and legal threshold values are mostly in place. Certification schemes benefit from legal references.

The impacts of agricultural activities, such as the application of fertilizers or pesticides, are more complex. Good agricultural practice is considered to provide protection. However, impacts on surface and groundwater bodies are time-delayed, and tracing measured pollution to a specific source (the polluter) may be inconclusive in many cases. Thus, controlling and auditing agricultural practice assumes a key role in assuring protection of water quality. Almost all of the analyzed schemes address that point.

In addition, *avoidance of excessive water consumption* is addressed by most schemes. These schemes require water management plans, efficient use and reuse, and optimization of irrigation if used. The criteria and indicators in place appear to be useful, effective and practical. On the other hand, even efficient and sparing use of water can be excessive if the consumer is large enough to absorb modest water resources. Without taking availability and the entire consumer context into account, negative impacts cannot be avoided through good management.

This leads to the final and most crucial point: areas where water is scarce. Scarcity exists, but is notably difficult to standardize. *Physical scarcity* can be categorized easily in terms of volume of available water resources per year and capita, or a withdrawal-availability ratio. There are useful approaches, such as the Water Availability Index or Water Scarcity Index, to classify levels of availability and scarcity that can support the basic global definition of areas where water is *physically scarce*.

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

- regional resolution of the data:
  - Does it suit actual water flow conditions, according to the catchment or watershed level?
  - How far downstream could users be affected?

- economic aspects of water scarcity:
  In some regions water is sufficiently available in a physical sense, but the population cannot afford an appropriate supply system. 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.

When a biomass project is to be certified according to water-related sustainability, the overall context needs to be taken into account. A number of the certification schemes analyzed above are prepared to consider this. In particular, the *Green Gold Label (GGL) programme,* the *Roundtable on Sustainable Biofuels (RSB)* and the *Sustainable Agriculture Network* (*SAN)* have adopted ambitious criteria in this area.

While certification schemes 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 made by single projects. Within a watershed, all users are interdependent. Water management needs to involve all affected parties. A biomass-producing and water-consuming project cannot be responsible for the overall water policy. On the other hand, certified good practice at 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 schemes wherever water is a crucial aspect.

While the criteria and indicators provided by *sustainable forest management schemes* such as the *Sustainable Forestry Initiative (SFI)* or the *Forest Stewardship Council* (*FSC*) are applicable to all types of forest management, including biomass harvesting for bioenergy, they were created with conventional management in mind (i.e. for timber and pulp and paper). To increase the relevance of SFM certification to biofuel feedstock production, criteria can be adapted through periodic review processes to address issues unique to more intensive management regimes. In addition, guidance documents such as biomass harvesting guidelines and regional Best Management Practices can complement certification standards, addressing potential issues arising from bioenergy feedstock production. With the right criteria, SFM certification schemes can be adapted by green energy certification schemes to ensure sustainability along the entire value chain of forest bioenergy.

Certification of bioenergy-related water impacts will remain a challenge. Ambitious schemes are in place. However, in the following years there will be a need to verify the practicability of schemes and consider how to successfully avoid adverse effects. It can be assumed that successful implementation will need to be fostered through regional, national and international policy, as well as overarching stakeholder involvement at least at the watershed level.

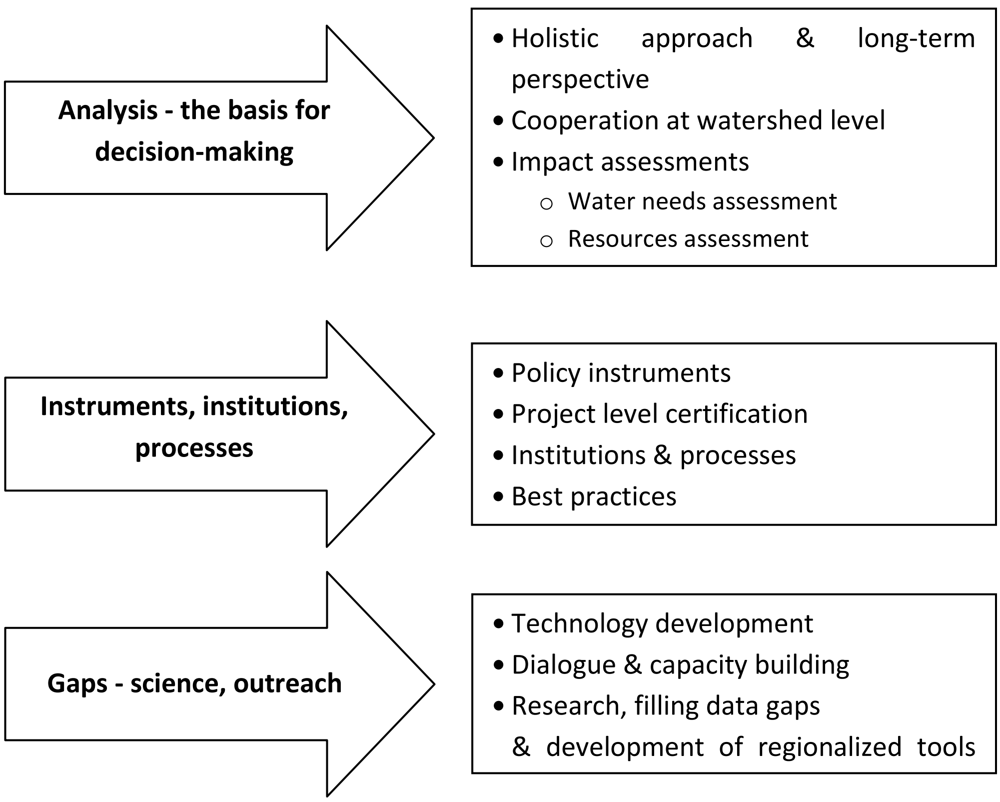
7 Recommendations for decision makers

This report shows that the interactions between bioenergy and water are complex. Water is a precious resource that is already scarce in many parts of the world. The extension and intensification of bioenergy production has the potential to increase existing pressures on water resources, in terms of both quality and quantity. However, as the report also shows, bioenergy development presents opportunities to improve water productivity and to mitigate some of the impacts of current land use on water. Hence, in order to adequately address identified risks *and* opportunities, decisions concerning bioenergy need to be based on an understanding of the interlinkages between bioenergy and water and should aim to help ensure overall sustainability.

Based on key considerations and lessons learnt, as presented in the report, this chapter makes recommendations to decision makers (e.g. in governments and industry) on how to address the bioenergy and water nexus on both the policy and project level.

Figure 7.1 shows three clusters of recommendations, from analysis as the basis for decision-making, to options for action and the identification and filling of gaps

Figure 7.1: Recommendation clusters



7.1 Analysis – the basis for decision making

Analysis should be the starting point for any decision-making at the policy or project level. It needs to be carried out at different levels (spatial, life cycle, time horizon), as well as taking into account the broader context.

A holistic approach and a long-term perspective

- Competition for water resources for different uses – not only bioenergy production – should be addressed through integrated water use planning and resources management.
- To identify the best use of available water, the context – i.e. local, national and regional conditions – should be considered. There is no "one size fits all" solution. It is all about choices: matching the right feedstocks, conversion and end product with these local, national and regional conditions. When assessing these conditions, other (existing and possible future) uses of water need to be considered.
- A life cycle perspective needs to be applied, 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.
- Possible beneficial effects/synergies should be taken into account, e.g. with regard to food *and* fuel production. Many concerns that have been raised relate to feedstock production when energy crops, rather than waste and residue, are used. Thus, changes in agriculture should also be considered when seeking solutions. If planned well, bioenergy production can help serve multiple purposes, for instance through combined systems or modernization of technology (e.g. drip irrigation, irrigation using grey water) where negative consequences may be outweighed by double dividends).
- Inter-relationships with other resource needs should be considered, as there are trade-offs (e.g. between land and water use, biodiversity, GHG emission reduction, effects on soil). When assessing bioenergy impacts, all relevant impact categories need to be assessed and trade-offs among them may need to be made according to the relevant objectives (energy balance vs. water balance vs. land use, etc.).
- Future developments such as climate change, population growth and changing consumption patterns have the potential to change the volume and availability of water. Therefore, global trends, particularly the need to adapt to climate change, should be reflected in development strategies, and life cycle analysis should be extended to cover such dynamics.

Cooperation at watershed level

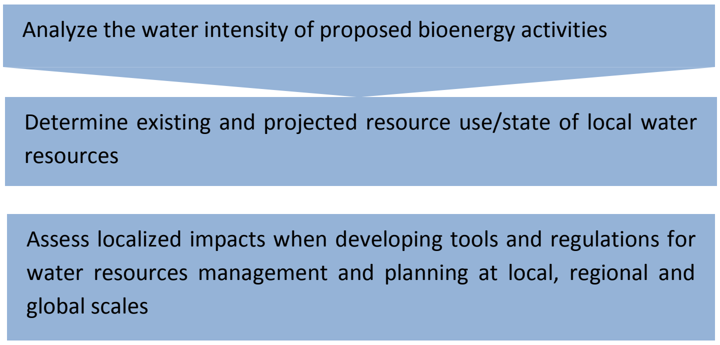
- Activities should be carried out at appropriate levels (local, national and regional), with consideration given to the entire watershed and its future development options.
- Within a watershed, all users are interdependent. Water management needs to involve all parties concerned.

Basing decisions on impact assessments to help ensure sustainable water management

- Understanding and assessing impacts is crucial for sustainable water management. The expansion and intensification of bioenergy production could add to existing pressures and have significant implications for the state of water resources in regions where it occurs. Impact assessments can help to minimize negative effects on water resources and optimize the opportunities provided by bioenergy production.
- Impacts on water resources are not easily quantifiable, in that water consumption varies spatially and temporally, different water sources are not necessarily commensurable, and impact depends on the state of the resource base that is drawn upon.

- Bioenergy systems should be analyzed from a comprehensive socio-ecological perspective, with consideration given to underlying ecological functions in agricultural and natural landscapes and to broader livelihood and development implications.
- Sustainable land and water use should be promoted, 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.
- In short, informed decision-making related to bioenergy production should be based on a solid understanding and assessment of potential impacts. The steps shown in Figure 7.2 should be followed.

Figure 7.2: Steps towards informed decision-making



Analyzing the water intensity of proposed bioenergy activities

- Estimating the total water demand of bioenergy production requires measuring volumes of water abstracted, consumed and altered. Indicators characterizing the inventory of water use provide useful tools for water resources management and planning at the local, regional and global levels. Accounting for blue water withdrawal and consumption, and green water consumption, across product life cycles enables us to better understand the total water demand within certain time frames and spatial boundaries. These assessments also enable us to measure the efficiency of bioenergy feedstock production and conversion systems, and to identify potential management strategies or feedstock varieties to optimize water use at the plant, farm, regional and global scale. Life cycle water use indicators may also be used to account for water use avoided due to displacement of products by co-products of bioenergy production. However, these applications must be interpreted with care since displacement effects may take place elsewhere and with a significant time delay.
- Careful translation is needed from the inventory assessment to impact evaluation. Water inventory evaluation often employs, by necessity, *spatial and temporal* aggregation that sums more than one form of water consumption (blue, green and grey water) in locations where the relative importance of water-related aspects differs. Thus, it often does not give a clear indication of potential social and/or environmental harm or trade-offs. Similarly, *temporal* aggregation over an annual period ignores the inter-seasonal variability of water use and water scarcity (which can be substantial in some regions), therefore possibly not conveying important information about seasonal water use competition or excess unless complementary assessments are made.

- Water footprint (WF)[79] accounting and, more generally, water life cycle assessment (LCA), as they have been applied to bioenergy, are currently *insufficient* in their treatment of ecological and social impacts for the purposes of decision-making and the mitigation of detrimental effects. Most LCA studies have not made localized assessments that distinguish among types of water use and the sources from which water has been drawn or account for local conditions.
- Location-specific information on water resource use and its impacts 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 WF studies as conventionally applied, 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, which is needed to conduct proper life cycle impact assessment (LCIA).

Determining existing and projected resource use/the state of the local water resource

- Understanding impacts on water resources requires recognizing the complexity of these impacts and directing studies towards the characterization of impacts within local physical and social contexts, as well as future development opportunities. Understanding the availability/scarcity of the water resources in an area used for bioenergy production is therefore critical. It is essential that indicators account for this availability/scarcity. Information about water volumes alone are insufficient in efforts to minimize impacts, since a given level of consumption in a watershed with still-abundant water supplies can be expected to have far less impact than the same consumption in a watershed experiencing severe water scarcity.
- There is no universally suitable quantitative tool with which to characterize the impact of water consumption. However, the most credible approach is to use tools that quantify consumption in the context of any existing stress on the resource base in question. Consumption of water to produce bioenergy reduces its availability for other human uses, including food production, domestic uses, industrial activity, and in-stream uses such as hydroelectricity generation, recreation and fish production. In addition, less water is available to fulfil ecosystem functions, with the risk of serious damage to ecosystems if replenishment levels drop below certain levels. Thresholds may exist beyond which far-reaching consequences could occur – including complete transition to new ecosystem states. Such consequences may occur rapidly once these thresholds are crossed. A return to the previous ecosystem state can then be difficult.
- Tools applied for this purpose should consider the need for sufficient environmental flows to remain intact in order to maintain stable ecosystems. Environmental flows are one of the tools that can complement water footprinting and LCA when trying to link characterization of the resource base with activities' water intensity. Frameworks such as ELOHA (Ecological Limits Of Hydrologic Alteration) look holistically at how water is used within the watershed, and can thus help identify new governance arrangements needed for negotiated water allocations.

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

[79] 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 report, however, we refer to these analyses simply as "water LCA" and 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.

- LCIA and/or weighted or disaggregated water footprint values can be important tools for identifying regions of concern with regard to blue, green and grey water impacts. However, some local nuances can be lost through the spatial aggregation of detailed information, even when this is done in the thorough and spatially discrete manner described in Chapter 2 of the report.
- Even efficient and sparing use of water can be excessive if the consumer is large enough to absorb scarce water resources. Good water management is not a guarantee against negative impacts unless the scope is extended to consider water availability and takes the whole consumer context into account.
- For this reason, localized concerns, including cumulative effects, impact on key habitats, indirect effects, social realities and resilience to scarcity, should be investigated carefully as a complement to this type of quantitative analysis. For example, because water moves not only vertically (through evaporation and transpiration) but also laterally, through hill slopes and soils, and as groundwater and rivers, any influence on water quantity or quality can be transmitted through a catchment and have a significant impact downstream. Outside a basin, water also moves virtually in time and space through the trade of agricultural commodities.

7.2 Instruments, institutions, processes

Addressing the impacts of bioenergy production on water availability and quality requires the implementation of judicious water policy instruments and legislation for both bioenergy feedstock production and conversion. A number of policy instruments have been highlighted in this report. Appropriate institutions and processes need to be established and supported to ensure effective implementation of such instruments.

Design and implementation of effective water-related policy instruments

Strategic planning should be the basis of policies and legislation. This involves building on water resources and water needs assessments of both the bioenergy and other sectors, for which trade-offs need to be identified and integrated solutions developed. Policy instruments should help to ensure efficient water use and improvement of water quality in both local and regional water contexts.

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

- publicly available records are maintained on water consumption by bioenergy systems and other water-using activities;
- different settings (e.g. OECD, developing and/or emerging countries, rural and/or urban areas) for governance and the application of policy instruments are taken into account;
- water regulations and laws are established to support integrated, cross-sectoral water resources planning and monitoring;
- water policies and institutions for bioenergy development are part of an integrated, intersectoral policy approach that assesses full costs and benefits, including the opportunity costs of using water;

- the impacts of policies affecting bioenergy water use indirectly, such as climate change, energy and trade policies, are taken into account. In this respect, given the potentially large impacts of the expansion of bioenergy production in developing countries, it is important to ensure that the rural poor have secure access to land and water prior to bioenergy development;
- indicators and transparent criteria are established that are consensus-based and practical;
- effective participation by all users is promoted. Policy instruments should trigger cooperation between water users in a watershed, e.g. with regard to watershed-level restoration. 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;
- models (e.g. WEAP[80]) are applied to simulate the behaviour of water users confronted by different environmental policy instruments, in order to assess water allocation across users and sectors, with consideration given to regulatory and technical restrictions;
- models are applied that measure economic effects (on the economy as a whole and on various economic sectors) associated with different environmental policy instruments and water allocation outcomes; and
- scenarios are used to evaluate technological trends in bioenergy production, as well as in demand for bioenergy products, along with development options for competing water uses.

Water resources management as part of policy- and decision-making can contribute to mitigating water quantity and quality impacts, and promote better practices for the production of feedstocks and their conversion into bioenergy. Policy instruments that can be used for water resources management include:

- *enabling conditions*, which are actions to change the institutional and legal environment in which water is supplied and used. They may include the development of institutions, such as mechanisms for exercising water rights and for taking collective action (e.g. water user associations that manage water allocation within irrigation systems as a group), but also the privatization of utilities;
- *market-based incentives*, which directly influence the behaviour of water users by providing incentives to conserve water, including water pricing, water markets (e.g. tradable water use rights and, more recently, water pollution trading), effluent charges and other types of taxes, and subsidies;
- *non-market instruments or command-and-control (CAC) approaches*, such as water quotas, licenses and pollution controls (e.g. water standards); and
- *direct interventions*, such as investments in efficiency-enhancing water infrastructure or conservation programmes.

Policy instruments that address water quantity during bioenergy production

Bioenergy 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, as well as supporting the adoption of, for instance, sustainable land and water management practices and

[80] "Water Evaluation and Planning: WEAP" (http://www.weap21.org)

technologies. This includes incentives for enhanced soil moisture conservation measures, such as rainfall capture, conservation tillage and precision agriculture, as well as advanced irrigation systems to reduce the amount of water applied per unit of biomass produced.

- Command-and-control approaches, such as quotas, or specific technological and efficiency standards focus on reaching specific water use levels, while market-based tools – e.g. subsidies and charges (like water pricing) – can help users to identify least-cost options to improve water efficiency.
- Comprehensive water and land use planning is 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 crop evapotranspiration (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 evapotranspiration (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 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 excessive amounts of crop residues are extracted from fields and used as bioenergy feedstocks. 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 to support efficient water use. This is consistent with the concept of integrated water resources management (IWRM), "a process which promotes the coordinated 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."[81]

Bioenergy 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

[81] "Global Water Partnership" (http://www.gwp.org)

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.

- 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 bioenergy production

Bioenergy feedstock production

- The main water quality concerns on the feedstock production side are non-point source pollution related to possible sediment, pesticide and nutrient loadings to water bodies resulting from soil erosion, 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, are already being implemented, as are incentives to change tilling practices. Developed and emerging countries have made considerable progress in controlling non-point source pollution through instruments that are both non-market-based (or command-and-control, e.g. standards, quotas) and market-based (e.g. subsidies and charges, i.e. water pricing). For instance, farmers have received subsidies for using specific Best Management Practices (BMPs) such as reduced tillage or no-till practices. Reduced tillage reduces the rate of mineralization, 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 quality improvements. These approaches have had considerable success in developed countries, but are more difficult to implement in developing countries where legal and enforcement systems often are less developed.
- It should be noted, however, that controlling non-point source pollution is challenging due to the difficulty of tracing 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, 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 levels of pollutants in the environment, not individual 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 and emitters;
- avoiding an excessive burden in the polluting sector in the short term; and
- ensuring long-term efficiency in the polluting sector.

Bioenergy feedstock conversion

- 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).
- Better utilization of these by-products, with consequent less impact on water quality, generally requires strict regulation as well as the existence of a market and a return to by-products or recoverables. As water quality impacts from land disposal of stillage can 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.
- Policy instruments which could be used to prevent water pollution on the conversion side include the establishment of technology-based and ambient-based standards (future technologies could incorporate better management of water quality), discharge permits, tradable water quality permits for stillage to match Total Maximum Daily Load (TMDL) levels, or water pricing.
- 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.

Voluntary certification schemes that support sustainable bioenergy development on the project level

- On the project level, a range of voluntary certification schemes exists which could help to reduce negative impacts from bioenergy production on the local level. Therefore, the voluntary use of such schemes by industry is highly recommended. National governments are also asked to consider these schemes when developing policies or taking bioenergy-related decisions, but may in addition want to use sustainability indicators for bioenergy developed by the Global Bioenergy Partnership (GBEP) for the national level.
- Certification of bioenergy-related water impacts will remain a challenge. Ambitious schemes are in place and under development. However, in the coming years there will be a need to verify the practicability of schemes and consider how to successfully avoid unintended outcomes, with (in the worst cases) adverse impacts on the state of water.
- Certified good practice at project level will not prevent negative developments when sound water policy is absent. Therefore, successful development and implementation of certification schemes need to be promoted in national, regional and international policy as well as

overarching stakeholder involvement, at least at the watershed level. Appropriate institutions and processes need to be established and supported.

Dissemination of best practices

As a rapidly growing sector that has attracted huge investments in recent years, bioenergy may both provide best practice examples and have spillover effects on the agricultural sector, enabling the modernization of technologies (e.g. drip irrigation) and the improvement of management practices (e.g. through the upgrading of extension services). Bioenergy production may also promote special training through certification schemes.

Processes and institutions

- Inter-ministerial task forces need to be established to coordinate different policy objectives;
- Stakeholder engagement should be implemented from the planning through the implementation phases; and
- Ground-truthing needs to be supported at the watershed level to verify information gathered through remote sensing by collecting information "on location", i.e. on field trips to the areas in question.

7.3 Gaps – science and outreach

Developing and deploying new technologies

New technologies – in both cultivation and conversion – may help to mitigate pressure on water resources, but they need to undergo a due diligence check prior to widespread deployment.

Intensifying 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, IEA Bioenergy Task 43, Oeko-Institut and UNEP, as well as processes referred to in the report, such as the GBEP and organizations behind different voluntary certification schemes and sustainability standards; and
- building the capacity of the different groups concerned by this report. This is especially important for decision makers in emerging and developing countries.

Conducting further research, filling data gaps, and further developing regionalized tools and economic models

- International cooperation should be supported with regard to research concerning the effects of bioenergy development on water quantity and quality as compared to reference scenarios, including consideration of other energy sources (e.g. oil, nuclear).
- Emerging and still largely unexplored issues need to be addressed, such as the potential and risks of the use of algae cultivation in coastal zones, use of land-based algae and genetically modified organisms (GMOs).

- Data gaps need to be filled, especially in developing countries where one of the main constraints on water management is lack of updated and spatially disaggregated data (e.g. on land use, water availability and use, and bioenergy developments). Monitoring should be conducted on a regular basis to comply with regulations and to ensure 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.
- Regionalized tools need to be developed further. Currently employed life cycle impact assessment (LCIA) and the water footprint studies are inadequate without the differentiation of localized impacts.
- Economic models that integrate water quantity, water quality and the overall socio-economic consequences of bioenergy use should also be developed further, to support socially inclusive policy formulation for sustainable bioenergy development and avoid potential long-term adverse consequences on the poor.

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Annex I – List of workshop participants

Last name	First name	Organisation	Country/Region
Ahiataku-Togobo	Wisdom	Renewable Energy Expert (GEDAP), Ministry of Energy	Ghana
Baddache	Farid	BSR	France
Berndes	Göran	Chalmers University of Technology	Sweden
Bonnet	Jean-Francois	University of Bordeaux	France
Brancante Machado	Pedro	Brazilian Government, Ministry of External Relations	Brazil
Campos	Cesar Cunha	Fundacao Getulio Vargas (FGV) - main director	Brazil
Dallemand	Jean-François	Joint Research Centre, European Commission	IT
Diaz-Chavez	Rocio	Imperial College, UK	UK
Dornburg	Veronika	Shell	Netherlands/global
Eisentaut	Anselm	IEA	global
Essombe	Cedric	UNEP	global
Fehrenbach	Horst	IFEU	Germany
Fingerman	Kevin	University of California, Berkeley	USA
Fritsche	Uwe R.	Oeko-Institut	Germany
Gavilan	Ignacio	BP Biofuels	UK/global
Gheewala	Shabbir	JGSEE (The Joint Graduate School of Energy and Environment)	Thailand
Guarany	Cleber	Fundacao Getulio Vargas (FGV)	Brazil
Haye	Sebastien	RSB Secretariat	global
Hennenberg	Klaus	Oeko-Institut	Germany
Jewitt	Graham	University of KwaZulu-Natal	South Africa
Kartiwa	Budi	Indonesian Agroclimate and Hydology Research Institut, Ministry of Agriculture	Indonesia
Leagnavar	Punjanit	UNEP/Oeko-Institut	global
Lorne	Daphne	IFP - French Petroleum Institute	France
Malavelle	Jerome	UNEP	global
Metzler	Jasmin	UNEP/Oeko-Institut	global
Moraes	Márcia	Universidade Federal de Pernambuco	Brazil
Neto	André Elia	CTC - Centro de Tecnologia Canavieira	Brazil
Nguere	Massaer	Institut Sénégalais de Recherches Agricoles	Senegal
Orr	Stuart	WWF International	global
Otto	Martina	UNEP	global
Pasdeloup	Marie-Vincente	UNF	global
Ramos Taipe	Cayo Leonidas	Universidad Nacional Agraria La Molina	Peru
Sapp	Briana	PANGEA	Belguim/global
Senatore	Giuliano	Fundacao Getulio Vargas (FGV)	Brazil
Unfried	Juergen	University of the Philippines / Kasla Energy Philippines Inc.	Philippines
Verhoest	Chrystelle	Laborelec	Belgium
Vugteveen	Pim	IUCN	Netherlands/global
Walter	Arnaldo	University of Campinas (UNICAMP)	Brazil
Wani	Suhas	ICRISAT India	India
Yacob	Shahrakbah	Applied Agricultural Resources S/B (www.aarsb.com.my), involved RSPO	Malaysia
Yeh	Sonia	University of California, Davis	USA

Annex II – Roundtable on Sustainable Biofuels (RSB): Principle 9, Criterion 9 and Indicator 9 for sustainable water use in biofuel operations[82]

RSB Principle		
Principle 9. Biofuel operations shall maintain or enhance the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.		
RSB Criterion	**Scope and Requirements**	**Indicators**
Criterion 9a. Biofuel operations shall respect the existing water rights of local and indigenous communities.	Operators who must comply: Feedstock Producer, Feedstock Processor, Biofuel Producer. Minimum requirements: The use of water for biofuel operations shall not be at the expense of the water needed by the communities that rely on the same water source(s) for subsistence. The Participating Operator shall assess the potential impacts of biofuel operations on water availability within the local community and ecosystems during the screening exercise of the impact assessment process and mitigate any negative impacts. Water resources under legitimate dispute shall not be used for biofuel operations until any legitimate disputes have been settled through negotiated agreements with affected stakeholders following a free, prior and informed consent (as described in 2a and its guidance) enabling process. Where the screening exercise has triggered the need for a Water Assessment (RSB-GUI-01-009-01), Participating Operators shall: • identify downstream or groundwater users and determine the formal or customary water rights that exist; • evaluate and document the potential impacts on formal or customary water rights that exist; • respect and protect all formal or customary	9.a.i.1. The participating operator provides objective evidence demonstrating that her/his/its biomass/biofuels operation(s) do not negatively affect (i.e. reduce and/or alter in quality or quantity) the water supply to communities which rely on the same water resource(s), as described in the RSB Screening Exercise (RSB-GUI-01-002-02). This may include objective evidence such as: • identifying the communities which rely on the same water resource(s) as her/his/its biomass/biofuels operation(s); • analyzing the water supply to communities which rely on the same water resource(s); • analyzing whether the water supply to communities which rely on the same water resource(s) is affected in quality or quantity by her/his/its biomass/biofuels operation(s). 9.a.i.2. The participating operator provides objective evidence demonstrating continuous monitoring of the actual and potential impacts of her/his/its biomass/biofuels operation(s) on the availability of water resource(s) within the local community. 9.a.i.3. The participating operator provides objective evidence demonstrating that the use of the water resource(s) for her/his/its biomass/biofuels operation(s) is not legitimately disputed by stakeholders which rely on the same water resource(s). 9.a.i.4. The participating operator provides objective evidence demonstrating that the use of the water resource(s) for her/his/its biomass/biofuels operation(s) has been agreed with free, prior, informed consent by stakeholders which rely on the same water resource(s). **The following indicators are applicable where the screening exercise**

[82] For this voluntary certification scheme, also see Chapter 6, Section 6.1.1.

	water rights that exist through the Environmental and Social Management Plan (ESMP) to prevent infringement of such rights. No modification of the existing rights can happen without the Free Prior and Informed Consent (as described in 2a and its guidance) of the parties affected.	**has triggered the need for a Water Assessment (RSB-GUI-01-009-01):** 9.a.i.5. If the screening exercise indicated any significant potential impacts of biofuel operations on water availability within the local community, the participating operator provides objective evidence demonstrating that a water rights impact assessment has been completed and any actual or potential negative impacts of her/his/its biomass/biofuels operation(s) on the availability of water resource(s) within the local community have been mitigated. 9.a.i.6. The participating operator provides objective evidence demonstrating that the following steps were undertaken: • identify all stakeholders which rely on the same water resource(s); • identify formal water rights relating to the same water resource(s); • identify customary water rights relating to the same water resource(s); • evaluate and identify measures to fully protect the formal or customary water rights to the same water resource(s) and to prevent infringement and/or compromising of such rights; • ensure that the formal or customary water rights to the same water resource(s) are only modified based on Free Prior and Informed Consent of stakeholders relating to and/or relying on the same water resource(s); and • evaluate and identify measures to continuously monitor and ensure comprehensive implementation of the requirements detailed in indicator 9.a.i.6. as listed above. 9.a.i.7. The participating operator provides objective evidence demonstrating that the outcomes and agreements resulting from the consultation process detailed under indicator 9.a.i.6. are fully implemented.
RSB Criterion	**Scope and Requirements**	**Indicators**
Criterion 9b. Biofuel operations shall include a water management plan which aims to use water efficiently and	Operators who must comply: Feedstock Producer, Feedstock Processor, Biofuel Producer. 9.b.1 Minimum requirements Participating Operators shall develop and implement a water management plan and integrate it into the Environmental and Social Management Plan (ESMP).	9.b.i.1. The participating operator provides objective evidence demonstrating that a water management plan relating to her/his/its biomass/biofuels operation(s) which ensures efficient use of the water resource(s) and that water quality is maintained or enhanced, has been integrated into the ESMP and implemented accordingly. 9.b.i.2.The participating operator provides objective evidence

to maintain or enhance the quality of the water resources that are used for biofuel operations.	The water management plan shall be made available to the public, unless limited by national law or international agreements on intellectual property. The water management plan shall be consistent with local rainfall conditions, not contradict any local or regional water management plans, and include the neighboring areas, which receive direct run-off from the operational site. Any negative impact on these neighboring areas shall be mitigated. The Participating Operator shall undertake annual monitoring of the effectiveness of the water management plan. 9.b.2 Progress requirements: The water management plan shall include steps for reusing or recycling wastewater, appropriate to the scale and intensity of operation.	demonstrating that the water management plan relating to her/his/its biomass/biofuels operation(s) is available to the public unless this is limited by national law or international agreements on intellectual property. 9.b.i.3.The participating operator provides objective evidence demonstrating that the water management plan relating to her/his/its biomass/biofuels operation(s) is consistent with local conditions of rainfall, water storage, water distribution and water treatment. 9.b.i.4. The participating operator provides objective evidence demonstrating that the water management plan is consistent with any other regional or local water management plans. 9.b.i.5. The participating operator provides objective evidence demonstrating that the water management plan includes neighboring areas which receive direct water run-off from her/his/its biomass/biofuels operation(s). 9.b.i.6. The participating operator provides objective evidence demonstrating that any negative impacts resulting directly or indirectly from her/his/its biomass/biofuels operation(s) on the water resources of the neighboring areas are mitigated fully. 9.b.i.7. The participating operator provides objective evidence demonstrating that the water management plan is reviewed and revised periodically (i.e. at least annually) to assess its effectiveness at achieving its stated objectives. 9.b.i.8. The participating operator provides objective evidence demonstrating that best practices measures for reusing or recycling of wastewater have been identified and are implemented within three years from initial certification.
RSB Criterion	**Scope and Requirements**	**Indicators**
Criterion 9c. Biofuel operations shall not contribute to the depletion of surface or groundwater resources beyond replenishment capacities.	Operators who must comply: Feedstock Producer, Feedstock Processor, Biofuel Producer. 9.c.1 Minimum requirements: Water used for biofuel operations shall not be withdrawn beyond replenishment capacity of the water table, watercourse, or tank from which the water comes. Irrigated biofuel crops and freshwater-intensive biofuel operations systems shall not be established in long-term	9.c.i1. The participating operator provides objective evidence demonstrating that her/his/its biomass/biofuels operation(s) does/do not contribute to exceeding the replenishment capacity of the water table(s), watercourse(s) or water tank(s) at any time during the year. 9.c.i.2. Where freshwater intensive biomass/biofuels operations are established in drought prone areas or where irrigated crops are used in drought prone areas, the participating operator provides objective evidence demonstrating that best available practices are used, and that measures are implemented to mitigate changes in water quantity and

	freshwater-stressed areas, unless the implementation of: • good practices or • an adequate mitigation process that does not contradict other requirements in this standard ensures that the water level remains stable. Participating Operators shall not withdraw water from a natural watercourse to the extent that it modifies its natural course or the physical, chemical and biological equilibrium it had before the beginning of operations. **Where the screening exercise has triggered the need for a Water Assessment (RSB-GUI-01-009-01), Participating Operators shall:** • Identify critical aquifer recharge areas, replenishment capacities of local water tables, watercourses, and ecosystem needs. The potential impacts of biofuel operations on any of these aspects shall be evaluated, and any negative impacts mitigated. • Define the use and share of water resources for biofuel operations in agreement with local experts and the community; any water user committees shall be consulted. 9.c.2 Progress requirements: The Participating Operator shall demonstrate commitment to the improvement of water efficiency over time through the implementation of water-saving practices.	quality. 9.c.i.3. In drought-prone areas, irrigation is not used unless the operator can demonstrate objective evidence that the level of the water resource used remains stable. 9.c.i.4. The participating operator provides objective evidence demonstrating that the use of water from natural water bodies for her/his/its biomass/biofuels operation(s) does not result in a permanent change in its natural course or change the physical, chemical or biological equilibrium the water body had before the biomass/biofuels operation(s) started. 9.c.i.5. The participating operator provides objective evidence demonstrating that efficiency of water use has improved within three years of certification through implementation measures to conserve water. **The following indicators are applicable where the screening exercise has triggered the need for a Water Assessment (RSB-GUI-01-009-01):** 9.c.i.6. The participating operator provides objective evidence demonstrating that critical aquifer recharge areas, replenishment capacities of local water tables, watercourses, and ecosystem needs have been identified and evaluated. 9.c.i.7 The participating operator provides objective evidence demonstrating that any potential negative impacts of her/his/its biomass/biofuels operation(s) on local water tables, watercourses, and ecosystem needs will be mitigated. 9.c.i.8 The participating operator provides objective evidence that the use and sharing of water resources for biomass/biofuels operation(s) has been agreed upon with local experts and the community, and that all water user committees have been consulted.
RSB Criterion	**Scope and Requirements**	**Indicators**
Criterion 9d. Biofuel operations shall contribute to the enhancement or maintaining of the quality of the surface and groundwater	Operators who must comply: Feedstock Producer, Feedstock Processor, Biofuel Producer. 9.d.1 Minimum requirements: • Biofuel operations shall not occur on a critical aquifer recharge area without a specific authorization from legal authorities. • Participating Operators shall implement the	9.d.i.1. The participating operator provides objective evidence demonstrating that biofuels are not produced or processed in critical aquifer recharge areas, without official authorization from relevant legal authorities. 9.d.i.2. The participating operator provides objective evidence demonstrating that best available practices to maintain or enhance the quality of water resources to their optimal level are implemented in

resources.	best available practices which aim to maintain or enhance the quality of surface and ground water resources that are used for biofuel operations to the level deemed optimal for the local system for sustained water supply, ecosystem functioning and ecological services. • Adequate precautions shall be taken to contain effluents and avoid run-off and contamination of surface and ground water resources, in particular from chemicals and biological agents. • Buffer zones shall be set between the operation site and surface or ground water resources. **Where the screening exercise has triggered the need for a Water Assessment (RSB-GUI-01-009-01), Participating Operators shall:** • determine the optimal water quality level required to sustain the system, taking into account local economic, climatic, hydrologic and ecologic conditions. 9.d.2 Progress requirements: • For existing operations, degradation of water resources that existed prior to certification and for which the Participating Operator is directly accountable shall be reversed. Wherever applicable, operators (except small-scale operators) shall participate in projects that aim to improve water quality at a watershed scale. • Wastewater or run-off that contains potential organic and mineral contaminants shall be treated or recycled to prevent any negative impact on humans, wildlife, and natural compartments (water, soil).	her/his/its operation(s). 9.d.i.3. The participating operator provides objective evidence demonstrating that sufficient precautions have been taken to contain effluents from her/his/its biomass/biofuels operation(s) and prevent contamination of water resources. This includes treatment and/or recycling of wastewater and the establishment of buffer zones. 9.d.i.4. The participating operator provides objective evidence demonstrating that emergency plans and measures are in place, known and implemented in her/his/its operation(s) in case accidental contamination of water resources is identified. 9.d.i.5. For biomass/biofuels operations where degradation of water resources existed before said operation was accepted as a participating operator or part of a participating operator, the participating operator provides objective evidence demonstrating that within three years of certification measures to reverse the degradation of water resources have been implemented and that the participating operator has taken part in projects to improve water quality at the watershed level. 9.d.i.6 The participating operator provides objective evidence that wastewater or run-off with organic or mineral contaminants are treated, recycled or properly disposed of within three years of certification. **The following indicators are applicable where the screening exercise has triggered the need for a Water Assessment (RSB-GUI-01-009-01):** 9.d.i.7. The participating operator provides objective evidence that she/he/it has conducted studies to determine the optimal water quality level required to sustain the system, taking into account local economic, climatic, hydrologic and ecologic conditions.

Annex III – Bonsucro (formerly the Better Sugarcane Initiative, BSI), with reference to the application of this certification scheme in Brazil[83]

Principle 3 - Criterion 3.1:

To monitor production and process efficiency; to measure the impacts of production and processing so that improvements are made over time.

The water indicator in this principle is related to *sugarcane yield* (total yield per year/total ha cut/weighted average age at harvest) for each category of agricultural water regime. Standard values depend on whether this consists of irrigated or rain-fed agriculture:

- Irrigated (85 t cane/ha harvested/year);
- Supplementary (65 t cane/ha harvested/year); and
- Rain-fed (45 t cane/ha harvested/year).

Values for a reporting period or a five-year rolling average can be used. Seed cane production (yields and area) should be excluded and non-cane areas and roads and contours should be excluded from area harvested. Supplementary irrigation is applied where the system is unable to supply the full crop requirement.

In Brazil: The Bonsucro/BSI standard for sugarcane yield can be achieved in Brazil.

Principle 4 - Criterion 4.1:

To assess the impacts of sugarcane enterprises on biodiversity and ecosystem services. This principle provides two agricultural indicators and one mill indicator associated with water quality.

One agricultural indicator is *nitrogen and phosphorus fertilizer (calculated as phosphate equivalent) applied per hectare per year*, whose **standard is < 120 kg/ha/y**.

Notes: The environmental burden is kg phosphate equivalent, measuring risk (i.e. amounts applied) rather than level in downstream water. Quantities of nitrogen and phosphorus fertilizer applied are calculated as the phosphate equivalent as a measure of potential effects on eutrophication per hectare per year. To minimize losses from over-application and consequent groundwater or downstream contamination.

The figure is: [(kg/ha nitrogen x potency factor nitrogen) + (kg/ha phosphorus x potency factor phosphorus)]; the potency factor (PN) nitrogen is 0.42 and the potency factor phosphorus is 3.06 (Source: *The Sustainability Metrics: Sustainable Development Progress Metrics recommended for use in the Process Industries*, IChemE – Institute of Chemical Engineers, London, 2002).

[83] For this voluntary certification scheme, also see Chapter 6, Section 6.1.4.

In Brazil: Considering the application of 100 kg N/ha and 30 kg P_2O_5 to sugarcane in Brazil, the final value is 62.04 kg/ha/y phosphate equivalent.

= 100 x 0.42 (PF nitrogen) + 30/4.67 x 3.06 (PF phosphorous)

= 61.65 kg/ha/y phosphate equivalent

The second agricultural indicator related to water quality is *herbicides and pesticides applied per hectare per year,* whose **standard is < 5 kg active ingredient/ha/y**.

Notes: This indicator aims to minimize air, soil and water contamination. Quantities of pesticide (including herbicides, insecticides, fungicides, nematicides, ripeners) applied are calculated as a measure of potential toxic effects on the environment. Also note the requirement to use only products registered for use and at registered rates, and to comply with the Stockholm Convention on Persistent Organic Pollutants (POPs) and requirements in relation to agrochemicals rated as 1a, 1b or 2 under World Health Organization (WHO) classification.

In Brazil: The value applied in Brazil is 50 g active ingredient per tonne of cane. Average Brazilian production is 85 tonnes of cane per hectare, resulting in 4.25 kg active ingredient per hectare.

The mill indicator related to water quality is *aquatic oxygen demand per unit mass product*, whose **standard is 1 kg COD or 0.5 kg BOD_5/t product**.

Notes: Oxygen demand by calculation of quantity and analysis of run-off. Environmental burden can be expressed in terms of either COD or BOD_5, depending on the routine measurements available.

In Brazil: The majority of Brazilian mills use the effluents of the sugarcane crop, so discharging into water bodies is equal to zero.

Principle 4 - Criterion 4.2:

To implement measures to mitigate adverse impacts where identified.

This criterion, related to water quality and water quantity, presents one agricultural and mill indicator associated with a *document plan and implementation of mitigation measures*, whose standard is the existence of a list which is part of an environmental plan.

Notes: Existence of a list of identified adverse impacts such as smoke, fallout from fires, water pollution downstream, drift from agrochemical spraying and noise. Existence of a mitigation plan and verification of the implementation of mitigation measures, including consultation with affected stakeholders. Programmes with objectives developed at the sectorial level can be considered.

In Brazil: Mills usually have environmental management due to environmental and technical requirements demanded by the environmental agency.

Principle 5 - Criterion 5.2:

To continuously improve the status of soil and water resources.

This criterion, related to water quantity, presents one agricultural and one mill Indicator, related to *net water consumed per unit mass of product (in this case, water consumed is captured water).* The mill standard is 20 kg water per kg sugar or 30 kg water per kg ethanol, and the agricultural standard is 50 kg water per kg cane.

Notes: In processing, water used less water returned from a mill to watercourses; in agriculture, water captured/bought for use in irrigation.

In Brazil: In the mill, the water captured is around 2 m^3/t cane, which returns to the environment through discharges into the river or irrigation. In Brazil the part that returns to rivers is considered discharge; the quantity applied on the soil is considered loss. Water consumed is considered:

In agriculture: water captured/bought for use in irrigation.

In processing: water used less water returned to watercourses (this means that water consumed is water captured on the surface and/or underground less effluent discharged into rivers.

In Brazil: Maximum water consumption is the total consumed by 2 m^3/t cane (equal to the volume captured). Considering the average production of 100 kg sugar per tonne cane and 85 litres of ethanol per tonne of cane (about 68 kg ethanol), the water consumed is 20 kg/kg sugar or 30 kg/kg ethanol.

In agriculture, the water depth applied in the plantations for sugarcane “salvation irrigation” is from 100 mm/ha to 300 mm/ha (equivalent to 1 000 to 3 000 m^3/ha). Considering a yield of 85 tonnes of cane per hectare, water use in irrigation can represent between 12 and 36 kg of water per kg of sugarcane, a value less than the indicator (< 50 kg/kg cane).

Annex IV – Sustainable Agriculture Network (SAN) Principle 4 on water conservation[84]

4.1 The farm must have a water conservation program that ensures the rational use of water resources. The program activities must make use of the best available technology and resources. It must consider water re-circulation and reuse, maintenance of the water distribution network and the minimizing of water use. The farm must keep an inventory and indicate on a map the surface and underground water sources found on the property. The farm must record the annual water volume provided by these sources and the amount of water consumed by the farm. Water is vital for agriculture and human existence. Certified farms conduct activities to conserve water and avoid wasting this resource. Farms prevent contamination of surface and underground water by treating and monitoring wastewater. The Sustainable Agriculture Standard includes measures for preventing surface water contamination caused by the run-off of chemicals or sediments. Farms that do not have such measures guarantee that they are not degrading water resources through the implementation of a surface water monitoring and analysis program, until they have complied with the stipulated preventative actions.

4.2 All surface or underground water exploited by the farm for agricultural, domestic or processing purposes must have the respective concessions and permits from the corresponding legal or environmental authorities.

4.3 Farms that use irrigation must employ mechanisms to precisely determine and demonstrate that the volume of water applied and the duration of the application are not excessive or wasteful. The farm must demonstrate that the water quantity and the duration of the application are based on climatic information, available soil moisture, and soil properties and characteristics. The irrigation system must be well designed and maintained so that leakage is avoided.

4.4 The farm must have appropriate treatment systems for all wastewaters it generates. The treatment systems must comply with applicable national and local laws and have the respective operating permits. There must be operating procedures for industrial wastewater treatment systems. All packing plants must have waste traps that prevent the discharge of solids from washing and packing into canals and water bodies.

4.5 Critical Criterion. The farm must not discharge or deposit industrial or domestic wastewater into natural water bodies without demonstrating that the discharged water complies with the respective legal requirements, and that the wastewater's physical and biochemical characteristics do not degrade the receiving water body. If legal requirements do not exist, the discharged wastewater must comply with the following minimum parameters:

Water Quality Parameter	Value
Biochemical Oxygen Demand ($DBO_{5, 20}$)	Less than 50 mg/L
Total suspended solids	
pH	Between 6.0 – 9.0
Grease and oils	Less than 30 mg/L
Fecal coliforms	Absent

The mixing of wastewater with uncontaminated water for discharge into the environment is prohibited.

4.6 Farms that discharge wastewater continuously or periodically into the environment must establish a water-quality monitoring and analysis program that takes into account potential contaminants and applicable laws. The program must indicate the wastewater sampling points and frequency and the analyses to be carried out. A legally accredited laboratory must conduct all analyses. Laboratory results must be kept on the farm for at least three years. The program must comply with the following minimum requirements for analysis and sampling:

[84] For this voluntary certification scheme, also see Chapter 6, Section 6.1.6.

Water Quality Parameter	Wastewater discharge rate (cubic meters/day)		
	Less than 50	50 to 100	More than 100
	Sampling Frequency		
Biochemical Oxygen Demand ($DBO_{5, 20}$)	Annual	Half-yearly	Every three months
Total suspended solids	Monthly	Weekly	Daily
pH			
Grease and oils	Annual	Half-yearly	Every three months
Fecal Coliforms			

4.7 Critical Criterion. The farm must not deposit into natural water bodies any organic or inorganic solids, such as domestic or industrial waste, rejected products, construction debris or rubble, soil and stones from excavations, rubbish from cleaning land, or other materials.

4.8 The farm must restrict the use of septic tanks to the treatment of domestic wastewater (grey water and sewage) and non-industrial wastewater to prevent negative impacts on underground or surface water. The tanks and their drainage systems must be located in soils suitable for this purpose. Their design must coincide with the volume of wastewater received and treatment capacity, and must permit periodic inspections. Wastewater from the washing of machinery used for agrochemical applications must be collected and must not be mixed with domestic wastewater or discharged to the environment without previous treatment.

4.9 If total or partial compliance with the requirements of this standard that relate directly or indirectly to the contamination of natural water bodies cannot be proven, the farm must conduct a surface water quality monitoring and analysis program. The program must indicate the sampling points and frequency, and must be continued until it can be proven that farm activities are not contributing to the degradation of the quality of the receiving water bodies. This does not exclude monitoring and water-analysis obligations stipulated by law or as indicated by local authorities. At a minimum, the following analyses must be conducted:

Parameter	Sampling Time
Suspended solids	During the rainiest month of the year.
Total nitrogen	
Phosphorus compounds	
Specified pesticides	Immediately following the end of the pesticide application re-entry period.

Additional analyses may be required as a result of the types of contamination identified during the audit.