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Understanding the Nexus

Background paper for the Bonn2011 Nexus Conference

BONN PERSPECTIVES
A FRESH LOOK AT SUSTAINABILITY

Coordinating lead institution responsible for the content
Stockholm Environment Institute (SEI)

Main contributors
Food and Agriculture Organization of the United Nations (FAO)
International Food Policy Research Institute (IFPRI)
Stockholm International Water Institute (SIWI)
TERI - The Energy and Resources Institute
World Business Council for Sustainable Development (WBCSD)
World Wide Fund For Nature (WWF)

Additional contributors
Deutsches Institut für Menschenrechte (DIMR)
Global Water Partnership (GWP)
Organisation for Economic Co-operation and Development (OECD)
Potsdam Institute for Climate Impact Research (PIK)
World Bank (WB)
World Economic Forum (WEF)

For further information about this paper, please contact Holger Hoff, main author.
Email: holger.hoff@sei-international.org

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Background paper for the Bonn 2011 Nexus Conference: THE WATER, ENERGY AND FOOD SECURITY NEXUS

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EXECUTIVE SUMMARY

This paper for the Bonn 2011 Conference presents initial evidence for how a nexus approach can enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors. It also underpins policy recommendations, which are detailed in a separate paper.

Challenges and tightening constraints

Despite substantial progress in many areas, human development has been inequitable: around a seventh of the world's population – the so called 'bottom billion' – does not have a secure food supply and has only limited access to clean water, sanitation or modern sources of energy.[1] At the same time humans are over exploiting natural resources in many regions. We have severely modified or completely replaced many terrestrial and aquatic ecosystems, and many *ecosystem services* are degraded.

Another challenge to the task of safeguarding resources is *rapidly increasing demand* for them. Population growth, an expanding middle class with changing lifestyles and diets, and the urgent need to improve water, energy and food security for the poorest all place growing pressure on limited resources. Unless there are significant changes to the ways that we produce and consume, agricultural production will have to increase by about 70% by 2050 and about 50% more primary energy has to be made available by 2035. Such increases would have far-reaching implications for water and land resources. *Climate change* is also likely to aggravate pressure on resources and so add to the vulnerability of people and ecosystems, particularly in water scarce and marginal regions. A nexus approach is needed to help climate mitigation measures (e.g. REDD+[2] or CCS[3]) be more 'water smart', adaptation measures (e.g. irrigation) to be less energy intensive, and to avoid damaging consequences for food production and other vital ecosystem services.

As *urbanization* continues apace, half of the world's population now lives in cities. There are today about 1 billion urban slum dwellers, a number projected to swell to 2 billion by 2030. While in principle services can be provided more efficiently in cities than in rural areas, urban living promotes more resource intensive lifestyles and concentrates consumption and waste production. Cities should shift to green and pro-poor development pathways by, e.g., reducing wastage and closing water and other material loops with their hinterlands, while extending services to the poor.

Globalization, e.g. through trade and foreign direct investment, can bring much needed technological innovation and jobs to developing regions and can also provide resources where there is regional scarcity (e.g. through so-called 'virtual water imports').[4] However, increasing economic connectedness also externalises resource extraction to other regions and exposes countries to volatility in the global market. Only if social and environmental externalities are accounted for or 'internalized' can the benefits of globalization be shared equitably and natural capital maintained.

The combined pressures described above can undermine resilience in the face of societal and environmental shocks or crises. Such pressures threaten to drive social-ecological systems at all levels across critical thresholds, e.g. via land degradation, water scarcity or food crises. The main challenge under these constraints will be to reconcile long-term and global objectives (e.g. climate protection, ecosystem stewardship and equity goals) not only with immediate economic benefits, but also with the need to secure local livelihoods and the non-negotiable human rights to water and food.

1 More than a billion people don't have access to sanitation or modern source of energy.

2 REDD: Reducing Emissions from Deforestation and forest Degradation

3 CCS: Carbon Capture and Storage

4 E.g. if wheat is imported, the importing country relies on external water resources for growing that wheat

The water, energy and food security nexus

Productivity and the availability of water, energy and land vary enormously between regions and production systems. There is a large potential to increase overall resource use efficiency and benefits in production and consumption, e.g. by addressing intensive agriculture (which often has higher water productivity but lower energy productivity than other forms of agriculture) or water- and energy-intensive meat products. The nexus approach can boost this potential by addressing externalities across sectors. For example, nexus thinking would address the energy intensity of desalination (also termed 'bottled electricity'), or water demands in renewable energy production (e.g. biofuels and some hydropower schemes) or water demands of afforestation for carbon storage. Also, action to avoid or land degradation saves water and energy, for example by increasing soil water storage and groundwater recharge, as well as reducing the use of energy-intensive fertiliser.

Water, which has only very recently received attention in the Green Economy debate, is an essential input for all biomass growth and hence for all ecosystem services and associated jobs and livelihoods. Improved water resources and intact ecosystems ('natural infrastructure') can mutually reinforce each other and generate additional benefits.

Opportunities to improve water, energy and food security

A nexus approach can support a transition to sustainability, by reducing trade-offs and generating additional benefits that outweigh the transaction costs associated with stronger integration across sectors. Such gains should appeal to national interest and encourage governments, the private sector and civil society to engage. A number of opportunities emerge from the evidence presented in this paper. These include:

Increased productivity of resources

Sustainable and inclusive intensification, and decoupling of economic development from resource use – both fundamental to a Green Economy – can be achieved through technological innovation, recycling (e.g. productive sanitation)[5] and reducing wastage. The nexus focus is on system efficiency, rather than on the productivity of isolated sectors.

Waste as a resource in multi-use systems

Cross-sectoral management can boost overall resource use efficiency. In multi-use systems in particular, waste and by-products can be turned into a resource for other products and services, e.g. in green agriculture,[6] wastewater-energy integration or multi-use reservoirs.

Stimulating development through economic incentives

Innovation to improve resource use efficiency requires investment and reductions in economic distortions. Economic instruments for stimulating investment include, e.g., pricing of resources and ecosystem services, water markets and tradeable rights, and payments for ecosystem services. A nexus approach can also help to avoid 'sunk costs', i.e. investments that lock development into non-sustainable pathways.

Governance, institutions and policy coherence

Regulation and collective action can help to guide investments and innovation to minimize negative externalities and share benefits equitably. Enabling conditions for horizontal and vertical policy coherence include institutional capacity building, political will, change agents and awareness-raising. Additional opportunities can be realized if the nexus is addressed coherently across all scales through multi-level governance.

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5 Productive sanitation systems safely recycle excreta, other organic waste products and water to crop and other biomass production, in order to increase overall resource use efficiency.

6 A green agriculture or 'greening of agriculture' aims at simultaneously increasing farm productivity and profitability, reducing negative externalities, and rebuilding ecological resources through practices from conservation agriculture, such as minimum tillage, biological pest control and soil fertility enhancement, crop rotation and livestock–crop integration (UNEP 2011b).

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Benefiting from productive ecosystems
Improved ecosystem management and investment in natural capital can provide multiple ecosystem services and increase overall benefits. Natural infrastructure can complement human-made 'hard' infrastructure to a greater extent, and can even deliver some services more efficiently. Green agriculture or a shift towards integrated 'agro-ecosystems' and landscape management can provide additional benefits, such as carbon sequestration and resilience to climate risks, while improving food security.

Integrated poverty alleviation and green growth
Sustainable use of resources strengthens a wide range of ecosystem services and maintains the human 'life support system', on which the poorest depend most directly. Provision of clean water and energy would immediately improve the health and productivity of the 'bottom billion'. Green agriculture can generate more rural jobs and increase diversity and resilience of production systems.

Capacity building and awareness raising
Capacity building and social learning can help to deal with the increasing complexity of cross-sectoral approaches, and also to level the playing field among the nexus sectors and actors. Awareness raising (and supporting governance) can promote sustainable lifestyles and consumption patterns. New and targeted trans-disciplinary nexus research, fully integrated assessments of water, energy and food at all scales, and Green Economy metrics and indicators will enable quantitative trade-off analyses.

Towards a Green Economy
The concept of a 'Green Economy' is yet to be clearly defined. According to UNEP,[7] a Green Economy is an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. Its carbon output and pollution is low, and its resource use efficiency is high. In a Green Economy natural capital is valued as a critical economic asset and as a provider of benefits for the poor. The Green Economy approach 'seeks, in principle, to unite under a single banner the entire suite of economic policies (...) of relevance to sustainable development'.[8] Hence the Green Economy itself is the nexus approach par excellence. To succeed, a Green Economy must go beyond sectoral solutions and actively address the water, energy and food security nexus, in-line with human rights-based approaches. However, there are still large gaps in knowledge on interactions, feedbacks and adaptation options across the nexus. This paper is an initial attempt to fill these gaps.

7 UNEP: United Nations Environment Programme
8 UNCSD 2010

1. Introduction and context

1.1. Why do we need a nexus approach?

This paper for the Bonn 2011 Conference, organized in preparation for the Rio+20 summit, provides evidence that improved water, energy and food security can be achieved through a nexus approach – an approach that integrates management and governance across sectors and scales. A nexus approach can also support the transition to a Green Economy, which aims, among other things, at resource use efficiency and greater policy coherence. Given the increasing interconnectedness across sectors and in space and time, a reduction of negative economic, social and environmental externalities can increase overall resource use efficiency, provide additional benefits and secure the human rights to water and food. Conventional policy- and decision-making in 'silos' therefore needs to give way to an approach that reduces trade-offs and builds synergies across sectors – a nexus approach. Business as usual is no longer an option.

Accelerating development

Development has rapidly accelerated over the past half century, but the benefits of development and progress on water, energy and food security (e.g. per capita calorie production has increased from 2280 to 2800 kcal per day) have been very unequally distributed between and within countries. A range of pressures from global and regional change, such as population growth, economic development and changing lifestyles, are growing simultaneously, and sometimes amplifying each other. There is also a rapidly expanding affluent middle class in emerging and developing countries, which tripled in size in developing Asia between 1990 and 2005.[9] While in principle this is a positive development, the consumption patterns, diets and resource use of this class are quickly approaching those of developed countries (e.g. in terms of per-capita consumption of resource-intensive meat, fruit and vegetables and added sugar and fat.)[10] Additional resources must also be made available to meet the food and energy needs of the poorest.

Urbanization

Continuing urbanization, often driven by deteriorating rural living conditions and a quest for a 'better life', means that city dwellers now account for 50% of the total global population. With about 800,000 new urban residents every week, that proportion is projected to reach 70% by 2050.[11] Resource demand and waste products are concentrated in cities because of higher population density and higher per-capita resource consumption compared with rural areas; for example, cities account for about 75% of all greenhouse gas emissions.[12] Cities are spatially disconnected from their resource base, which increases the need for transport, for example long-haul transfers of real and virtual water.[13] Cities also pose new challenges to securing adequate living conditions for the poor. There are currently 1 billion slum dwellers[14] (projected to increase to 2 billion by 2030) who are especially food insecure and disconnected from (or dependent on highly over-priced) government water and energy services. However, there are opportunities for cities to increase resource efficiency and to move toward sustainability, because they are economic and knowledge centres, and have lower per-capita infrastructure costs and more localized transportation needs compared to rural areas. A nexus approach in cities would include integrated planning of infrastructure for water, wastewater and energy. Cities also need to build synergies with their hinterlands and watersheds, by providing markets for agricultural products, by recycling waste products into and out of cities, e.g. through cascading water uses (i.e. re-use of increasingly lower-quality water for purposes that

9 The Economist 2011

10 FAOSTAT

11 UNPD

12 UNEP 2011b

13 Siebert et al.

14 UN Habitat 2003

demand lower water quality), and by promoting nexus approaches through peri-urban agriculture and landscaping.

Case study 1. Masdar City[15]

This new master-planned city in the United Arab Emirates aims to produce no waste and to be carbon neutral, relying on different types of green technology. It will be entirely supplied by renewable energy generated by (ground-based and roof-mounted) photovoltaics, which are connected through a smart grid; concentrating solar power; evacuated tube collectors; and geothermal heat pumps. In response to the extreme water scarcity in the region, Masdar City is designed to reduce the domestic consumption of water to a maximum of 100 litres per person per day through use of low-flow showers, highly efficient laundry systems, water tariffs, real-time monitoring, and smart water meters. It also aims to reuse 100% of processed wastewater for irrigation. While the specific situation of Masdar City limits that the transferability of these solutions, it can nevertheless stimulate innovations in various cities in a similar context.

Climate change

Climate change is mostly driven by energy use and changes in land use. Climatic variability adds further pressures, for example from accelerating drying of drylands, reduced glacier water storage, more frequent and intense extreme events (such as droughts or floods), and less reliable water supplies, as well as less reliable agricultural productivity. The food sector alone contributes about a third of total greenhouse gas emissions[16] through energy use, land use change, methane emissions from livestock and rice cultivation, and nitrous oxide emissions from fertilized soils. At the same time climate change mitigation places new demands on water and land resources (and also impacts on biodiversity), for example from REDD+, biofuels, carbon sequestration and carbon capture and storage (CCS).[17] Climate adaptation measures, such as intensified irrigation or additional water desalination, are often energy intensive. Thus climate policies can impact on water, energy and food security, and adaptation action can in fact be maladaptive if not well aligned in a nexus approach and implemented by appropriately interlinked institutions.

Globalization

Globalization has been an important driver of development. It connects and integrates markets, brings investment, and provides access to technology that supports innovation and increased resource use efficiency. International *trade* has grown rapidly (food trade somewhat more slowly) and the traded precentage of food produced has grown globally from about 10% in 1970 to 15% in 2000.[18] Trade can also mitigate local scarcities. This is evident in the Middle East and North African (MENA) countries, which increasingly have to rely on food imports[19] (and associated imports of virtual water). However, trade also externalizes resource extraction and waste products, often across large distances,[20] and transportation itself is also energy intensive. Therefore apparently positive bends in national environmental 'Kuznets curves' (i.e. as a country grows wealthier it reduces its resource use intensity) may in fact only reflect the externalization to other regions. Also, disturbances and shocks (e.g. price shocks) can become more contagious across regions with increasing trade (and financial) connectivity.

Foreign direct investment (FDI) has become a major driver of change in many developing countries. For example, more than 200 million hectares, or between 2 and 20% of agricultural land in sub-Sa-

15 The input of Federico Cugurullo to this case study is gratefully acknowledged.

16 Sachs et al. 2010

17 Jackson et al. 2005, Zomer et al. 2006

18 Andersson 2010

19 Allan 2001, Elhadj 2008

20 Hoff 2009

haran countries, have been sold or leased over the past few years, or are currently being negotiated over,[21] to help meet the rapidly growing demand for food, feed and other bioresources in particular from China, India and some Arab countries. China now also meets half of its demand for wood products from overseas.[22] Gradual liberalization of economies, commercialization of agriculture and rural labour, and changing roles of the state and private sector are providing the impetus and support for rapidly increasing FDI. Foreign investors are reacting to increased domestic pressure on resources and simultaneous export restrictions by some major agricultural producers, as well as growing distrust in the functioning of world markets.[23]

While investment in agriculture is much needed in developing countries as it can bring innovation and production gains, the present sudden wave of FDI poses significant challenges to local people's livelihoods, access to land and water, and food security. There has been only sporadic assessment of the socio-economic effects of FDI, e.g. dispossession of pastoralists[24] or the exclusion of local people from the benefits of FDI who cannot make upfront investments.[25] Institutional capacity for managing the environmental and socio-economic effects of FDI is developing only slowly.[26] In order for FDI to be sustainable and inclusive[27] (reducing the risk of land and water 'grabbing'[28] and retaining domestic control over resource use) regulation, institutional development and social learning in the target countries need to catch up with the rapid acquisition of land. Key elements of integrated water and land resources planning and management are: secure property rights; transparency and accountability of contracts; participation through free, prior and informed consent; and effective anti-corruption measures. Like other facets of globalization, FDI is also quite volatile, as observed during the recent financial crisis when FDI flows to Africa dropped by one third.

Case study 2: Making foreign direct investment in Ethiopia inclusive and sustainable

Ethiopia is one of the few countries which meets the Comprehensive Africa Agricultural Development Programme (CAADP)[29] target of investing at least 10% of its national budget in agriculture. However, like most of sub-Saharan Africa, it needs additional (foreign) investment to improve infrastructure, market access, water and land productivity, and rural income.[30] Accordingly, Ethiopia promotes FDI through tax exemptions, long-term leases at fixed prices, preferred water rights and zero water charges for investors. In response to these policies and in combination with external drivers, total FDI in Ethiopia has increased by approximately a factor of 10 over the past five years – however, no comprehensive FDI data are available. Land is sometimes sold or leased for as little as USD 1.50 per hectare per year,[31] on average around USD 3–10,[32] over periods of 25–50 years.[33] Given the long-term implications, appropriate national frameworks need to be in place for aligning FDI with sustainable development planning.

While investment in green and rainfed agriculture and rehabilitation of marginal land could increase co-benefits across the nexus, including enhanced carbon sequestration[34] and additional rural jobs, investments currently

21 Oxfam 2011, Friis et al. 2010

22 Xiufang et al. 2011

23 Von Braun et al. 2009

24 Elias 2008

25 German et al. 2010

26 Horne 2011

27 'Inclusive' is used here to indicate pro-poor development or activities.

28 von Braun et al. 2009

29 Created under the New Partnership for Africa's Development (NEPAD) to revitalize agriculture and rural development

30 Sulser et al. 2010

31 Vidal 2011

32 Access 2010

33 Rowden 2011

34 CA 2007, Lal 2006

favour high-input agriculture – including large-scale irrigation infrastructure – in the most productive areas,[35] often for biofuel production (the same is true for domestic investors).[36] Integrated water and land resources planning will have to address this imbalance.

The Ethiopian government argues that the country has 'three million hectares of [land] ... not used by anybody [which]...should be developed'.[37] However, informal and customary land rights and downstream water uses are often neglected when claiming that land is unused.

If investments are transparently planned and implemented and formal and informal land and water rights respected, there are significant pro-poor and sustainable development opportunities. These include outgrower schemes and contract farming, equity sharing or producer-consumer partnerships as found in the fairtrade sector. Internationally, codes of conduct and guidelines[38] have been or are currently being developed for FDI, which now need to be adapted, implemented and enforced. It is also encouraging that international investors are beginning to voluntarily establish and follow their own commitments.[39]

Degradation of the resource base

Growing demand and non-sustainable management have increased man's ecological footprint and caused degradation of the natural resource base in many regions, including severe modification of ecosystems. Humans have altered more than three quarters of the Earth's ice-free land surface[40] and already appropriated almost a quarter of its net primary productivity,[41] primarily for food production.[42] Desertification and land and soil degradation have reduced water and land productivity, water and carbon storage, biodiversity and a wide range of ecosystem services. These processes are not (fully) reversible at timescales relevant for policy-making. While water is a renewable resource, pollution and overuse can still have long lasting impacts, such as degraded and depleted aquifers and loss of aquatic ecosystems and wetlands.

Scarcity of water, land and other resources

Scarcity is rapidly escalating due to increasing demand, resource degradation and pollution. Unless there are significant changes towards more sustainable production and consumption patterns and reduced rates of population growth, by 2050 agricultural production would have to grow by another 70% (by 100% in developing countries), and agricultural land would have to expand by about 10% globally (by 20% in developing countries and by 30% in Latin America).[43] Even the most optimistic scenarios of improvements in productivity through technological development still project an increase in agricultural water demand of at least 20% by 2050.[44] These estimates could become much higher if new biofuel strategies were fully implemented. Much of the required growth in agricultural production will have to come from intensification on current cropland, e.g. through mechanization, fertilization and irrigation. However, this will increase demands for blue water (see box 5 for definition), energy, and other inputs unless new, integrated and nexus-based approaches materialize. It also would increase the requirements for fertilizer. Also of interest is that fossil phosphorus reserves could be depleted within just 50 years time if the world were to replace 10% of its energy requirements with energy crops.[45]

35 Cotula 2011
36 FAO 2011b
37 IANS 2011
38 Von Braun et al 2009, FAO 2010, FAO 2011
39 SFA 2011 and Xiufang et al. 2011
40 Ellis 2011
41 Haberl et al. 2007
42 MA 2005
43 Bruinsma 2009
44 De Fraiture et al. 2007
45 Rosemarin et al.. 2011

Global energy demand, according to a 'reference scenario' that projects current trends into the future, will grow by 40% up to 2030 – with all the growth coming from non OECD countries. China, India and the Middle East would under this scenario double their primary energy demand, while demand in Africa and Latin America would increase by about 40%. Almost 70% of the increase in global oil demand up to 2030 is projected to take place in China and India alone. Biofuel demands could grow by 100% by 2030.[46] However, alternative scenarios that place a strong emphasis on demand management show a significant reduction in these growth rates.[47] Unfortunately, technological innovation and higher resource productivity are typically counteracted by a corresponding increase in production or consumption levels – the so-called 'rebound effect'[48] – so that there is no net reduction in resource (over-)exploitation.

Water, energy and food security

We are a long way from achieving water, energy and food security for all the world's people. In hotspot regions such as South Asia (where lack of land is also becoming an issue – see figure 5), and sub-Saharan Africa, large fractions of the population remain marginalized and deprived of their human rights and development opportunities.

Box 1. Water, energy and food security: human security in the nexus

Water security is defined in the Millenium Development Goals as 'access to safe drinking water and sanitation', both of which have recently become a human right.[49] While not part of most water security definitions yet, availability of and access to water for other human and ecosystem uses is also very important from a nexus perspective.[50]

Energy security has been defined as 'access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses' (UN), and as 'uninterrupted physical availability [of energy] at a price which is affordable, while respecting environment concerns'.[51]

Food security is defined by the FAO as 'availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life'. Adequate food has also been defined as a human right.

The emphasis on access in these definitions also implies that security is not so much about average (e.g. annual) availability of resources, but has to encompass variability and extreme situations such as droughts or price shocks, and the resilience of the poor.

While water, energy and food security have so far been mainly constrained by unequal access, humanity is now also approaching limits in global resource availability and sink strength, such as phosphorus supply or atmospheric CO_2 concentration. It is increasingly recognised that conventional supply-side management is coming to an end in many cases. Resource limitations in all sectors require a shift towards increased resource use efficiency, demand management and more sustainable consumption patterns. Without such changes, current development trajectories threaten to drive social-ecological systems at all scales towards critical thresholds. Crossing such thresholds could result in, for example, food crises such as currently experienced in the Horn of Africa; basin closure;[52] or crossing of 'planetary boundaries',[53] which define a safe operating space for humanity. The newly emerging sustaina-

46 IEA 2009
47 WWF Energy Report
48 Hertwich 2005
49 UN General Assembly 2010
50 Grey et al. 2007
51 International Energy Agency
52 Basin closure describes a situation where all water resources within a river basin are fully allocated (Falkenmark et al.. 2008).
53 Rockström et al. 2009

ble development goals[54] could provide an institutional foundation to address these boundaries as well as equity issues associated with the allocation and distribution of limited resources. Crossing critical thresholds at any scale could result in (possibly irreversible) system changes – so-called 'regime shifts' – bringing negative impacts for ecosystems, socio-economic development and poverty alleviation. Such changes may also cause social unrest, conflicts and migration.

New approaches

New approaches are needed, given that the overall costs of inaction are generally higher than those of pro-active adaptation, as the cases of climate and biodiversity protection[55] or land degradation[56] demonstrate. More integrated policy- and decision-making that account for external costs across sectors, space or time (e.g. carbon leakage)[57] will have to complement conventional approaches aimed at only improving sectoral resource productivity. This can lead to improved overall resource use efficiency, sustainable resource management and equitable benefit sharing. Because policy changes are often outpaced by the accelerated development, institutions need to be flexible, adaptive, and enabled to cooperate with institutions representing other sectors. In some cases new institutions may be required.[58] Existing integrated frameworks, such as Integrated Water Resources Management (IWRM)[59] or Integrated Natural Resources Management (INRM) need to be revisited in order to better resonate with requirements across various sectors. IWRM needs to evolve towards partnerships with water-using sectors whose policies and strategies are governed by many factors outside the water sector.[60]

There is a need for a coordinated and harmonized nexus knowledge-base and database indicators and metrics that cover all relevant spatial and temporal scales and planning horizons. Full life-cycle analyses across the nexus are also needed. Such an improved nexus understanding could underpin new decision- and policy-making in a Green Economy framework.

Case study 3: opportunities for demand management and green solutions in Jordan

Jordan is among the most water scarce countries in the world, with about 80% of its food supply dependent on food imports – which also entail imports of virtual water. Climate change is projected to further dry the country, and to lead to more (intense) droughts and increasing demand for irrigation. Jordan lacks significant fossil fuel reserves and has no hydropower potential, but instead depends on pumping surface and groundwater to the major demand sites over vertical gradients of more than 1000m. Accordingly, water supply accounts for about 25% of Jordan's total electricity demand.[61] Groundwater resources are severely over-exploited. Most of Jordan's water use is in agriculture, while agricultural contribution to GDP and total employment is only around 3%.

Besides food imports and associated virtual water (and to a much smaller extent 'virtual energy'), the focus of Jordan's water strategy is on large-scale supply-side infrastructure projects. These include fossil groundwater transfer from the Disi aquifer to the city of Amman, and an even larger conduit from the Red Sea to the Dead Sea combined with desalination,

54 E.g. recent declaration on sustainable development goals, available at: www.uncsd2012.org/rio20/index.php?page=view&nr=273&type=230&menu=38

55 Stern 2006, TEEB 2010

56 Nkonya et al. 2011

57 carbon leakage: emission increase in one region caused by emission reduction policies or measures in another region

58 Walker et al. 2009

59 Integrated Water Resources Management, i.e. the '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 ecosystems' (GWP 2000).

60 WWDR 2009

61 Scott et al. 2003, McCornick et al. 2008

plus a nuclear power plant near Amman. Given Jordan's already high water prices and the enormous costs and energy demands associated with new projects, conventional supply-side water management is reaching its limit.

However, demand-side management options have large untapped potential. These options include greater reliance on food imports (with associated virtual water imports); reducing water loss in urban systems (80% of Jordan's population live in cities) which approaches 50% of total supply; substituting freshwater use in agriculture for treated wastewater; increased energy efficiency in the water sector; and energy recovery from wastewater. With its long-standing experience in water management under scarcity and existing pilot schemes for integrated water and energy solutions, e.g. in wastewater recycling and low-energy pumps, Jordan could become a showcase for green technologies in the Arab world and beyond.[62] Jordan could extend its good example by better exploiting its large potential for renewable energy production (in particular solar). Such a 'Green Economy strategy' could also reduce its GHG emissions and its dependency on fossil fuel imports. Jordan's National Water Strategy explicitly supports the goals of increasing the energy use efficiency of its water supply and wastewater treatment, and of using alternative energy to meet 20% of energy demand for water pumping.[63]

New small-scale and decentralized infrastructure, such as rainwater harvesting, wastewater treatment and reuse and supplementary irrigation, offers additional development opportunities. These options could avoid the potential problem of sunk costs, which might block future alternative pathways, and could increase resilience to future shocks or crises (e.g. by reducing vulnerability of large water transfers to earthquakes and the sensitivity of large thermal power plants to droughts). Some of these options could also generate more jobs than large-scale solutions and avoid further marginalization of the poorest. Moreover, there are opportunities for integrated water and land (spatial) planning, which could preserve productive rainfed agricultural land that is currently being lost at high rates to the expanding city of Amman.

Stronger institutions that are better interlinked are key to a nexus approach, and may be more important than additional institutions. For example, a Ministry for Mega-Projects that was established in Jordan in 2010 to 'identify synergies and resolve conflicts between the various concerned ministries and government agencies'[64] has since been dissolved.

The nexus approach highlights the interdependence of water, energy and food security and the natural resources that underpin that security – water, soil and land. Based on a better understanding of the interdependence of water, energy and climate policy, this new approach identifies mutually beneficial responses and provides an informed and transparent framework for determining trade-offs and synergies that meet demand without compromising sustainability. The following guiding principles are central to the nexus approach:

- investing to sustain ecosystem services
- creating more with less
- accelerating access, integrating the poorest

62 See also UNEP Scoping Study for a Green Economy in Jordan

63 MWI 2008

64 Fakhoury 2010

1.2. Guiding principles for the nexus approach

Investing to sustain ecosystem services

The UN Environment Programme (UNEP) defines ecosystem services as the 'contribution of ecosystems to human well-being',[65] with particular importance for the livelihoods of the poor. As such ecosystems are central to the notion of the Green Economy, which aims at reducing ecological scarcity.[66] Provisioning ecosystem services include food, feed, biofuels, wood and fibre. Regulating services include carbon sequestration and climate and water regulation.[67] Ecosystems and the hydrological cycle are closely interlinked, and ecosystems serve as 'natural water infrastructure',[68] often providing services (e.g. improved water quality) more efficiently than man-made 'hard' infrastructure. Investments in hard infrastructure and end-of-pipe solutions often cause negative externalities, such as reduced ecosystem diversity and services, and reduced bio-diversity.[69] Investment in natural capital needs to go beyond terrestrial ecosystems and also encompass aquatic ecosystems and wetlands (e.g. peat wetlands, which store 30% of all global soil carbon on 3% of the world's land area).[70] Higher priority must be given to the water requirements ('environmental flow') of these aquatic systems, relative to other (blue) water (and land) uses.

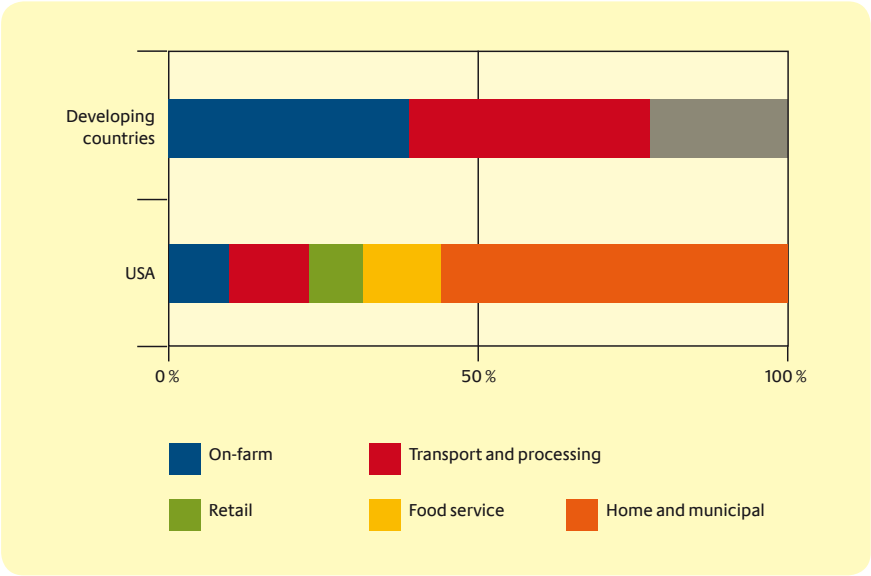
A precautionary approach that secures ecosystem services and maintains buffers against shocks and crises (e.g. floods) needs to avoid further ecosystem degradation and limit cropland expansion.[71] If intensive high-input agriculture, which is optimized for one particular ecosystem service (food production), can be transformed into 'green agriculture'[72] various other ecosystem services can be co-produced without compromising food security.[73] Natural capital can attract more investment when it becomes part of national accounting.[74] Payments for ecosystem services (PES) can provide economic incentives for sustainable ecosystem management.[75] However to date most PES target only individual sectors and services (e.g. water provisioning or carbon sequestration) and lack a nexus approach.

Creating more with less

The Green Economy depends on increased sectoral resource and overall resource use efficiency. Productivity is defined here as the output – such as kilograms of biomass, kilocalories of food or kilowatts of electricity – per unit of water consumed, or land or energy utilized. Water productivity in biomass production depends on various factors such as vegetation (feedstock in the case of biofuel production),[76] climate, and land and water management practices and land degradation status. The potential for increasing the productivity of water and land is particularly high in sub-Saharan Africa and south Asia.[77] Technologies for higher water productivity do not always have to be newly developed; for example rainwater harvesting and supplementary irrigation. If interventions and investments which increase water or land productivity are designed with the nexus in mind, they do not negatively affect energy productivity (and greenhouse gas emissions), or vice versa, but can instead increase overall resource use efficiency. Moreover, reducing wastage along the production and supply chain generally reduces pressure on resources and mitigates other looming scarcities, such as that of phosphorous.

65 UNEP/IWMI 2011
66 UNEP 2011
67 MA 2005
68 Diamond et al. 2006
69 Vörösmarty et al. 2010
70 Parish et al. 2008
71 Rockström et al. 2009
72 UNEP 2011b
73 Keys et al. 2011
74 See WAVES (Wealth Accounting and Valuation of Ecosystem Services) partnership and TEEB 2010
75 Smith et al. 2006
76 Gerbens-Leenes et al. 2009, Stone et al. 2010
77 Kijne et al. 2009

Figure 1: Make up of total food waste in developed and developing countries
(after Godfray et al. 2010)



Note: The grey part of the developing countries bar represents the combined percentage of the retail, food service, and home and municipal categories.

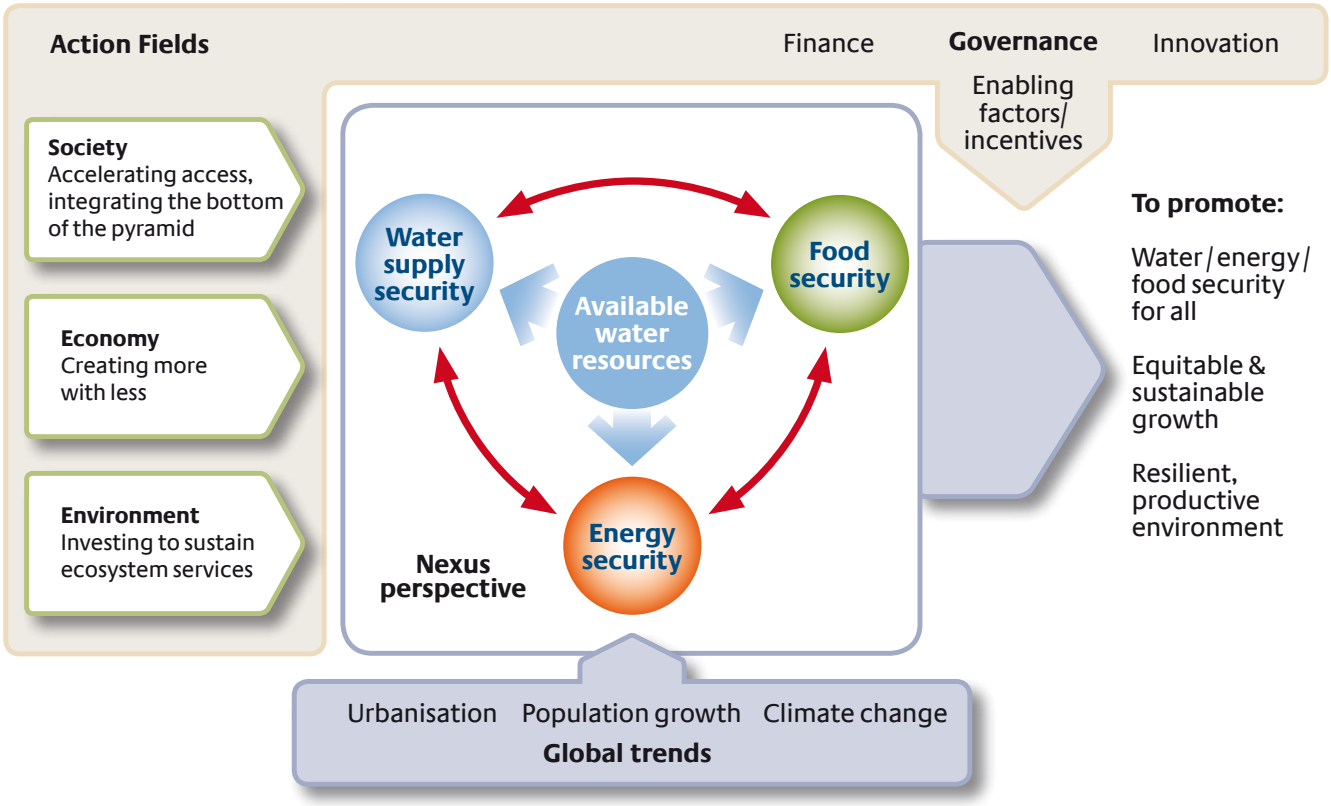
Accelerating access, integrating the poorest

There is considerable overlap between the 1.1 billion poor people without adequate access to water,[78] the (close to) 1 billion who are undernourished,[79] and the 1.5 billion who are without access to electricity[80] (and to some extent the 1 billion slum dwellers in developing world's cities). Synergies can be built and positive feedbacks generated across the three nexus sectors when improving living conditions and livelihood opportunities for the 'bottom of the pyramid'. While water, energy and food security are crucial for the potential to develop, at the same time such security depends on the level of development. For example, irrigation can reduce poverty,[81] while the level of poverty can determine the productivity of agricultural water.[82] Human and environmental health are closely interlinked, as illustrated negatively by excessive food or meat consumption, and positively by access to clean water and clean energy services. While access to clean and affordable water is a strong determinant of human health, healthy people at the same time can be more productive and contribute to economic development. Access to clean, affordable and reliable energy (and eventually the development of integrated energy systems through productive electricity and modern fuels) is crucial to the fight against poverty, while secure (rights-based) access to resources also leads to more sustainable use of natural capital. Hence investment and innovation that accelerate equitable access and benefits for the poor can have high rates of return in terms of development and environmental sustainability.[83] The poor themselves can become effective and efficient actors in a nexus approach.

78 Human Development Report 2006
79 IFRC 2011
80 IEA
81 Hussain 2005
82 Djurfeld 2004

83 WIR 2005

Figure 2: The water, energy and food security nexus



2.1. The nexus sectors

Water

Water plays a central role in the nexus, as illustrated by the expressions 'water flowing through the veins of the economy'[84] or 'water: the bloodstream of the biosphere'.[85] The latter expression implies that water is non-substitutable in biomass production, with biomass in turn being a central resource for energy and food security in a Green Economy. Water acts as a state variable and at the same time a control variable of change, and is placed centrally in the nexus (figure 2). While water is a renewable resource, and globally there is enough water to feed a growing and more wealthy population, demand temporarily or permanently outstrips availability in more and more regions of the world, most prominently in the bursting of regional 'water bubbles',[86] as seen in parts of India, China, and the MENA region.

Box 2. Different types of water and water uses: why is it important to distinguish them?

Green water: refers to water in soil that comes directly from rainfall, and which is available to plants and supporting natural and agricultural ecosystems. It is primarily managed via land use and agricultural practices.

Blue water: refers to water in rivers, lakes or aquifers that is available for irrigation, municipal uses (water supply and sanitation), and industrial

84 Conference thematic paper: www.water-energy-food.org/documents/bonn2011_thematic_profile_paper.pdf, accessed 29 August 2011

85 Ripl 2003

86 WEF 2009

and other uses. It is typically managed by means of water infrastructure.

According to their different uses, these two types of water have different opportunity costs: green water is only (consumptively) used by plants, while blue water can also be locally allocated to other uses and can often be recycled. Hence, there are different opportunities for intensification associated with blue and green water, and each is generally managed by different institutions.

Consumptive versus **non consumptive** water use: Consumptive water use refers to that fraction of water withdrawn from a source that is not returned (but instead evaporated). Agriculture is by far the largest consumptive water use globally (besides other ecosystems). For example, the thermoelectric power sector in the US is responsible for 49% of all blue water withdrawals, but only for 3% of consumptive blue water use.[87] If the return flow is polluted or heated, that may also be considered consumptive use because the changed water properties compromise further uses.

Energy

Energy is currently mainly derived from non-renewable resources, in particular from fossil fuels. While these would be increasingly phased out in a Green Economy, the percentage of renewables in total energy use (currently 13%)[88] is projected to grow significantly.[89] The EU, through its Renewable Energy Directive, aims for the EU as a whole to obtain at least 20% of total energy from renewables by 2020. The directive also includes the target that by the same date 10% of transportation fuel should come from renewables. By 2010 the US used 35% of its total corn crop for ethanol.[90] Achieving targets on specific contribution of renewables to total energy provisioning not only depends on supply-side enhancement, but also on effective demand management. While in principle renewables cannot be over-exploited or depleted, they may cause negative externalities in the other nexus sectors. For example biofuels, and to some extent hydropower, have higher water demand per unit of energy produced compared to fossil fuels. Also there is a risk of negative energy gains. For example, corn grown in the US for energy purposes may require more calories of input than it eventually produces (though different analyses have produced conflicting results.)[91]

There is currently a large gap in per-capita energy use within and between countries: while low-income countries use about 420 kg of oil equivalent per capita per year, high income countries use about 5300.[92] Whereas in high-GDP countries the biggest proportion of energy use goes to processing, transport and heating, in low-GDP countries cooking consumes the highest share. Improving and providing new and clean forms of energy (e.g. electrification) can be key to creating production and job opportunities, and sustained improvements to people's health and lives in low-GDP countries.

Food

Food production has grown impressively over the past decades, in particular in response to the Green Revolution.[93] However, these improvements in growth and the side-effects of that growth have been very unevenly distributed.[94] While production growth in the tropics has to a large extent been achieved via agricultural land expansion (mostly at the expense of forests and landscape carbon storage), in other regions growth was mostly based on intensification on existing agricultural land,[95] requiring additional inputs of water, fertilizers and energy. Water productivity has increased with intensification (e.g. mechanisation and more fertilizer

87 OECD 2011
88 IPCC 2011
89 Shell 2011
90 USDA

91 E.g. Pimentel et al. 2005, Shapouri et al. 2010
92 WDI 2010
93 Borlaug 2002.
94 CA 2007
95 Foley et al. 2011

use), energy productivity has not: for example the energy intensity of corn production in the US has only improved from 2.7 to 2.2 GJ per ton of product over the last 60 years.[96] Expansion onto new land as well as intensification (also through shorter fallow periods) both can impact on other ecosystems and associated services, depending on geographic conditions and agronomic practices.[97]

The following section identifies and – to the extent possible – quantifies the interactions and feedbacks between the water, energy and food sectors, externalities across sectors, space and time, and opportunities for improving overall resource use efficiency for equal benefit sharing.

2.2. Interactions across the nexus

Water for energy

Water for energy currently amounts to about 8% of global water withdrawals (this proportion reaches 45% in industrialized countries, e.g. in Europe).[98] Water is required for the extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing biofuels and for generating electricity (see below). New or non-conventional sources of fossil resources, such as tar sands or shale gas, or ways to extract those resources, such as hydraulic fracturing (known as 'fracking') are particularly water intensive as well as polluting.[99] Biofuels are substantially more water intensive than fossil fuels,[100] requiring about 10,000–100,000 litres per GJ of energy (almost all of their water demand is for growing feedstock, very little of which is for further processing). Oil and gas production require about 1–10 litres of water per GJ of energy, oil sands about 100–1000 litres.[101]

These numbers indicate that water-use efficiency can decrease when replacing conventional with non-conventional resources, in particular with biofuels as a renewable resource. Note that biofuel production in some locations (such as India), relies mostly on blue water/irrigation, while in others (such as Brazil), it is mostly green-water/rainfall dependent. Also, some of the water uses in the energy sector are consumptive, while others are not. Hence water productivities and opportunity costs are not immediately comparable across different uses and resources.

Case study 4: Ningxia region, China: severely water-constrained, but rich in integrated alternatives[102]

Ningxia, bordered by three of China's largest deserts, has very low water availability: just 200 m^3 per capita, or about 15% of China's average. Water availability is further decreasing due to climate change and pollution – 90% of China's aquifers under major cities are polluted.[103] More severe drought in recent times (in particular in the 1990s) and desertification (with half of Ningxia's land affected) have compromised land and water productivity. Afforestation, as supported by German Development Cooperation in Ningxia, can help to rehabilitate land, but also comes at a cost: throughout China new forests are increasingly depleting local water supplies due to the high water demand of trees. Water demands are growing rapidly, in part as a result of changing diets – on average the annual water demand for food has grown in China from 250 to 860m^3 per capita between 1960 and 2000.[104]

The Yellow River provides most of the irrigation water in Ningxia, with projected higher water availability as a result of the large south-

96 Smil 2008
97 Foley et al. 2011
98 SOER 2010
99 GAO 2010
100 Gerbens Leenes et al. 2009
101 WEF 2011

102 The input of Xiaojing Fei to this case study is gratefully acknowledged
103 Orszag 2011
104 Liu et al. 2008

north transfer project, which will eventually deliver 45 km^3 annually to the north of China.[105] Given that pumping across such large distances is very energy intensive (with additional energy demands again resulting in higher water demands), alternative agricultural water supply and demand measures are currently being tested in the Ningxia region, including drip irrigation, zero tillage, shifting to less water intensive crops, etc. It is not yet clear how much of China's fast growing spending in agricultural research and development (faster than in any other world region)[106] is being directed to green agriculture.

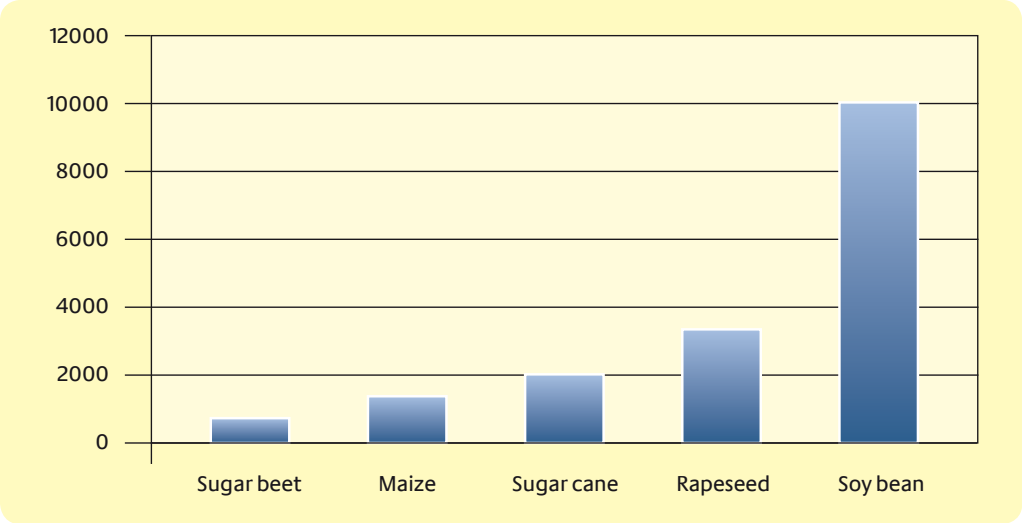
The Ningxia region is close to China's main coal-mining region, so that its energy mix is dominated by coal (including for electricity, household heating and cooking). Because of the water intensity of generating electricity from coal (20% of China's consumptive water use goes into coal-fired power plants)[107] and its high greenhouse gas emissions, China is seeking and testing energy savings and alternative energy sources. Ningxia is rich in solar energy and wind and there is further potential for diversifying energy sources, including in biogas production linked to pig farming and sanitation. Pilot programmes run by the Ningxia Centre for Environment and Poverty Alleviation achieved a 30% reduction in household coal use. Biofuels may locally also provide new opportunities for cleaner energy access and improved rural livelihoods. However, its overall resource use efficiency and risks for food security need to be assessed further. Nationwide, China (the third-largest bio-ethanol producer after the US and Brazil) has recently moved away from maize to other feedstocks, such as sweet sorghum or jatropha, due to national food security concerns.[108]
Shifting water to economically more efficient uses in industry is encouraged by granting additional water rights to companies that install water saving measures. There is further potential for increasing water use efficiency by allocating water to the service sector, which is generally less energy intensive than the chemical sector.[109]

Unless integrated in multi-use systems or grown on marginal land, biofuels can compete with food production for water and land, expand into other ecosystems,[110] and can potentially lower the resilience of food production systems.[111] Furthermore, the carbon balance of new biofuel plantations is often negative over many years.[112]

The enormous water and land demands that would accompany any significant increase in the contribution of biofuels to total energy supply is illustrated by the fact that current global energy demand (about 500 Exajoule per year) is more than 10 times higher than the total energy content of all food and feed (including waste) produced on current cropland.[113] As a rule of thumb, it takes about the same amount of water to produce 1 litre of liquid biofuel as it takes to produce food for one person for one day.[114] For illustration we calculated the water consequences of a substitution scenario of transportation fuel, according to which about 30 million barrels of ethanol and 23 million barrels of biodiesel would be required per day to substitute fossil transportation fuels completely.[115] What would the consequences of this be in terms of water? Well, replacing only 10% of the required ethanol with first generation biofuels would require an additional 600 km^3 of water per year[116] – much more than the global consumptive municipal and industrial water use

105 Water Technology a)
106 Beintema et al. 2010
107 Orszag 2011
108 Qui et al. 2010
109 Kahrl et al. 2008
110 WWF 2011
111 Naylor 2008
112 Fargione et al. 2009
113 Heinke et al.
114 WWDR 2009
115 de la Torre 2007
116 Schaphoff pers. comm.

Figure 3: Water use intensity of some major biofuels (litres of water evaporated per litre of biofuel produced)



Source: Hoogeveen et al. (2009)

put together.[117] (Again, opportunity costs vary a lot for the different types of water that could be used for this endeavour.) Another analysis finds that less than 10% of the world's primary energy demand could be met from biofuel planted on abandoned agricultural land (which is not competing for water with food production).[118] Some claim that a shift to ligno-cellulosic (second generation) biofuels would decrease competition for land and water.[119] However, this would primarily result in a shift to resources with other opportunity costs (e.g. green instead of blue water and marginal instead of crop land), rather than a reduction of total resource use. Large potentials for reducing freshwater use may lie in the use of algae (also called third generation biofuels) when this technology becomes available.

The energy sector also has impacts on water quality and hence on availability of clean water, most clearly shown by oil contamination in the Niger delta and more recently in the Gulf of Mexico, but also in oil-shale/oil-sand fields in North America.

Electricity is the fastest growing form of energy use, projected to grow by 87% by 2035,[120] with almost one third of that growth coming from China alone.[121] Hydropower production – while already providing 16% of global electricity generation and 86% of the global renewable energy[122] – is still far below its economically and technically feasible potential in several regions, e.g. Africa only taps 5% of its potential.[123] Many countries (particularly Brazil, India and China) are expanding their hydropower production significantly and many OECD countries are seeking to upgrade the efficiency of existing hydropower facilities. The renewed interest in hydropower is driven by energy security and climate change concerns (around one fifth of the projects registered under the CDM are hydropower projects). It is a largely carbon-free and stable source of (and way to store) energy, though release of methane gas may occur depending on the context, and in some cases susceptibility to drought can become a problem. Hydropower reservoirs provides storage which

117 Shiklomanov 2000
118 Campbell et al. 2008
119 IPCC 2011
120 IEO 2010
121 IEA 2009
122 Renewble Energy Essentials: Hydropower IEA 2010
123 BMZ 2007

Table 1. Water productivity in electricity production.

	Photo-voltaics	Concen-trating solar power	Gas	Coal / oil / nuclear	Hydro-power	Biofuels
m^3 / MWh	~ 0	~ 2	~ 1	~ 2	~ 60 (variable)	~ 180 (variable)

Note that the extraction and processing of fossil fuels adds between 0.05–1 m3 / MWh to these figures.)

can also support the deployment of wind and solar energy in integrated systems. However, depending on climate, the technology used and their surface area, hydropower reservoirs can have significant evaporative losses. At the same time, hydropower – particularly large dams – are controversial because of potentially serious ecological and social damage, such as flooding of ecosystems and/or relocation of local communities. Hence, an increase of biofuels and hydropower in the energy mix can have significant water and other costs.

More detailed comparisons also need to address water quality aspects and be context specific: for example, Norwegian reservoirs which have been proposed for storage of excess wind-generated electricity – 'Europe's green battery',[124] have relatively low evaporative losses due to the cold climate. Furthermore, in-stream/run-off-river hydropower plants have much lower losses than those fed by reservoirs and full life-circle analyses also have to take into account evaporation from the original vegetation that was replaced by the reservoir. Furthermore, there is a positive flood and drought mitigation effect of reservoirs, on downstream river sections. Other co-benefits derived from multi-use reservoirs can increase their overall water use efficiency further.[125] Water productivity of thermal power plants also varies enormously, with closed-loop cooling reducing withdrawals, but at the same time increasing consumptive water use.[126] Dry cooling, which relies on air rather than water for cooling, reduces the energy productivity of thermal power plants (depending on climate conditions) and increases capital costs drastically.[127] Coastal power plants use seawater, hence require no freshwater. The installation of CCS[128] technology in power plants for reducing CO_2 emissions can increase water consumption by up to 90%.[129] Return flows from power plants are warmer or polluted and hence can compromise other downstream water uses, including aquatic ecosystem services.

Energy production needs to be addressed in the context of the overall energy system, from extraction to end use, including externalities, as well as overall efficiencies and the benefits derived from water used throughout the full life-circle. A full system view can lead to important insights: for example, conversion of biomass into electricity yields on average 80% more transportation kilometres (when used in electric vehicles) than conversion into biofuel (when used in internal combustion vehicles).[130]

124 Science Daily 2010

125 see e.g. IPCC 2011

126 OECD 2011

127 OECD 2011

128 CCS: Carbon Capture and Storage

129 SOER 2010

130 Campbell et al. 2009

Potential for improving water use efficiency in the energy sector:

- Water productivity in ethanol processing has increased by 30% over the past decade and there is scope for further improvement.[131]

- Freshwater demand in energy production can also be reduced by using marginal water (e.g. brackish water), or by co-producing water in oil and gas extraction through treatment of surplus water in constructed wetlands.[132]

- Multi-use reservoirs can increase the total water use efficiency of hydropower compared to dams that solely generate power.

- Solar energy, which requires relatively little water, can contribute more to energy security – even at higher latitudes, as for example via the planned DeserTec electricity link that would supply Europe with solar power from Northern Africa.

Energy for water

Energy is required for lifting, moving, distributing, and treating water. Non-conventional water sources, such as reclaimed wastewater or desalinated seawater, are often highly energy intensive. Energy intensities per m^3 of clean water produced vary by about a factor of 10 between different sources, e.g. about 0.37 kWh from locally produced surface water, 0.66–0.87 kWh from reclaimed wastewater and 2.6–4.36 kWh from desalinated seawater[133] (desalinated water is also termed 'bottled electricity'). Groundwater – which provides close to half of total consumptive irrigation water use[134] – is generally more energy intensive than surface water, so that up to 40% of total energy use in some countries is used for pumping groundwater.[135] Pumping from greater depth (as groundwater tables fall) increases energy demand exponentially – by a factor of 80 when going from a depth of 35 to 120 m. Also water (and virtual water) imports to cities become more energy intensive as the distance from the source grows. Transporting 1 m^3 of water over 350 km horizontally requires about the same amount of energy as desalinating 1 m^3 of seawater.[136]

Global desalination capacity currently stands at 45 million cubic metres per day, half of which is in the MENA region, where a growth by 500% is projected up to 2030.[137] Other regions and countries, such as China, are following this trend.[138] Energy productivity of desalination is constantly growing, and there is also potential for greater co-generation of desalinated water and heat or electricity.

Irrigation is generally more energy intensive than rainfed agriculture and drip irrigation more energy intensive than flood irrigation (because the water must be pressurized).[139]

A lack of water security can lead to increasing energy demand and vice versa. For example, over-irrigation is often used in response to electricity (or water supply) gaps – it is common in parts of India for farmers to leave pumps on all the time because of unreliable power supplies (and because of free or subsidized power).

Case study 5: Improved energy access for sustainable intensification of the irrigation economy in Gujarat

In India, rapidly growing food and energy demands (and hence also water demands) are

131 Lloyd & Larson 2007
132 Sluijterman et al. 2004
133 Webber 2008
134 Siebert et al. 2010
135 WEF 2011
136 WBCSD 2009
137 IEA 2009
138 Watts 2011
139 Cooley et al. 2008

addressed through a mix of internal measures, e.g. increased agricultural subsidies for irrigation, electricity, fertilizer and seeds,[140] expansion of biofuels, inter-basin water transfers (i.e. linking of rivers, which comes at a significant additional energy cost), and external measures, in particular large-scale investments in land (e.g. in Africa).

Irrigation has been a major driver behind India's green revolution, providing food and income to large parts of the population. Currently 63% of cereal and 85% of sugarcane and most biofuel production takes place on irrigated areas, so livelihoods strongly depend on irrigation. Given that the monsoon climate makes rainfall (green water) available for only about four months per year and leaves river discharge highly variable, India strongly relies on groundwater for agriculture. Groundwater withdrawals have increased 113-fold between 1950 and 1985, which has made India the largest groundwater user in the world. This has led to severe over-exploitation of several aquifers. (Another side effect of this increased groundwater withdrawal may be a disturbance of India's monsoon circulation due to massive additional evapotranspiration and water input into the atmosphere – about 340 km^3 per year).[141] Pumping for irrigation is very energy intensive: about 20% of India's electricity use is for irrigation, and in fact more than half of India's hydropower production is going into pumping groundwater. The enormous groundwater over-exploitation is only possible due to flat and free power tariffs. These power subsidies are now difficult to reduce, given the dependence of India's rural population on this groundwater economy.

In Gujarat, the state government has introduced innovative win-win strategies involving support for massive rainwater harvesting, micro-irrigation and groundwater recharge schemes. In particular, the government has introduced an innovative 'Jyotirgram' (lighted village) scheme, which is based on redistributing electrical power and 'intelligent rationing', and covers more than 90% of Gujarat's villages. The scheme has 're-wired' the state with thousands of kilometres of new power lines, and separated electricity supplies for villages from that for irrigation tubewells. While villages can now rely on 24 hours of constant electricity, farmers were offered a reliable and predictable supply of eight hours of uninterrupted full voltage power along a strictly scheduled roster (which also helps to separate in time peak energy demand for irrigation from that for villages). This change from the previous

Power for groundwater pumping in Gujarat Photo credit: Tushaar Shah

140 Central Statistical Organisation, New Delhi

141 Douglas et al. 2009

situation of frequently interrupted, variable voltage power at unpredictable times, has had a number of positive effects. Helped by a succession of good monsoons, the groundwater levels throughout Gujarat have not only stabilised but are recovering; consumption of electricity for pumping groundwater and electricity subsidies has declined; the gap in livelihoods between rural villages and cities has narrowed; and enterprises such as mills, tailoring, welding and many others have a reliable power supply – vital for creating new jobs. Farmers have embarked on ambitious new cropping schemes made possible by a reliable supply of water during critical periods. Gujarat has recorded 9.6% annual growth in agricultural GDP, (compared to 2.9% at an all-India level) as a result of the new rural power system, combined with other infrastructure development, revitalized agricultural extension systems, reforms in agricultural marketing institutions, and new public and private investments.[142]

Key success factors for the introduction of the new power system were the early involvement of senior policy-makers, who saw the benefits for their constituencies, and the support of farming communities, who were convinced by the promotion of the scheme as an intervention to provide continuous power supply to uplift the rural population.

Potential for increasing energy use efficiency in water provisioning:

- By improving the productivity of rainfed agriculture, energy intensive irrigation can be limited or reduced.

- A shift from using fossil fuels to renewable energy for desalination can become an important contribution to a Green Economy, as long as externalities across the nexus are minimized. In Australia an 80 MW wind farm powers a desalination plant that provides Perth with 17% of its water supply.[143] This desalinated water can also be interpreted as a storage option for variable wind (and other) energy sources.

- Desalination of brackish water requires less energy than seawater desalination. Some regions have large reservoirs of brackish water.

- Energy recovery from wastewater can reduce the energy demand in the treatment plant or even allow an export of excess energy to the power grid. Technologies include methane production in anaerobic digestion and electricity production through microbial fuel cells. In Germany (and other places) there are initial examples of energy self-sufficient wastewater treatment plants.[144]

Water for food

Food production is the largest user of water at the global level, responsible for 80–90% of consumptive blue water use, plus a large fraction of green water use by terrestrial (agro-)ecosystems. Accordingly it is also responsible for resource over-exploitation. Water productivity in kcal per m^3 varies widely among crops, cropping systems, agricultural management methods and climates. As a rule of thumb, it takes on average about one litre of water to produce one calorie of food energy.[145]

142 Shah et al. 2009

143 Water Technology 2011b

144 Veolia 2010

145 FAO 2009

Table 2. Ranges of water productivity of different crops in kcal per m^3 and USD per m^3 of water[146]

	Wheat	Potato	Tomato	Apple
kcal per m^3	660–4000	3000–7000	1000–4000	520–2600
USD per m^3	0.04–1.2	0.3–0.7	0.75–3.0	0.8–4.0

It is important to differentiate between rainfed and irrigated agriculture, because the green and blue water involved have different alternative uses and hence opportunity costs (and energy requirements).

Livestock production complicates calculations of water productivity because of the various possible combinations of feed-water productivity and feed conversion efficiency by animal type, product, and production system. More than one third of global crop production is used for animal feed rather than direct human consumption.[147] Other feed sources for livestock include fishmeal, grazing, residues (e.g. brans and oil cakes) and wastes, some of which come at no water cost.

Table 3. Global average water productivity (in kcal per m^3), and consumptive water-use from grazing (in per cent), of selected livestock products[148]

	Meat from beef cattle	Meat from sheep and goats	Milk from dairy cattle	Meat from pigs	Meat from poultry	Eggs from poultry
Global average water productivity in kcal / m^3	34	30	332	666	371	578
Water-use from grazing in %	84	75	80	0	0	0

Table 3 shows that products from ruminants (i.e. cattle, sheep, goats) have much lower water productivity than those from pigs and poultry. However, opportunity costs of the large amounts of water consumed by ruminants from grazing land are very low, because often there are few alternative uses of the green water that is evaporated. For some marginal grazing land there are practically no alternative productive uses of the landscape's green water. Therefore it is crucial to take into account information on the opportunity costs associated with green and blue water use when comparing data on water productivity across livestock and vegetal products. Given the large number of factors affecting water productivity in the livestock sector, there are also various entry points for increasing overall resource use efficiency within the food system, such as improved feed sourcing – e.g. more use of waste products and residues from processes for animal feed.

Reverse links from food production to water include land degradation and changes in run-off, and impacts on groundwater recharge, water quality (e.g. eutrophication) and on overall efficiency of

146 Molden et al. 2010
147 Foley et al 2011
148 Heinke et al.

water and land use for other ecosystem services, such as carbon sequestration.[149] Land degradation and erosion not only reduce soil water storage, but often also cause siltation of downstream reservoirs, which can reduce water availability and capacity for energy production from hydropower.[150] Reversal of such land degradation, much like the cultivation of marginal land, is generally very energy and water intensive. Another often very strong link is that between the political economy of agriculture and water management.

Potential for improving water-use efficiency and benefit sharing in food production

- Green agriculture, better crop management, improved nutrient status (though industrial fertilizer would require additional energy input), reduced unproductive evaporation from the soil (e.g. by mulching and early vegetation coverage), and rainwater harvesting and supplementary irrigation (which, unlike large irrigation projects, do not require much additional energy if co-located) can improve water productivity.

- Shifts in consumer behaviour, e.g. from red meat to poultry generally increase water productivity in the food sector.

- There are significant opportunities to increase food security at no additional cost, given the enormous losses and wastage in the food production and consumption chain (see figure 1). It has been estimated that up to 50% reduction of losses and wastage could be achieved by 2025,[151] by reducing losses in production, storage and transportation in developing countries, and end-user wastage in developed countries.

- A global analysis[152] shows that a hypothetical reduction of per capita calorie production from 3000 to 2000 kcal per day (which implies that wastage could be avoided), in combination with a global average reduction in the meat content of diets from 20 to 5% (which is still sufficient to meet protein demands) could reduce future annual global water demand for food production by 3000 km^3. The same could be achieved by increasing agricultural productivity globally by 50%.

- Virtual water trade with agricultural commodities can in principle also increase water use efficiency, as in the MENA region where imported food has on average lower virtual water content than food produced locally.[153] However, virtual water flows don't always go from regions or countries of high water productivity to those with low water productivity. On the contrary – for a number of reasons the direction of virtual water flows may go in the opposite direction.

- Several of these measures can simultaneously increase water and energy use efficiency in the food sector.

Energy for food

Mechanization and other modernization measures have helped to increase yields and to make agricultural labour more bearable. In response, however, energy inputs have increased significantly, in particular for land preparation, fertilizer (primarily nitrogen), irrigation and other inputs. Intensive agriculture today is very energy intensive, although the agricultural fraction of total global energy use is much smaller than the agricultural fraction of total global water use. That strong energy dependence of agriculture is also reflected in the close correlation

149 Keys et al. 2011

150 GWC 2011

151 Lundqvist, et al. 2008

152 Rockström et al.. 2012

153 Fader pers. comm.

between crop and oil prices,[154] making high input agriculture less profitable under higher energy costs. The full food production and supply chain is responsible for around 30% of total global energy demand.[155]

Energy productivity varies widely between food products, food production systems and regions. In some cases, in particular for horticultural crops, the energy productivity (kcal output per kcal input) may be less than one – for apples grown in the US the ratio is 0.18.[156] Sugarcane and cassava are among those crops with particularly high energy productivity.

The energy sector itself can also negatively impact food production (and other vital ecosystem services) by reducing available land through mining for fossil fuels or deforestation for biofuels. Biofuel development has also been identified as a contributor to higher cereal prices on world markets.[157] While it is difficult to disentangle the various contributing factors, it is generally assumed that biofuels accounted for about a third of the recent increase in agricultural commodity prices.

Potential for improving energy-use efficiency and benefit sharing in food production:

- According to the FAO,158 there are three main routes for the food system to become 'energy smart': more efficient energy use; energy substitution (i.e. more renewables); and improved access to sustainable forms of energy. Opportunities for greater efficiency in food production include cutting fertilizer overuse, more precise application of fertilizer, and green agriculture and agro-ecological alternatives such as intercropping, nitrogen fixing, and use of compost and other recycling of residues. Improvements in rainfed agriculture can reduce the need for irrigation and the associated additional energy input.

- Given that energy for agriculture is often subsidized via fertilizer (e.g. in China and India) or electricity for pumping of water (e.g. in India and Pakistan) or via greenhouses (e.g. in Europe), this is an obvious economic lever to reduce energy input – at least in principle.

- As in the case of water for food, reducing wastage offers significant opportunities for improving overall resource use efficiency, given the high losses along the production and consumption chain from food storage, transportation, processing, and consumption.

- Integrated multi-use systems (e.g. crop-livestock or agro-forestry) can simultaneously increase water and energy use efficiency and generate co-benefits beyond food production.

The water, energy and food security nexus

An integrated view across the nexus provides more comprehensive information on relative resource scarcity and productivity, and on the potential for sustainable intensification in different regions. In principle, such new analysis can also encourage more resource intensive production schemes to be allocated to better endowed regions. However, this would require regional and intra-regional collaboration, with fair trade agreements providing universal access to products and benefits. At the local scale, integrated analysis illustrates that human rights must be addressed simultaneously for all nexus sectors, in order to avoid for example improved water security at the cost of energy security.

Another important feature of the nexus is the increasing demand between resources (e.g. water for energy and energy for water), which points to

154 Kim, 2010

155 Faures pers. comm.

156 Pimentel 2009. However, it should be noted that apples are not only grown for their energy content.

157 Rosegrant 2008

158 Faures pers comm

opportunities and synergies for increasing total resource use efficiency, and possibly also substitutions between resources.

At the upstream end of the food production chain, irrigation plays a central role in the nexus: improvements in any one sector may involve trade-offs in others – e.g. introducing irrigation increases land productivity,[159] but the additional blue water requirements generally also increase energy intensity compared to rainfed agriculture.[160] Precision irrigation, which generally improves energy productivity, may not save much water because – depending on the context – it possibly reduces return flows,[161] and with that the availability of downstream water. There is large potential for sustainable and inclusive or pro-poor intensification in rainfed agriculture,[162] which can reduce the demand for irrigation and associated blue water and energy inputs.

Livestock products generally require larger amounts of water and energy inputs per kilocalorie than plant-based products. However, livestock systems and products vary enormously in this respect, and the opportunity costs associated with water consumed in the livestock sector are mostly very low.[163]

Case study 6: Intensification in the Brazilian Cerrado: sustainable and inclusive?

Brazil has achieved large production increases in the Cerrado, a savannah region roughly the size of the combined areas of Germany, France, the UK, Spain and Italy. Over a period of about 15 years a 130% increase in total grain production, a four-fold increase in soybean production and a 10-fold increase in beef exports have been achieved.

The agricultural intensification and land conversion behind these increases are the result of a 'system approach'. This approach has involved higher agricultural inputs (fertilizer, lime, etc.); plant and livestock breeding (e.g. high yielding forage grasses, tropical soy bean, cattle); introduction of double cropping and zero tillage; rehabilitation of land, e.g. with leguminous, nitrogen-fixing plants; to some extent an integration of crop-livestock and agro-forestry systems; and an increase in the land area under cultivation. This impressive development has been jointly achieved by the Brazilian government (the Ministry of Agriculture in particular, which has offered incentives such as attractive credits and issued coherent agricultural policies), Embrapa (the Brazilian agricultural research corporation, which has invested in agricultural research and development and new technologies), and the private sector, which has seized agro-business opportunities.[164]

The Cerrado is also increasingly becoming a biofuel-producing area, with biodiesel production from soy recently growing at an annual rate of about 50%, making the state of Mato Grosso the leading biodiesel producer in Brazil. Following Brazil's National Plan on Climate Change, which aims to increase domestic ethanol use by 11% per year,[165] Mato Grosso is also beginning to produce ethanol from sugarcane, which offers a better energy balance,[166] higher carbon savings, and has higher water productivity compared to, e.g., US corn-based ethanol.[167] This advantage is due in part also to the recycling of waste products (vinasse) as fertilizer.[168] Climatic conditions in the state also allow rainfed production of sugarcane without irrigation.

159 Rost et al. 2009

160 an exception may be irrigated maize in Nebraska, Grassini, pers comm.

161 return flow is excess irrigation water that returns from the field to the river or groundwater from which it was withdrawn

162 e.g. CA 2007

163 Heinke et al.

164 Economist 2010

165 Government of Brazil 2008

166 Macedo et al. 2008

167 Fargione et al. 2009

168 OECD 2011

Soy harvesting in the Brazilian Cerrado

Photo credit: Paulo Whitaker/Reuters

While production and resource use intensity in the Cerrado have grown through agricultural intensification, it is not clear how overall water and energy use efficiency have developed. From a nexus perspective it is important to better understand the overall changes in efficiency and benefits derived from this intensification. A number of externalities have to be taken into account, and competition for land in the Cerrado is one of these. Rapid expansion, in particular of soybean cultivation, is pushing Brazil's agricultural frontier further into the Brazilian Amazon, causing additional deforestation.[169] The Amazon forest is subject to further development pressure caused by new roads for transporting products from the Cerrado to the Amazon sea port of Santarem.[170] Expansion of soy plantations has also led to rapid clearing of the original Cerrado vegetation, and with an associated loss of vegetation and soil carbon.[171] Greater rural inequality, and in some cases increased poverty,[172] have been observed as a result of increased soy production and agricultural intensification in the Cerrado.

Brazil is promoting a transfer of the Cerrado development model to sub-Saharan Africa via new regional offices and other support, in part because of similarities between the two regions in terms of climate, (poor) soil conditions, large savannah regions, and initially low resource productivity.[173] However, given the unaccounted for externalities of the Cerrado development, it is vital to gain a better understanding of overall resource use efficiency and put more emphasis on benefits and access sharing for the poor before implementing the Cerrado model in other regions.

Further downstream in the food production chain, there are also opportunities for reducing wastage and increasing efficiency, through improvements in processing, distribution and retailing. Changes in lifestyles and consumption patterns can also reduce pressure on water, energy and land, and enable more equitable benefit sharing.

To date there is no consistent quantitative assessment of water, energy and food scarcity or security at the global scale. However, results from partial analyses for the current situation are presented in figures 4–6.

169 Martinelli et al. 2008

170 Fearnside 2006

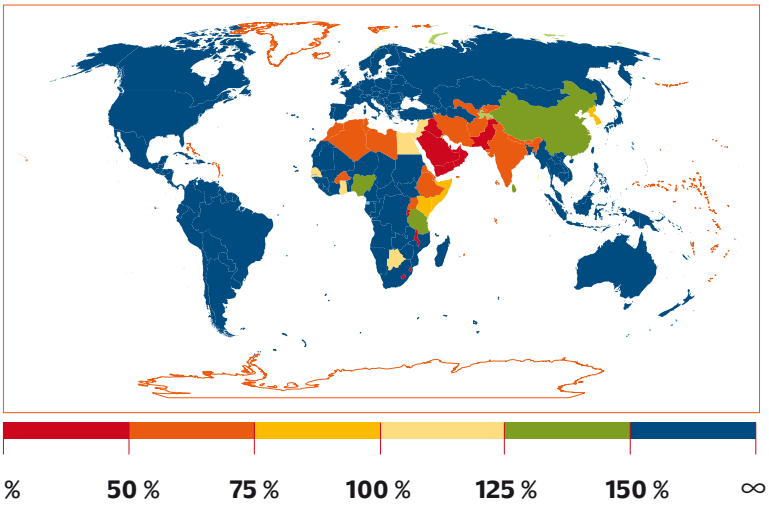
171 Fearnside et al. 2009

172 Weinhold et al. 2011

173 Galeranti et al. 2007

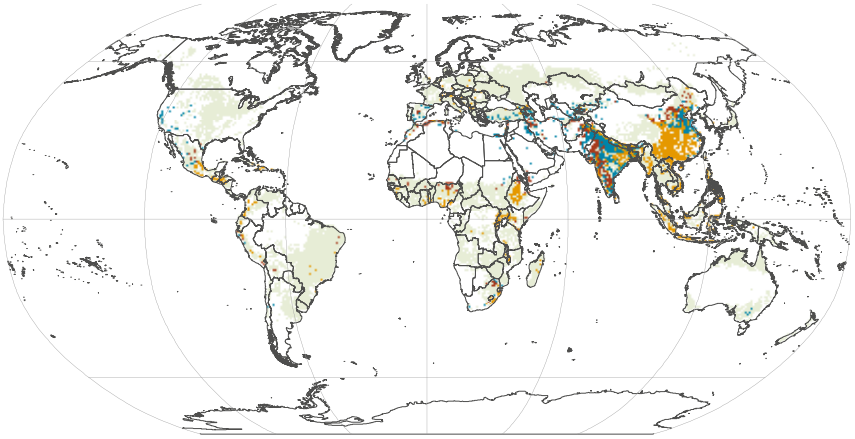
Figure 4. The water-food (and land) link: water-constrained potential for food self-sufficiency in % at country level

Water scarcity defined as the percentage ratio between green-blue water availability and the water requirements for producing a daily diet of 3,000 kcal with 20% animal products

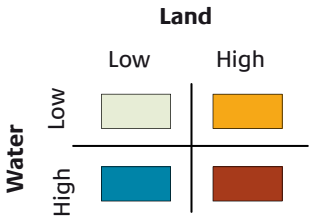


Source: Gerten et al., 2011

Figure 5. The water-land (and food) link: water and land scarcity in agriculture[174]



Agricultural Systems at Risk: human pressure on Land & Water



174 Adapted from FAO 2011b, based on FAO/IIASA's Global Agroecological zoning database. A distinctive population carrying capacity was assigned to each land suitability class. Water scarcity in irrigated areas was assessed by overlaying physical water scarcity by major river basin with the global map of irrigation areas, and comparing total water requirements for irrigation with water availability in the basin. Land scarce areas in dry climates are considered both land and water scarce

Figure 6. The water-energy link: gaps in meeting water demands of thermal power plants under low flow conditions

Cooling water consumption to Q90 ratio

- 0.5 - 1.0
- >1.0 (demand cannot be satisfied)

(c) Center for Environmental Systems Research, University of Kassel, Oct 2011 - Water GAP 2.2

Figure 4 shows the percentage of its food requirement that each country can produce domestically as constrained by current availability of blue plus green water and current agricultural water productivity.[175]

Figure 5 shows the results of an assessment of water and land scarcity in agriculture by comparing the rural population density with the suitability of land and availability of water for growing crops.

Figure 6 shows those thermal power plants for which cooling water demands (consumptive use) cannot be met, or are getting close to total available discharge, under low flow conditions.[176] The model simulates more than 63,000 thermoelectric units at 26,500 stations globally which account for approximately 3000 GW installed capacity.

These three figures show typical patterns of current water scarcity (although the aggregation level and details in the presentation of results vary between them). A comparison of figures 4 and 5 shows that those regions where there is highest pressure on land and water resources overlap strongly with those regions where food self-sufficiency is no longer possible. Figure 5 also clearly shows the pressing water and land scarcity in densely populated south Asia and south China.

Besides hot spots of water, energy and food insecurity, there are regions that hold significant potential for sustainable intensification of water and land use, in particular in sub-Saharan Africa and Latin America.[177] This potential includes marginal and degraded land which can be rehabilitated (e.g. for biofuel production).

Potential for improving resource use efficiency and benefit sharing across the nexus

- Improvements in rainfed agriculture as well as reducing land degradation and rehabilitating degraded land e.g. for biofuel production can significantly reduce pressure on (blue) water and land

- Integrated production of food, feed and biofuels can enable recycling of residues and waste products. Further integration with the co-production of other ecosystem services, such as timber production or carbon sequestration in multi-use systems, provides even more opportunities for generating additional benefits (e.g. biogas from agriculture for energy, crop rotation for food and biofuel, crop residues for feed) and reducing overall pressure on resources.

- Integrated planning across the nexus, involving also city and spatial planning, environmental protection and forestry, can unlock significant efficiency gains.

Figure 7. Biofuel-food production in a multi-use system: integrating a eucalyptus plantation with cattle raising

Photo: Laércio Couto

175 Only accounting for green water available on current agricultural land, agricultural expansion would increase the green water resource.

176 Low flow conditions are defined as Q90, the discharge that is exceeded for 90% of the time. Available discharge has been corrected for withdrawals for all other human uses.

177 FAO 2011b

2.3. Climate change and the nexus

Energy and food production and provisioning are major drivers of climate change. Electricity and heat production alone contribute 27% of global greenhouse gas emissions, agriculture contributes 15%, and land use change and forestry 14%.[178] Agriculture and water are at the same time among the most climate-vulnerable sectors,[179] subject to impacts such as further drying of already water-scarce regions, loss of glacier water storage, the effects of more (severe) extreme events, and region-specific changes in crop productivity. Food and electricity production are particularly vulnerable to drought as illustrated by the current food crisis in the Horn of Africa and the shut-down of nuclear reactors in France in 2003, or various incidences of reduced hydropower production in response to drought. Other ecosystem services are also threatened by more intense droughts as illustrated by reduced carbon storage associated with recent droughts in Amazonia.

Climate policies themselves may also feed back on water, energy and food security. Climate change mitigation via carbon sequestration, expansion of biofuels, or hydropower can create significant new water demands. For example, forests – such as those used for biofuel production or carbon sequestration – consume more water than most other vegetation.[180] The additional amount of water required for sequestering 3 Gt of carbon per year (half of it in soils through improved agricultural management and half through additional forest vegetation) has been estimated to be about 2300 km^3 per year.[181] Climate change adaptation on the other hand can be very energy intensive: irrigation requires more energy than rainfed agriculture, desalination more than conventional water supplies, and increased groundwater use and water storage may require additional pumping. Opportunities for less water intensive storage and less energy intensive irrigation through improved rainfed agriculture and green water and soil management have not been fully realized.[182] Hence climate policies also need to take an integrated perspective across the nexus to avoid maladaptation and negative externalities.

Furthermore, climate policies also have to address equity issues arising from the fact that most of the historical greenhouse gas emissions originate from the industrialized countries, while developing countries are projected to be hit hardest by climate change impacts.

Given that crisis often leads to change, the increasing climate pressure could provide new opportunities for overcoming inertia and lock-in, and facilitate integration of climate protection, ecosystem approaches and sustainable development goals within a Green Economy.[183]

2.4. International and geopolitical aspects of the nexus

Water, energy and food security have become global issues that are no longer contained within national or river-basin boundaries. As the human population grows, economies develop and globalization accelerates, the interdependence of countries and regions becomes more and more evident. This can lead to either more resource competition and potential conflict, or increased collaboration and co-management.

Many river basins are transboundary, with upstream water and land uses affecting downstream water, energy and food availability. The Syr Darya river provides an example of a temporal mismatch between upstream and downstream water demands: upstream Kyrgyzstan releases water for hydropower production primarily in winter for heating, while downstream Uzbekistan needs water in summer for irrigation.[184] Like in other transboundary river basins there is a lack of strong regional institutions for integrated management and governance across the nexus.

178 WRI
179 IPCC 2007
180 Calder 2005
181 Rockström et al. submitted
182 IWMI 2009
183 Smith et al. 2009
184 Cai et al. 2003

Case study 7: Biofuel and hydropower development in the Blue Nile basin can support regional collaboration

Ethiopia, the 'water tower' of the Nile[185] meets its energy demands almost completely from traditional non-sustainable biomass use (e.g. firewood and charcoal), a situation which has led to an almost complete deforestation – only 3% of its natural forest remains. Ethiopia has enormous hydropower potential, of which it currently uses less than 5%. Only 17% of the population has access to electricity.[186] Water and land resources are becoming severely strained in those few places where hydropower and also irrigation schemes for biofuels (in particular sugarcane) and other plantations (e.g. of flowers for export) have been developed more intensively, such as the Awash basin around the capital Addis Ababa.[187] This points to the fact that, while still minimal at the global scale[188], locally the effects of biofuels on water availability may soon be significant. Given that Ethiopia is the world's largest recipient of food aid[189] and is frequently threatened by droughts and famines, food security impacts of biofuel plantations could become a serious concern unless these plantations are integrated with overall land and water resources planning and provide income and livelihood opportunities for the poor.

Ethiopia's position as upstream riparian in the Nile basin makes new intensive water and land development – in particular reservoirs for hydropower and irrigation schemes – possibly contentious in terms of downstream water availability: the Grand Renaissance Dam is projected to become one of the largest dams in Africa (projected to triple current hydropower capacity of Ethiopia) and the Tana-Beles Corridor will host large-scale biofuel plantations – in 2010 alone USD 187 million have been invested to develop over 200,000 ha of biofuel plantations.[190] Egypt in particular has for a long time opposed any upstream development that could compromise river flows.

Local negative effects of biofuel expansion on food security can in principle be mitigated through improvements in agricultural yields through R&D, higher inputs (e.g. of fertilizer and water, mainly for irrigation), and integrated approaches such as conservation agriculture. Investment in human capital can ensure that biofuels development is inclusive and supports economic development.[191] While biofuel projects to date have largely focused on the production of liquid transport fuels, additional local benefits could be realized if there were also projects on cleaner cooking fuels (e.g. ethanol gels).

In a transboundary context, biofuel and hydropower development provide opportunities for collaboration and regional integration through equitable sharing of benefits associated with water and energy. Reservoirs in Ethiopia can generate additional benefits ('increasing the pie') through reduced siltation of downstream reservoirs and their lower evaporative losses compared to water storage in reservoirs in more arid and hotter climates further downstream. Ethiopia can also substantially increase the productivity of its large green water resource for rainfed biomass production through improved technologies and land use planning, without negatively affecting blue (river) water availability.

Most recently, partly in response to the political transition in Egypt, there are reports of new discussions between Sudan, Egypt and Ethiopia possibly initiating a new level of trilateral consultations about new multipurpose in-

185 Ethiopia provides about 85% of the total Nile discharge

186 McCornick et al. 2008

187 Bazilian et al. 2011

188 De Fraiture et al. 2008

189 World Bank Ethiopia Country Brief

190 Ethiopian Herald Dec 29 2010

191 BEFS: Bioenergy and Food Security Project of FAO

frastructure.[192] Egypt is becoming a significant investor in land in Ethiopia and hence is actively involved in upstream water development in the Nile basin.

The Nile Basin Initiative (NBI)[193] serves as a (transitional) institutional framework for managing transboundary trade-offs and opportunities, such as sharing hydropower benefits, stronger integration in agriculture markets and exploiting opportunities for regional trade. The NBI is also exploring the possibility of treating ecosystem services as regional public goods. These alignments of sector-development policies with regional markets and cooperation are good examples of a nexus approach to better manage and govern limited resources.

Trade in agricultural and other commodities helps to mitigate local scarcities. By 2050 about half of the world population, mostly living in poor water scarce countries, may have to rely to some extent on food imports,[194] unless productivity increases and/or cropland expansion can keep up with increasing demand. Trade can also increase overall resource use efficiency if trade flows follow productivity gradients, i.e. from high-productive to low-productive regions. However gradients of resource productivity may not have the same direction for different production factors (water, energy, land) and furthermore, subsidies often direct trade against productivity gradients. Trade also creates dependency: importing countries depend on international markets which in turn rely on a small number of source regions and countries, in particular North and South America and Australia for agricultural commodities. Food exports may shrink, for example from the US, where groundwater resources in the Midwest are over-exploited and a significant proportion of food production has recently been abandoned in favour of biofuel production (35% of the US corn crop is for biofuel).[195] Exports from Australia may increasingly suffer from its high climate variability and projected drying from climate change. More biofuel production also more tightly couples volatilities in food and energy prices in global markets.

A further increase in foreign direct investment (FDI) has been triggered by the recent food price crisis and export restrictions of several countries. FDI can appropriate or expropriate water and land resources in countries which experience acute food crises and receive food aid, such as Ethiopia or Sudan.

Energy security itself is often framed as a geopolitical issue in terms of supply dependence, such as the reliance of the EU on natural gas from Russia, or global dependence on oil from unstable political regions. Water scarcity can turn into national and geopolitical security threats (e.g. in Yemen), but joint water agreements can also foster broader trans-boundary collaboration.For exampleregional power sector integration and grid extensions can increase economic integration and trade, as well as mutual trust and understanding.

Beyond spatial externalities from globalization, the water, energy and food security nexus also extends into the future, in terms of GHG emissions, climate change, land degradation and biodiversity loss.These temporal externalities are not sufficiently taken into account in policy-making, largely due to the mismatch of timescales of policy-making and global change.

2.5. Knowledge gaps in the nexus

- More data are needed on sustainably available water resources, in particular on safe aquifer yields and for so-called 'economically water scarce' regions, such as sub-Saharan Africa.

- There is insufficient knowledge on the impacts of hydropower and other water resources development on aquatic ecosystems.

192 Granit et al. 2010

193 The Nile Basin Initiative (NBI) is a partnership among the Nile riparian states that seeks to develop the river in a cooperative manner, share socioeconomic benefits, and promote regional peace and security.

194 Rockström et al. 2012

195 USDA 2011

The relationships between river flows, the state of aquatic ecosystems and their services are not well established.

- There are scarce data on consumptive water use in the energy sector, compared to withdrawal data. Existing data are scattered and not consistently traced throughout the full lifecycle ('from the well to the wheel').

- Full life-cycle assessments in terms of water and energy use are generally insufficient and do not address the full nexus.

- Water productivity in agriculture is mostly calculated per kilogram of product, sometimes also per kilocalorie, but rarely takes into account the nutritional content of food products, which is also important for food security (see box 3).

- Energy productivity in agriculture requires further research. For example, there is conflicting evidence about the positive or negative energy balance of different biofuels.

- Uniformly applicable 'water footprint' frameworks do not yet exist that would allow comparison of water use efficiency for different forms of energy or food production. Such water footprint frameworks would have to consistently integrate water productivity with water scarcity and opportunity costs in any particular location.

- There is a lack of consistent and agreed upon water quality standards for different crops and production systems, which would standardize and promote wastewater reuse and hence increase water use efficiency.

- It is not clear how policy frameworks, such as the EU Common Agricultural Policy, affect water and energy use and resource use efficiency in food production, both in Europe and beyond. From a nexus perspective relevant frameworks may need to be revised

- Impacts of increasing energy scarcity on water and food security are not clear.

- There is no harmonized 'nexus database' or analytical framework that could be used for monitoring or trade-off analyses. Hence the effects of increasing energy or water scarcity on food and water or energy security, as well as potential synergies between land, water and energy management, are not well understood. Questions include to what extent can higher availability of one resource sustainably reduce scarcity of another, and how might this work at different spatial scales?

- There is no blueprint for overcoming institutional disconnect and power imbalances between sectors, e.g. blue and green water generally falling under different ministries, or energy often having a stronger voice than water or environment – indicating that the nexus may not be traded-off equally.

- Much like in the case of IWRM, it is not clear how to deal with the increasing level of complexity that comes with higher levels of integration. Implementation of such broader concepts is not straightforward and tensions arise when integrating across sectors, institutions, levels and scales.[196] For example, IWRM is still not sufficiently integrated with sustainable economic development.[197] These challenges may be aggravated by inertia, lock-in to existing paradigms and preference for linear thinking.[198]

196 Horlemann et al 2011
197 GWP 2009
198 Pahl Wostl

3. OPPORTUNITIES FOR IMPROVING WATER, ENERGY AND FOOD SECURITY THROUGH A NEXUS APPROACH

This paper synthesizes experience with the nexus, with evidence from selected case studies. These case studies illustrate challenges and opportunities for managing and governing the nexus. They are context specific, for example in terms of climate, production systems, social capital and governance cultures. Hence they are not immediately transferrable or scalable. There are no blueprint solutions or panaceas.[199] Nevertheless a number of recurring areas of opportunity for sustainably improving water, energy and food security emerged when compiling this paper. These include:

- Increasing resource productivity
- Using waste as a resource in multi-use systems
- Stimulating development through economic incentives.
- Governance, institutions and policy coherence
- Benefiting from productive ecosystems
- Integrated poverty alleviation and green growth
- Capacity building and awareness raising

These key opportunities are expanded on in the following sections. (Note that these are not formulated as policy recommendations. A separate conference paper elaborates on a set of policy recommendations for strengthening the nexus approach.)

3.1. Increasing resource productivity

Basic premises of a Green Economy are sustainable and inclusive intensification and decoupling of resource use and environmental degradation from development (e.g. measured as GDP or HDI). Both can be achieved through technological innovation, recycling and reducing wastage. Technological innovation (with context-specific applications depending on the respective development level) include:

- Rainwater harvesting (which is more of a rediscovery than an innovation)
- Desalination based on renewable energy
- Photovoltaic water pumps
- Second or third generation biofuels, e.g. based on lignocellulosic feedstocks or algae
- Genetic engineering/breeding, e.g. for drought resistant crops, and
- Aerobic direct seeding of rice to reduce water (and energy) demand.

There are large opportunities to increase overall resource use efficiency along the food production-consumption chain. These include closing of yield gaps in the field,[200] and reduction of losses (about 40% of food grown is never used) from storage, transportation and processing (in particular in developing countries) and wastage in consumption (in particular in developed countries).[201]

3.2. Using waste as a resource in multi-use systems

Cross-sectoral management can minimize trade-offs, build synergies and increase resource use efficiency. In particular in multi-use systems, wastes, residues and by-products can be turned into a resource for other products and services and co-benefits can be produced. Productive sanitation in com-

199 Meinzen-Dick 2007

200 Kijne et al. 2009

201 Lundqvist 2008

bination with wastewater reuse is an example of recycling and closing loops of water, nutrients and other resources. Other examples include multifunctional and green agriculture,[202] natural or constructed wetlands, agro-forestry, crop-livestock systems, land rehabilitation with biofuel crops such as jatropha,[203] and wastewater-energy integration. Reusing waste products instead of discharging them into the environment can also reduce clean-up costs.

3.3. Stimulating development through economic incentives

While some innovations may occur 'spontaneously' (in particular in response to increasing scarcities and higher prices),[204] improvements in resource productivity and resource use efficiency generally require investment (e.g. in research and development) and reductions in economic distortions and perverse subsidies. Economic instruments for stimulating investment include pricing of resources and ecosystem services (including externalities), water markets and tradeable rights, as well as payments for ecosystem services. The nexus approach can also help to avoid sunk costs, i.e. investments into long-term infrastructure that lock development into non-sustainable pathways. The private sector, sometimes termed 'the propeller of the Green Economy', can act as a driver of change. Economic and legal incentives and instruments can also spur such improvements.

Case study 8: Payments for ecosystem services: Green Water Credits in Kenya's Tana River

Payments for ecosystem services (PES) typify the Green Economy and the nexus approach. The goal of PES is to provide enabling conditions for more sustainable resource use and pro-poor benefits, while maintaining or restoring natural capital. At the global scale, REDD+ is one such payment mechanism, which promotes enhanced carbon sequestration through better land management. At the basin scale, various PES schemes have been established around the world, to support improved land and water management in upstream catchments to boost water yields, improve water quality and reduce erosion and sedimentation. One such scheme is Green Water Credits[205], a financial mechanism that offers incentives for farmers upstream in Kenya's Tana River to improve land and water management. Various soil and water conservation measures in the headwaters of the Tana River have been assessed to determine their potential to sustainably increase local productivity and water availability and, at the same time, to reduce siltation of downstream reservoirs. These reservoirs are especially important because Nairobi's water supply, most of Kenya's electricity supply, and several large irrigation schemes depend on them. A number of powerful economic actors, such as water and power companies and export producers, have come forward to support this ecosystem approach as an alternative to a conventional end-of-pipe solution, which in this case would be to build another reservoir once the old one has silted up. The Green Water Credits scheme in Kenya has brought on board Kenya's Water Resources Management Authority as the coordinating institution, as well as a local bank to handle the financial transactions.

3.4. Governance, institutions and policy coherence

Given that social and environmental values are not always well served by markets, regulation and collective action promoted by social learning can help to guide investments and innovation, so that negative externalities across sectors are minimized, ben-

202 IAASTD 2009
203 Garg et al. 2011
204 Moraes et al. 2011
205 www.greenwatercredits.info

efits are equitably shared and human rights are secured. Learning platforms for social innovation and adaptive management can enable horizontal and vertical policy coherence. Additional enabling conditions for a nexus approach include political will, change agents, capacity building and awareness raising.

There are large opportunities to be realized if the nexus is addressed coherently across all scales, through multi-level governance with differentiated (but clearly defined) responsibilities of institutions. At the local scale, trends for more participation and decentralization co-develop with new guidelines and codes of conduct.[206]

Case study 9: The water-carbon nexus in Australia: flexible and adaptive legislation[207]

This case study from Australia highlights the following enabling conditions for managing trade-offs:

- Rigorous processes to transparently and explicitly evaluate costs and benefits
- Frequent review of the efficacy of measures to allow appropriate adjustment (possibly also differentiated for different regions and contexts), and promoting adaptive management in the light of new knowledge
- Nexus institutions independent of line ministries, such as Australia's National Water Commission

Australia's 2004 National Water Initiative included a policy commitment to control so-called 'inflow interception activities' (e.g. afforestation) within water-use caps, so that new water users would be required to buy water entitlements in the market.[208] In 2011 the Australian Parliament adopted a Carbon Credits (Carbon Farming Initiative) Act that will enable land owners to earn and sell carbon credits for land management practices designated as approved methodologies that sequester carbon, such as tree planting and producing biochar.[209] That Carbon Credits Act, like the Clean Development Mechanism (CDM) procedure, does not rigorously regulate non-carbon impacts and risks perverse outcomes.[210] While tree planting in Australia is regarded as unequivocally good (in particular, well-planned restoration of indigenous tree cover can contribute to biodiversity conservation, salinity control and in some cases may increase crop and livestock yields) there are also possible negative externalities. Besides alienating prime agricultural land and diminishing biodiversity, some carbon farming practices may also increase evapotranspiration which, together with over-abstraction (e.g. for irrigation), could exacerbate water scarcity.[211] For example, in the Macquarie River catchment in central New South Wales it has been calculated that replanting 10% of the watershed with trees could reduce river flows by 17%, which would lead to further contraction of major wetland ecosystems like the Macquarie Marshes.[212] This could have knock-on effects for carbon storage if wetlands dry out. Given today's enormous demands for water, a restoration of natural vegetation and the associated 'natural' hydrology is no longer an option.

So a nexus approach needs to explicitly address and manage the costs, benefits and trade-offs between the goals of carbon sequestration and increased water availability. One way to do so could be through context specific

206 Von Braun 2009, FAO 2010, FAO 2011

207 Jamie Pittock's contribution to this case study is gratefully acknowledged

208 Commonwealth of Australia et al.., 2004

209 Parliament of Australia, 2011

210 Pittock 2010

211 CSIRO 2008, Cai et al. 2008, Pittock et al. 2011, van Dijk et al. 2007

212 Herron et al. 2002

application of the existing legislation: because water consumption by plantations varies across Australia[213] (e.g. in some semi-arid regions the lack of streams means that impacts would be negligible, or even positive in reducing salinity), landscape zoning could allow tree planting in some areas, while in other areas restrictions would apply.

The Carbon Credits (Carbon Farming Initiative) Act also allows ad-hoc regulation for reducing perverse impacts, including on water availability. Proposed regulations under the Act seek to manage the risk to water availability in a number of ways.[214] Credits would be refused for plantings in high run-off zones with more than 600 mm per annum average long-term precipitation (with a number of exceptions). However, this may discriminate against reforestation in high rainfall zones where the primary problem is water quality, not scarcity, as in Australia's wet tropics. It should be noted that this optional regulatory process for managing perverse impacts contrasts with a systemic and public review for each proposed carbon farming methodology and falls short of a strategic environmental assessment. A positive measure in the Act is a requirement that the carbon farming scheme be reviewed by December 2014, and reviewed at least every three years thereafter, which may enable perverse impacts to be periodically identified and managed.[215]

At the global scale, trade and FDI (largely driven by the private sector) can be directed towards better serving human security goals. Macro-economic and trade policies and improved global governance can better take into account impacts on local resources and global public goods, such as an intact environment, stable climate and stable water supplies.

While some new institutions may be required for alignment across sectors, such as inter-ministerial bodies or inter-agency programs,[216] it is more important to strengthen existing institutions so they can build new links across sectors and deal with the additional uncertainty, complexity and inertia when integrating a range of sectors and stakeholders. Strengthened institutions will also be able to better cope with the risks of marginalization and new disparities that are inherent to integrated approaches and collective action.[217]

3.5. Benefiting from productive ecosystems

Maintaining and restoring ecosystems will have to play a more prominent role when charting sustainable pathways. Improved management and investment in (restoration of) natural capital[218] can provide multiple services and increase overall benefits. Natural infrastructure and soft path solutions[219] need to complement human-made 'hard' infrastructure and end-of-pipe solutions, as they can deliver some services more efficiently (e.g. improved water quality). These additional benefits could also be derived if the surge of foreign direct investment in developing countries into agriculture and infrastructure, and the re-engagement by donors into agriculture, could to some extent be directed towards natural capital. Green and conservation agriculture ('agro-ecosystems') can provide additional benefits such as carbon sequestration and resilience to climate risks e.g. through improved moisture retention,[220] while generating additional jobs (reducing migration to cities), and improving food security.[221]

213 Polglase et al. 2011
214 DCCEE 2011
215 Parliament of Australia 2011
216 OECD 2011
217 Swallow et al. 2006
218 see WAVES (Wealth Accounting and Valuation of Ecosystem Services) partnership and also TEEB 2010
219 Gleick 2003
220 SOLAW 2011
221 UNEP 2011b

Well managed (agro-)ecosystems can integrate long-term, macro-economic objectives of improved resource use efficiency and environmental stewardship with immediate and local goals, such as better access to basic services, the human rights to water and food and secure livelihoods.

3.6. Integrated poverty alleviation and green growth

The nexus approach supports more sustainable (green) growth through smarter use of resources and through integrated agricultural and ecosystem (i.e. landscape) management. With that it strengthens a wide range of ecosystem services and maintains a healthy environment – the human 'life support system – on which the poorest depend most strongly. The provisioning of clean water and energy improves the health and productivity of the 'bottom billion'. Green agriculture can generate more rural jobs.

3.7. Capacity building and awareness raising

Capacity building and social learning – in which development partners can play a role – can help to deal with the increasing complexity of cross-sectoral approaches, and it can help to level the playing field among the nexus sectors.

Crises (such as climate change) sometimes provide opportunities in this respect, also because they integrate different actors and institutions horizontally and vertically behind a common goal.

New nexus indicators/metrics which address sustainable resource use, human well-being and equity as well as integrated assessments of water, energy and food sectors, are required for future quantitative trade-off analyses. System thinking, robust analytical tools, including life cycle analysis, and consistent data sets across the water, energy and food sectors are essential for building synergies, avoiding tensions, and to monitor and inform policies and regulations across the nexus.[222] One of the first studies of trade-offs across the nexus was an analysis of sugar versus biofuel production in Mauritius (see case study). Another early nexus analysis addressed the Zambezi River basin. It assessed the potential for co-developing hydropower production, new irrigation schemes and other water-dependent sectors, while maintaining wetlands and their ecosystem services in a river basin and regional (SADC) context.[223]

Case study 10: Sugar versus biofuel in Mauritius: a science-based integrated trade-off analysis

Analysis[224] shows that Mauritius can improve its economic water use efficiency by shifting from sugar production to bio-ethanol production. It can also reduce gasoline imports and overall GHG emissions by using the ethanol as transport fuel on the island. When shifting from first generation to second generation biofuels emission reductions would be lower, because of a lack of bagasse which can be used for additional electricity generation (requiring higher imports of fossil fuels instead). To maintain water and food security under projected drier conditions (resulting from climate change) more energy would be required for irrigation and desalination, to the extent that it may cancel out the GHG emission reductions that would result from shifting to bio-ethanol.[225]

Awareness raising (and supporting governance) can promote more sustainable lifestyles, consumption patterns and diets and "sufficieny"[226]. Healthier diets (e.g. less meat, fat and sugar) can at the same time also improve environmental health and reduce resource exploitation. Food companies are becoming interested in raising awareness about

222 Bazilian et al. 2011

223 World Bank 2010

224 Using SEI's WEAP (Water Evaluation and Planning) and LEAP (Long range Energy Alternative Planning) tools

225 Hermann et al.

226 Von Weizsäcker 2009

the water footprints of their products, however the footprint concept is not yet sufficiently advanced (in terms of local impacts of water use) to be useful in that respect.

Afterword

The nexus and its challenges and opportunities have not been consistently and comprehensively addressed before. This document provides a first overview of the nexus, with such detail as is currently available. However, it should be recognized that a lot more work will be needed to develop a solid data and knowledge base upon which to build a Green Economy.

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