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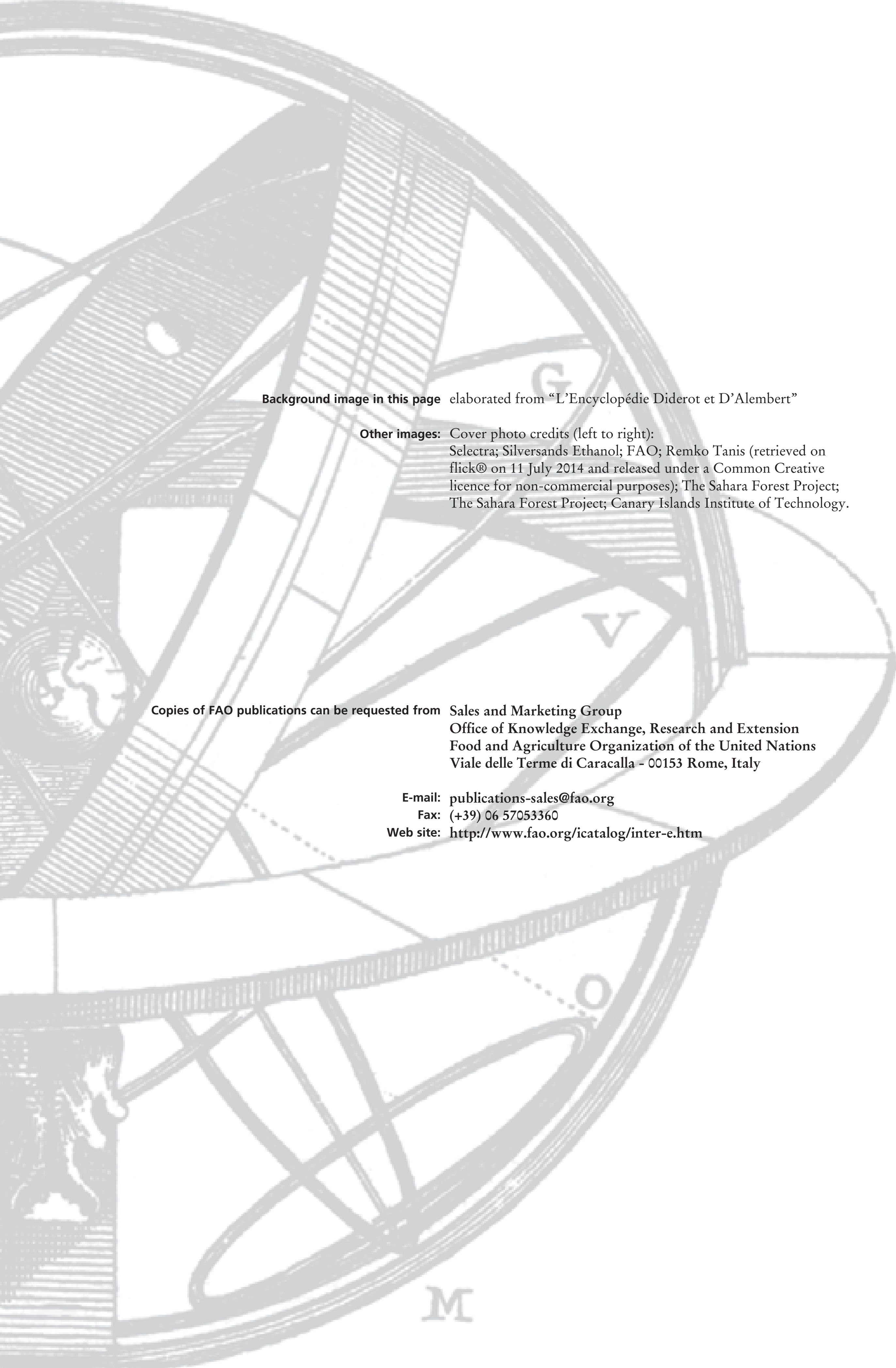
Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus

in the Context of the Sustainable Energy for All Initiative

ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [ENERGY] MONITORING AND ASSESSMENT



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Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus

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EXECUTIVE SUMMARY

This report proposes a way to carry out a water-energy-food nexus assessment approach in order to: a) understand the interactions between water, energy and food systems in a given context, and b) evaluate the performance of a technical or policy intervention in this given context. The ultimate goal of the Water-Energy-Food (WEF) nexus assessment is to inform nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions.

Part a) of the assessment focuses on the context analysis, providing information on the nexus context status:

- The current state and pressures on natural and human resources systems;
- Expected demands, trends and drivers on resources systems;
- Interactions between water, energy and food systems;
- Different sectoral goals, policies and strategies in regard to water, energy and food; this includes an analysis of the degree of coordination and coherence of policies, as well as the extent of regulation of uses;
- Planned investments, acquisitions, reforms and large-scale infrastructure;
- Key stakeholders, decision-makers and user groups.

Following the context analysis, a number of problem-specific tools are suggested for a more in- depth, quantitative analysis of the impacts of different resource uses and for the development of scenarios and strategic visions.

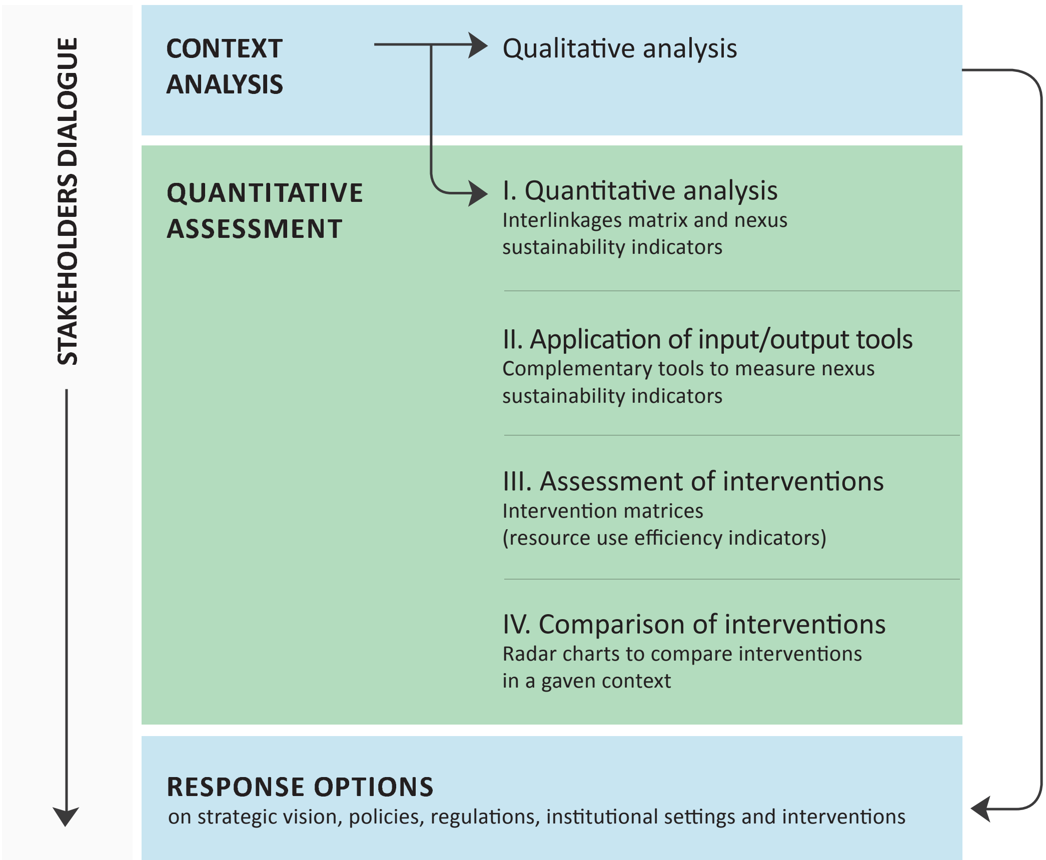
Part b) of the assessment looks specifically at the performance of technical and policy interventions in terms of resource use efficiency and productivity. Importantly, the performance of interventions should be also assessed versus the nexus context status. A set of basic indicators is proposed, out of which the final selection should take place in consultation with stakeholders. It is also possible to compare different interventions, based on how efficiently they make use of water, energy, food/ land, employment and financial capital.

Key stakeholders should be actively engaged in the assessment process to build consensus on strategic issues across sectors and scales and to decide on how to respond to these issues.

The different elements of the nexus assessment are illustrated in the following figure.

Figure E.1

The components of the *nexus assessment 1.0*



The proposed WEF nexus assessment approach helps "walking the talk" regarding nexus promotion. It is innovative in many ways:

- it provides a stepwise process to address policy-making and intervention in a nexus manner;
- the indicators it proposes have been selected on the basis of available international datasets in case one wishes to carry out a nexus rapid appraisal, as the second best option to generating context specific information;
- it combines quantitative and qualitative assessment methods;
- last but not least, it considers it is essential to link intervention assessment to context status as a key condition to assess the sustainability and appropriateness of interventions. The approach shows how to do this in practice.

Given its innovative character, the proposed nexus assessment approach should be considered work in progress, to be improved as lessons from its implementation will be drawn.

CHAPTER 1

INTRODUCTION

Due to global transformational trends, such as population growth, economic development and climate change, energy, water, land and human resources are increasingly under pressure to support societal development and to maintain necessary services. Decision-makers need improved tools in order to be better informed about trade-offs and synergies between different development and management choices, and to help them identify options on how to sustainably manage resources.

This report proposes a way to carry out a water-energy-food nexus assessment that can be used by stakeholders concerned with the development and management of resources, and in line with the global sustainability agenda. The *WEF nexus assessment* can be used to assess the nexus interlinkages at any scale, although data are usually available at country level. It can highlight synergies between sector interventions, so-called 'win-win' solutions, helping stakeholders to develop insights into different options, which might not be apparent at first glance. The objectives of such an assessment are to:

1. provide an overview of the current nexus status of the context in terms of natural resources and their uses to sustain society, through the identification and quantification of key nexus interlinkages;

2. apply specific tools to derive this information that is not readily available (for which indicators are not already available);

3. review and suggest how specific Nexus interventions can be assessed and compare the performance of specific interventions on the basis of the context status against WEF sustainability goals; and

4. interpret the results of the nexus assessment, contextualize possible interventions and appropriate response options.

The ultimate goal of the WEF nexus assessment is to inform nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions.

Adequate stakeholder engagement at all stages of the nexus assessment is a key condition to ensure high quality assessment and response. The report focuses on the different elements that compose the Nexus Assessment 1.0, as a stepwise approach to define nexus issues and assess the impacts of different intervention options. It is worth pointing out that this approach breaks new ground in that it proposes building blocks to carry out the nexus context analysis, nexus performance of interventions, and a combination of both types of assessments. Therefore, it should be considered as work in progress to be revised based on lessons drawn from its use.

This work was undertaken in the context of the Sustainable Energy for All initiative (SE4All), a UN action-focused global network, supported by partner organizations from governments, national and international organizations, businesses and civil society organizations. FAO is a lead organization in charge of advancing the High-Impact Opportunity (HIO) on the Water-Energy-Food Nexus (together with Germany). HIOs are categories of action that have been identified as having significant potential to advance the three objectives of SE4All:

- Ensure universal access to modern energy services.
- Double the global rate of improvement in energy efficiency.
- Double the share of renewable energy in the global energy mix.

More information is available online at www.se4all.org/.

The document is divided into six chapters. Chapters 2 and 3 highlight what the water-energy-food nexus is and why it is important, and outline the nexus concept, as a link between different societal interests and targets with the natural and human resources they rely upon. These linkages can change because of drivers external to the water, energy and food sectors and many of those drivers are outside human control (or are simply considered external factors). Chapter 4 presents the nexus assessment, as a stepwise approach to quantify nexus issues and assess the impacts of different intervention options. Chapter 5 presents a number of typical nexus-related interventions, highlighting for each their performance in terms of resource use efficiency and suggesting a set of indicators specific for each type of intervention. Finally, chapter 6 summarizes the lessons learned and suggests possible ways forward.

CHAPTER 2

WHAT IS THE WATER-ENERGY-FOOD NEXUS?

Water, energy and food are essential for human well-being, poverty reduction and sustainable development. Global projections indicate that demand for freshwater, energy and food will increase significantly over the next decades due to population growth, economic development, urbanisation, growing demand for food and diversified diets, climate change, resource degradation and scarcity (Hoff 2011). Already agriculture accounts for 70 percent of total global freshwater withdrawals, making it the largest user of water. Water is used for agricultural production and along the entire agro-food supply chain, and it is used to produce, transport and use all forms of energy (FAO 2011a). At the same time, the food production and supply chain consumes about 30 percent of total global energy (FAO 2011b). Energy is required to produce, transport and distribute food as well as to extract, pump, lift, collect, transport and treat water.

This situation is expected to be exacerbated in the near future as 60 percent more food will be required to be produced by 2050 in order to meet the demand of more nutritious and better quality food. Global energy consumption is projected to grow by close to 50 percent by 2035 and 80 percent by 2050 (IEA 2010). Total global water withdrawals are projected to increase by 50 percent by 2025 in developing countries, and 18 percent in developed countries.

The basis of the Water-Energy-Food Nexus is an attempt to balance different uses of ecosystem resources (energy, water, land, soil and socio-economic factors). There are clear interactions between water, food and energy that may result in synergies or trade-offs between different sectors or interest groups. For example, an estimated 30 to 50 percent of the food produced globally goes to waste and this translates to wasting 1.47-1.96 Gha of arable land, 0.75-1.25 trillion m^3 of water and 1 to 1.5 percent of global energy (Aulakh and Regmi 2014). The incentives for a nexus approach include "economic efficiency, resource efficiency and improved livelihood options" (Bazilian et al 2011).

As demand grows, there is growing competition over natural resources between the water, energy, agriculture, fisheries, mining and other sectors. For instance, large-scale water infrastructure projects may have synergetic impacts, producing hydropower and providing water storage for irrigation, but this might happen at the expense of downstream ecosystems and food systems. Similarly, growing bioenergy crops in an irrigated agriculture scheme may improve energy supply, but it may also result in increased water withdrawals and in risks to food security. It is thus important to understand the synergies and trade-offs in order to develop response options to ensure the sustainability of the environment and people's livelihoods. By highlighting these interdependences, the Nexus concept corroborates the need to view water, energy and food not as being separate, but as being complex and inextricably entwined. This, in turn, allows for more integrated and cost-effective policy-making, planning, implementation, monitoring and evaluation related to the different Nexus sectors. At the same time, a nexus approach to policy-making helps to reflect the broad range of views and expertise involved throughout the process, promoting dialogue between different sectors, seeing solutions to open challenges as collective efforts.

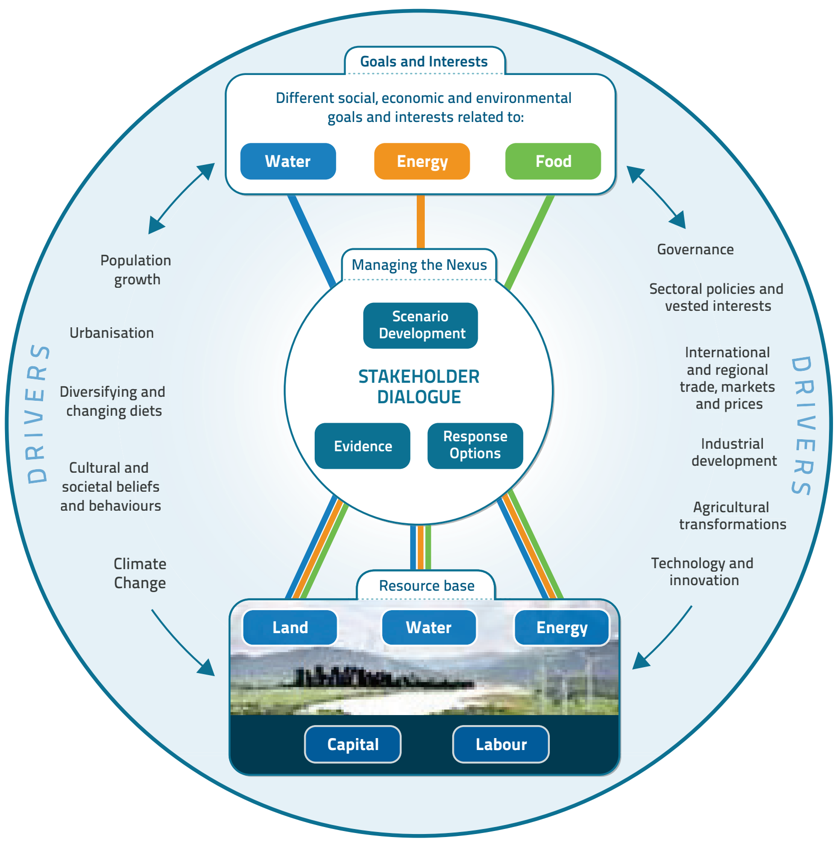
CHAPTER 3

CONCEPTUALIZING THE WATER-ENERGY-FOOD NEXUS

The FAO concept of Water-Energy-Food Nexus explicitly addresses interactions and feedback between human and natural systems. It focuses on the resource base, including both biophysical and socio-economic resources, on which we depend to achieve social, environmental and economic goals pertaining to water, energy and food. Interactions take place within the context of external global drivers, such as demographic change, urbanization, industrial development, agricultural modernization, international and regional trade, markets and prices, technological advancements, diversification of diets, and climate change as well as more site-specific internal drivers, like governance structures and processes, vested interests, cultural and societal beliefs and behaviours. Figure 1 illustrates the FAO Approach to the Water-Energy-Food Nexus.

Figure 1

The FAO Approach to the Water-Energy-Food Nexus: the management of the nexus helps determine national and local nexus-related goals and ways to achieve them vis-à-vis the resource base



BOX 1 – THE MAIN COMPONENTS OF *MANAGING THE NEXUS*

Evidence

Data are collected and analysed to discuss and identify the interlinkages of water, energy and food systems and the impact that any change in the system – for example, a policy decision, a large-scale investment or a change in agricultural practice – can have on the environment and livelihoods. This work needs to clarify the problem, the system of the analysis and identify critical interlinkages. It includes collecting data on both the status of the natural resources, as well as on social and economic aspects. This helps to better understand current constraints and to review key policy papers and processes, strategies and plans relevant to the Water-Energy-Food Nexus (e.g. national energy plan, IWRM strategy of main river basins, land rights, biomass development strategy) by the team carrying out the assessment.

The analysis can be done in a qualitative manner or in a more quantitative manner, which includes using the 'inter-linkage tables' (Tabs. 2-4) of the nexus assessment to guide the quantification of the sustainability status of a given context. The correct understanding of societal priorities and different and often competing local environmental, economic and social goals is important and is part of this component. The information is then used to assign weights to different indicators for the assessment.

Scenario Development

This includes highlighting the effects of possible interventions or new policies on the natural environment and the society. Specific interventions are identified and discussed (they can consist of technical interventions, including the deployment of new technologies or incentives) and they are assessed with the nexus assessment. The Scenario Development phase highlights impacts on the different economic, social and environmental goals that need to be accounted for when developing a shared vision for food security, sustainable water and sustainable energy, which may not be visible at first sight.

Response options

Different stakeholders engage in an open and participatory policy dialogue to build consensus among themselves on specific policy issues related to effects of interventions and choose among them. This component is normally based on the outcomes of the scenario development phase (including the nexus assessment) but can also be based on non-quantitative information and therefore immediately follow the 'Evidence' component.

This can be done at regional, national or local level and can involve key decision-makers and experts to discuss about replication, up-scaling or revision of the design and scope of the interventions. At the national level this exercise typically involves representatives from different sectors and Ministries, and with different backgrounds (technicians, politicians).

These four components do not necessarily need to be addressed in sequence; they are complementary and recursive.

The *nexus assessment* includes the *Evidence* and *Scenario Development* elements of Fig. 1. and it is the basis for “nexus” responses. These responses can apply to:

A) the planning and implementation of new policy measures (e.g. incentives and other financial instruments), institutional mechanisms, legislation, planning, and corrective measures at project level), and

B) monitoring and evaluation of the above.

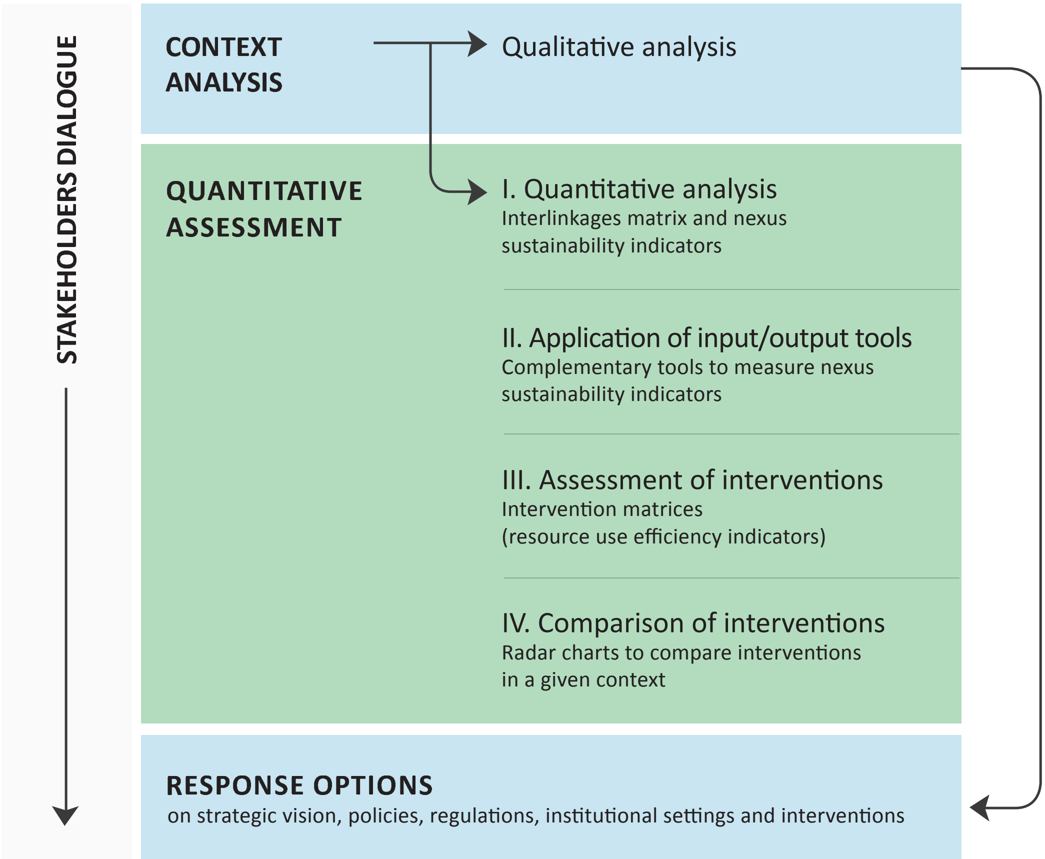
Response options can be developed at regional, national or local level. They can involve key decision-makers and experts to discuss about replication, up-scaling or revision of the design and scope of the interventions. At the national level, this exercise typically involves representatives from different sectors and Ministries, and with different backgrounds (technicians, politicians). This process lays the basis of a closer inter-ministerial policy dialogue.

Given FAO’s mandate to achieve food security, special emphasis is given to food and agriculture-related issues, and to energy, water and land as key natural resources to reduce hunger. These natural resources and the activities they support are essential for food production and along the value chain. Energy, water, and land resources play a central role in achieving food security and ensuring sustainable water and energy for all. Furthermore, agriculture (including fishery, aquaculture and forestry) is fundamental to maintain society and is both a driver and constraint for development. The way agricultural systems develop has important impacts on both natural systems and human systems, and the respective services they provide. Environmental services include climate, nutrient cycle, ocean and water, and environmental health, which are fundamental to sustain life. Socio-economic services include human nutrition, health, poverty reduction, employment and cultural views.

The sustainable management of agriculture to sustain the environment and livelihoods should also consider external drivers, adding further complexity to the picture.

Figure 2

The components of the *nexus assessment 1.0*



CHAPTER 4

NEXUS ASSESSMENT

4.1 The components of the nexus assessment

A nexus assessment involves a participatory process that helps policy-makers to understand critical situations, where resources (both human and natural) are under pressure, and which tipping points exist in terms of possible interventions (e.g. a new policy or a new plant). The proposed assessment approach can be used for:

- **Assessment of the context nexus status:** This can be achieved either in a qualitative manner – e.g. through experts' opinion or multi-stakeholder consultation. (*Response options* can already be derived from such a qualitative assessment), however, they are usually strengthened if they rely on a quantitative assessment. This helps understand societal priorities and different and often competing local environmental, economic and social goals. A set of tools can be used to quantify sustainability indicators.

- **Quantitative assessment:** This includes highlighting the effects of possible interventions or new policies on the natural environment and the society. Specific interventions are identified and discussed (they can consist of technical interventions, including the deployment of new technologies or incentives) and their nexus links are quantified at two levels: intervention and against the context status. The need to assess interventions against context status is innovative but it is proposed as an essential task to better analyse the appropriateness of different interventions according to the context where they are implemented. For instance, the same irrigation system will have the same "nexus performance" per se but its appropriateness will be very different in different contexts.

Figure 2 illustrates the different components of the nexus assessment to achieve the above mentioned objectives. These components can in theory be carried out independently from each other. However, as mentioned above, we contend that the nexus performance of interventions should always be carried out against the nexus status of the context where they are implemented.

The nexus assessment outlined is the first version of an assessment that can be refined over time, as new experience is gained and more useful indicators are identified with good coverage, and become freely available.
In this process it is possible to identify four main building blocks of the assessment:

I. Context quantitative **analysis** to determine the sustainability of the context (bio-economic pressure): Data are collected and analysed to identify and assess the interlinkages of water, energy and food systems. This work needs to clarify which environmental and social resources are under pressure, identify the critical interlinkages and competing interests, and therefore which criticalities may arise in the future. It includes collecting data on both the status of the ecosystem resource as well as socio-economic aspects, making use when possible of existing datasets, using meaningful nexus sustainability indicators. Information on pressure on nexus aspects (and its graphical visualization) can also be used for a purely qualitative participatory analysis.

II. Application of input/output tools to quantify impacts and draw scenarios: If data needed for key indicators are not available from existing datasets, they need to be found using available tools. This applies particularly when the reference system is different from the national level, for which much more data are usually available. This includes the development of possible scenarios, highlighting the effects of current trends (business as usual) or new policies on the natural environment and the society.

III. Assessment of (the performance of specific) **interventions**: Specific interventions are assessed in terms of their performance, which is how efficiently the environment and human resource bases are used. The efficiency of water, energy, land and human time use can vary before and after an intervention, as well as among different interventions.

IV. Comparison of interventions: Different stakeholders engage in an open and participatory policy dialogue to build consensus among themselves on specific policy issues related to effects of interventions. This can be done at regional, national or local level and can involve key decision-makers and experts to discuss about replication, upscaling or revision of the design and scope of the interventions. At the national level this exercise typically involves representatives from different sectors and Ministries, and with different backgrounds (technicians, politicians, etc.). This process lays the basis of a closer inter-ministerial policy dialogue.

4.2 Operational development goals to structure the components of the nexus assessment

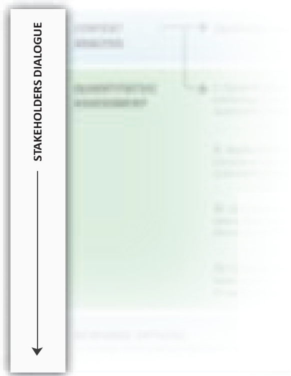
Whilst nexus-related goals should be defined at the appropriate level through the stakeholder engagement process, sustainability goals regarding water, energy and food are needed in order to build the nexus matrices that should be used in the nexus assessment matrices. Such sustainability aspects in the water, energy and food sectors are therefore used as a reference in the assessment component. They are combined so as to highlight interlinkages and define a reference sustainability operational framework. The operational sustainability aspects that are proposed are adapted from those internationally agreed upon regarding energy and food and, for water: Food Security objectives (FAO, 1996), Sustainable Energy for All objectives (UN, 2012) and those proposed by UN-Water (UN-Water 2014). Indeed societal goals cannot be achieved without taking into account the limits of the natural and human systems. The three sustainability aspects proposed[1] and their components used for the nexus assessment are listed hereafter:

- Sustainable Water
  - Access to water resources for different uses
  - Sustainable use and management of water resources
  - Resilient societies and ecosystems to water-related disasters

- Sustainable Energy
  - Access to modern energy services
  - Efficient use of energy
  - The energy produced and consumed is clean/renewable

- Food Security
  - Food Availability
  - Food Access
  - Food Utilization & Nutrition
  - Stability of Food Prices and Supply

4.3 Stakeholder dialogue



For an assessment to have any long-term impact, it should be carried out as part of a broader process of engaging and discussing with key stakeholders and experts.

Stakeholder dialogue is a continuous process that brings together the different working areas through a participatory process of engaging with all relevant stakeholders and experts. The dialogues have to be designed for a specific context – regional, national, local or basin level – and problem, e.g. to evaluate a national policy on water, energy and food systems, or to choose among specific possible project interventions.

1 The goals used, especially the water goals, are chosen just for the sake of the assessment work and are not based on any internationally agreed process.

Strong emphasis is placed on inviting stakeholders from a broad range of sectors and interest groups, including economy and finance, as well as from different levels of governance, like mayors of medium/large-sized cities, farmers' rights organizations, irrigation agencies, energy utilities, national government representatives, and the private sector (e.g. hydropower company, mining industry).
The overall objective of stakeholder dialogues is to build a shared understanding of:

- Current state of natural resources and ecosystems;
- Expected trends and drivers of resource uses and management;
- Goals and interests of different sectors/user groups in regard to water, energy and food;
- Key interactions of water, energy and food systems, including trade-offs and shares of different resource uses and ecosystem management;
- Opportunities for linking to ongoing decision-making processes.

BOX 2 - WHY DO WE NEED STAKEHOLDER DIALOGUE?

- To engage and bring together actors from different sectors and levels of governance.
- To develop a shared understanding of the national, regional, and international context in which future interventions will be embedded and to ensure that these interventions are aligned with national needs and priorities.
- To directly link ongoing and emerging decision-making process.

A stakeholder dialogue brings together different perspectives and enables stakeholders to jointly identify solutions for sustainable development. The proposed assessment of nexus interactions and interventions is usually greatly enhanced by a process of stakeholder dialogue and engagement. Ideally, the dialogue process helps to make explicit the different goals, interests and uses of stakeholders and offers a process to reconcile these differences. It helps to raise awareness of the interlinked nature of global resources systems and build common ground among the different stakeholders.

Stakeholder involvement is also needed to source relevant information at the needed aggregate level and scale.

An effective stakeholder engagement approach must first identify appropriate stakeholders or stakeholder representatives to include in the process. This will significantly shape the scope and reach of the assessment and will strongly depend on the expertise and contacts of national partners and advisors. Strong emphasis will be placed on inviting stakeholders from a broad range of sectors, including economy and finance, as well as from different levels of governance, like mayors of medium and large-sized cities, farmers' rights organizations, energy and water utilities, irrigation agencies, national government representatives, and the private sector (e.g. hydropower company, mining industry).

The extent to which stakeholders participate and engage in the process varies widely from mere exchange of information to shared decision-making and action. This is not to say that a high level of engagement is necessarily better for effective policy-making, yet it reflects a number of factors, including:

- The willingness of the stakeholder group to take part in the activities of the public sector;
- Their capacity to make a meaningful contribution;
- Political will and political freedom: The extent to which the institutional setting is conducive to their participation, including the provision of adequate information;
- The topic: Some topics will only allow for a limited participation by external stakeholders. Typically these include monetary and fiscal issues, which require technical rigour, and/or are associated with high risks;
- Time issue: Rather than having policies ratified through an often cumbersome exercise, it might be better to focus on implementation while incorporating adequate feedback mechanisms by the different stakeholders in monitoring and assessment of progress.

It should be clear from the beginning what is the objective and the expected level of participation. The process can then be designed as appropriate, differing in who and how many people participate and in time and financial requirements. One-way communication may be cheaper and faster in the short term, but two-way communication systems can deliver community support for the project, improve the identification and management of environmental and social risks and ensure that compensation mechanisms and community development programmes closely match community needs and aspirations.

The outcome of these dialogue processes strongly depends on how problems are defined and addressed, how stakeholder groups are organized and how the process is structured and carried out. Much work has been done in this regard, developing approaches, methods and tools to improve dialogue processes and communication.

Table 1

Overview of stakeholder participation techniques

TYPES/LEVEL OF PARTICIPATION	**EXAMPLES** OF PARTICIPATION TECHNIQUES	**TYPE OF IMPACT**	**INTENSITY** OF PARTICIPATION
Information: one way flow	From government to public: public information, press conferences From public to government: questionnaires, surveys, toll-free telephone 'hot lines'	Impact on stakeholders' level of information and knowledge but no influence on who decides	LOW
Consultation: two-way flow and exchange of views	Public hearings, government-led working groups, workshops, field trips		
Shared decision-making: Shared control over decisions	Joint committees, advisory councils, task forces	Impact before or on decision	
Shared decision and action	Negotiation, participatory budgeting, co-management of natural resources	Impact to the decision	HIGH

BOX 3 - REFERENCES ON STAKEHOLDER DIALOGUE

FAO has put together four learning modules to improve Capacity Development approaches in projects and programmes. Learning module 2 in particular focuses on engaging with local and national actors in assessing and developing capacities. The modules also offer a toolkit with examples, methods and instruments.

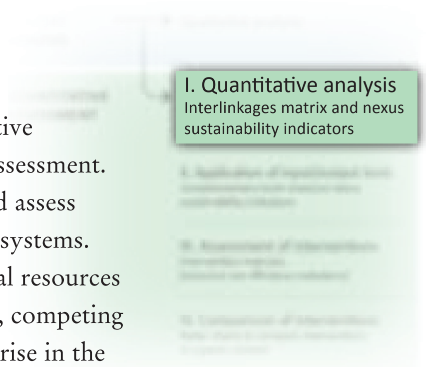
EasyPOL is a FAO platform, offering a broad range of resources useful at the various stages of policy processes on agricultural and rural development and food security. It includes issue papers, analytical tools, case studies, methodological guidelines and other conceptual and technical materials.

UNEP and Stakeholder Research Associates have published the Practitioner's Handbook on Stakeholder Engagement to outline good practices to stakeholder dialogue, with the broader aim of promoting the use of stakeholder engagement worldwide as a way of advancing sustainable development goals.

The Stakeholder Dialogues Manual has been developed by the Collective Leadership Institute in 2011 specifically for the Private Sector Cooperation and Corporate Social Responsibility (CSR) programme of the Gesellschaft für Internationale Zusammenarbeit (GIZ). It serves as a practical how-to guide to approaching cross-sector collaboration and stakeholder engagement with the private sector.

The Participatory Methods website of the Institute for Development Studies (IDS) provides numerous tools and methods for inclusive social development. It explains what participatory methods are, where and how they have been used, their problems and potentials and the debates about them. The focus is on participatory approaches to strategic analysis and programme design, monitoring and evaluation. It also includes resources on participatory learning, research and communication in organizations, networks and communities.

4.4 Quantitative context analysis



Whilst this activity can be carried out in a qualitative manner, in this section we focus on quantitative assessment. Data are collected and are analysed to identify and assess the interlinkages between water, energy and food systems. This work clarifies which environmental and social resources are under pressure, identifies critical interlinkages, competing interests and therefore which 'nexus' issues may arise in the future. It includes collecting data on both the status of the ecosystem resource as well as socio-economic aspects, making use when possible of existing datasets.

We propose interlinkages matrices as a tool to identify clear nexus synergies and trade-offs in terms of the sustainability of the ecosystem and human system at different scales. Tables 2 to 4 highlight some synergies (in blue) and trade-offs (in brown) between sustainable energy, water and food security. For some linkages no clear trend can be identified, meaning that trade-off relations are weak or are valid only for exceptional intervention types.

The application of the nexus linkage matrices provides a framework to better understand relevant interlinkages both for the assessment team and local experts. The input of key stakeholders is required at this initial stage to identify:

- Current and expected trends in resource uses and management by different sectors and user groups with reference to key drivers underlying these trends;
- Social, economic and environmental development goals of different sectors and user groups;
- Key nexus interlinkages, including trade-offs and synergetic uses and management of resources and ecosystems.

A typology of countries is proposed to help in assessing the context nexus status. This is because:

- not all the nexus linkages are of same relevance to all countries, and such typology helps (ex-ante) what is expected to be more critical for certain countries; for instance, if water is deemed the most problematic WEF factor (i.e. the scarcer one), then the analysis of WEF interlinkages should start with the matrices that include water objectives;

- it strengthens the assessment by allowing for a comparison between the status of a particular context and similar ones. This possibility for comparison is useful to quantify benchmarks and nexus pressure points (see section 4.8).

Not all the relations are relevant for all countries and the country typology mostly concerned about the specific 'nexus issues' is highlighted in the interlinkages matrices.

As a simple way to analyse (ex-ante) what is expected to be more critical for certain countries or society typologies, four country categories are suggested:

1. Agriculture-based economy, dry country (i.e. Agriculture employs >20 percent of total hours of human activity, Renewable water resources is < 1,500 m^3/inhabitant/year)

2. Agriculture-based economy, water rich country (i.e. Agriculture employs >20 percent of total hours of human activity, Renewable water resources[2] is > 1,500 m^3/inhabitant/year)

3. Affluent country, with natural resource constraints (i.e. Economic activities not based on agriculture employ >20 percent of total hours of human activity, >20 percent of energy and 20 percent of agriculture products are imported)

4. Transition country, experiencing strong population growth (i.e. Economic activities not based on agriculture employ between 35 percent and 90 percent of active population, population is rising > 0.5 percent p.a.)

Each relation identified in the Tables will be more relevant for certain country typologies and less relevant for others. Indicative information about which country typology can be interested in deepening which specific linkage is reported in the tables below. This helps identify the relevant set of WEF links. Therefore, the entry points to read the three interlinkages matrices (that can be seen as one single 3D matrix) are twofold:

- The 'nexus issues' that are more relevant for the stakeholders involved;

- The 'nexus issues' that are usually of relevance for a country typology.

2 Total renewable water resources per capita

Table 2 (part 1 of 3)

Water and energy linkages

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE
ACCESS TO WATER RESOURCES FOR DIFFERENT USES	**Water pumping and groundwater management** Access to modern energy facilitates the provision of water and sanitation services, for example through electricity (solar) pumping of groundwater resources. ❶❹ **Energy for clean drinking water** Energy can be used to boil and sterilize water for drinking and cooking. ❶❹ **Water desalination** Water desalination can provide freshwater for agriculture and sanitation in costal dry countries. A large amount of energy (electricity) is needed to desalinate water resources. ❶❹	**Energy efficient water technologies** Energy can be saved and used more efficiently adopting technologies that also make efficient use of water resources. ❶❹	**Dams and hydropower** Dams and hydropower projects can lead to non-equitable water entitlements and rights, particularly for downstream communities (e.g. water diversions, water use and access). ❶❷ **Bioenergy production** Biofuel production, especially in developing countries, can lead to insecure and inequitable water entitlements (land and water grabs). ❶❷
SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	**Water for power generation** Thermal plants (including nuclear) consume large amounts of water, etc. so the energy mix and related water that cannot be used for other purposes, such as drinking water supply or irrigation. ❹	**Irrigation systems** Energy waste in irrigation due to Irrigation equipment, operations and maintenance problems. Irrigation systems can increase water-efficiency and energy-efficiency at the same time (e.g. drip irrigation) as well as reduce costs, keeping in mind the impact such systems may have on soil moisture and quality, agricultural productivity and crop diversity. ❶❹ **Management of water by utilities** Reduction of water losses and management improvements in water utilities leads to less energy consumption to pump, lift and transport water. ❸❹	**Energy recovery from biomass, organic waste and wastewater and water quality** Reducing the pollution potential of wastewater by converting oxygen demanding organic matter that could cause low oxygen levels in surface waters. Nutrients, like nitrogen and phosphorous, are conserved in biogas effluents and can be used to displace chemical fertilisers in crop production. Biogas produced from wastewater can be used in direct combustion (e.g. absorption heating and cooling, cooking, space and water heating, drying, and gas turbines) and in internal combustion engines and fuel cells for production of mechanical work and electricity. Recycled nutrients can be used as fertilisers instead of mineral fertilisers. ❶❷❹

● synergy between nexus sustainability aspects
● trade-off between nexus sustainability aspects
● relevance to country typology

Table 2 (part 2 of 3)

Water and energy linkages

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE
SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES (cont'd)	**Hydropower production** Hydropower provides access to modern energy and when associated with storage in reservoirs, contributes to the stability of the electrical system by providing flexibility and grid services. Large-scale and small-scale hydropower infrastructure may significantly affect water flows (fluctuations and alterations), sediment load, nutrient flows and water quality. Particularly downstream areas, aquatic and wetland ecosystems may be negatively impacted if social and environmental impacts are not considered in the management. ❶❷❹ **Irrigation systems** Access to modern energy makes possible active water management through power irrigation, benefiting crop and livestock production. Access to modern energy can lead to unsustainable water pumping from underground aquifers by households, farmers and other water users. ❶❷❹ **Water pollution by fossil energy use** Water for extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing biofuels and for generating electricity → competing uses over resources. Freshwater demand in energy production can 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. Tar sands, shale gas, hydraulic fracturing are particularly water- intensive as well as polluting. Water contamination from oil. ❹	**Water productivity in agriculture** By improving the productivity of rainfed agriculture, energy-intensive irrigation can be limited or reduced. Productivity increases in ethanol production. ❶❷❹	**Fossil fuel pollutants** Renewable energy, such as wind and solar power, leads to less water pollutants due to avoidance of fossil fuel burning. Some renewables such as solar or geothermal can have some negative impact on water quantity and quality. ❸❹ **Bioenergy competition with food and water uses** Water is needed for biomass production for feed and energy. There might be competition over these water resources from other users. Some energy crops are very water-extensive (e.g. miscanthus), and it would be more sensible to grow other crops or in rainfed areas. Production of bioenergy can contribute to water pollution. Fossil energy has a smaller water footprint than biofuel production, indicating that water-use efficiency can decrease. ❸❹

Table 2 (part 3 of 3)

Water and energy linkages

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE
RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS	**Technologies for resilience to water-related disasters** Increased access to energy services will most likely support economic development, which will have far-reaching impacts on ecosystems (e.g. the uptake of technologies for water purification and storage). ❶❹	NO CLEAR TREND	**Energy for irrigation systems** Renewables can provide the energy needed for active water management through power irrigation (e.g. solar water pumping), especially in isolated rural locations, therefore making communities more resilient. Irrigation can also play an important role in mitigating the impacts of floods and droughts. Depending on the context, drainage of wetlands may increase the risk of flooding, and excessive irrigation (and lack of drainage) may promote soil salinization and desertification. ❹ **Hydropower and Flood Risks** Both large-scale and small-scale hydropower infrastructure may increase the risk of flooding and put additional stress on fisheries and ecosystems. Deforestation and accompanying infrastructure constructions (e.g. roads) will further alter watershed ecosystem and reduce their resilience to flood risks. ❶❷

- synergy between nexus sustainability aspects
- trade-off between nexus sustainability aspects
- relevance to country typology

Table 3 (part 1 of 4)

Food and Water linkages

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS
FOOD AVAILABILITY	**Water allocation by sector** Rising demand from agriculture and other sectors is leading to competition for water, resulting in environmental stress and socio-economic tensions. Intra-sectoral competition is also pervasive within agriculture – between livestock, fisheries and aquaculture, staple and non-food crops. The demand for water of cities and industries is growing causing pollution and putting pressure on rural communities. ❶❹ **Livestock production** More water is needed for feed production, drinking and servicing of animals, processing (slaughterhouse, tanneries, cooling). Intensive industrial livestock production and inappropriate grazing and water practices contribute to widespread degradation and pollution of water and land resources (manure, nutrients, bacterial and viral pathogens, drug residues, heavy metal loads), particularly around watering sites and run-off effluents. Species and breeds of livestock, and social and cultural aspects of livestock farming, synergies can be found with livestock as integral part of agricultural water resource management. Livestock can be efficient and effective water user when it largely depends on crop residues and by-products, and on well-managed rangelands unsuitable for crop production. ❹	**Availability of freshwater resources for agriculture** Erratic precipitation patterns and subsequently unpredictable soil moisture availability over the course of a growing season reduces nutrient uptake, and consequently yields. ❶❹ **Crop production and processing** Improvements in water use efficiency and productivity have the potential to improve both food security and water sustainability in many parts of the world. Less water is required to produce more food. Irrigation plays an increasingly strategic role through water use efficiency, improved water services, yield growth and higher cropping intensity. Groundwater resources provide a flexible, on-demand source of water for irrigation. Increasing demand for water can result in extra pressure on resources and ecosystems (overpumping of groundwater resources, sinking water tables, water shortages, and salinization. Agricultural production may cause water pollution through the discharge of pollutants and sediment to surface and groundwater (eutrophication, spread of water-borne diseases, aquatic weeds,), through net loss of soil by poor agricultural practices, and through salinization and waterlogging of irrigated land. At the same time, the use of polluted surface, groundwater and wastewater contaminates crops, degrades ecosystems and poses serious risks to public health. The associated agrifood-processing industries are also a significant source of organic pollution. ❶❷ **Livestock production** Most water used by livestock is returned to the hydrological cycle, but some of it evapotranspires or is polluted. Polluted water can be treated at point-source and returned to the hydrological cycle. ❶❷	**Water stress due to agriculture** Improvements in water use efficiency and productivity may reduce water stress, and support agricultural development and economic growth. ❶❹ **Dependency on food imports** Water scarcity and low productivity may cause dependency on food imports (and vulnerability to volatile food prices). ❶❹

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS
FOOD AVAILABILITY (cont'd)	**Inland fisheries and aquaculture** Expansion and intensification of crop production affect inland fisheries negatively. Disputes over uses of water for irrigation and fisheries are often difficult to resolve due to different spatial and temporal water needs. Growing demand for water from aquaculture can result in increased competition with other water users if the water resources are limited. This includes both quality and flow requirements for sustaining aquatic habitat. Intensification of production usually results in increased water use to maintain water quality. Nutrient enrichment of water bodies may provide nutrients beneficial to aquaculture production in some extensive culture systems. However, excessive loadings with urban, industrial and agricultural wastes can have severe consequences for aquaculture operations. With increasing aquatic pollution, eutrophication and physical degradation of aquatic habitats, there are risks of mass mortalities of farmed stock, disease outbreaks, product contamination and reduced productivity. 3 4	**Groundwater resources** Groundwater abstraction provides an important source of water, particularly for irrigated agriculture, but has proven difficult to regulate, resulting in sinking water tables, water pollution and salinization. 1 4 **Wastewater resources** Particularly in water-scarce countries, investments in re-use of drainage water and (treated) municipal and industrial wastewater can offset scarcity. Wastewater is nutrient rich, and is available close to the centers of population and markets. However, contaminants in wastewater pose risks to human and environmental health and need to be closely regulated. Wastewater reuse can reduce pollution and help optimize resource recovery and use in agriculture and for cities. Risks of using polluted water. 3 4 **Water desalination for irrigation** Desalinated water is more costly than conventional water resources and is not affordable for most crops. Nevertheless, as costs are declining, desalinated water is more commonly used for agricultural applications, particularly for high-value crops. Desalinated water is of high quality and can have less negative impact on soils and crops in comparison with direct use of brackish water. 1 4 **Land use** Achievements in production can degrade land and water systems upon which production depends. This includes surface and groundwater pollution, depleted groundwater storage, erosion, nutrient depletion. 1 2 3 4	

- synergy between nexus sustainability aspects
- trade-off between nexus sustainability aspects
- relevance to country typology

Table 3 (part 3 of 4)

Food and Water linkages

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS
FOOD AVAILABILITY (cont'd)		**Water-forestry interactions** Forests influence the amount of water available and regulate surface and groundwater flows, while maintaining high water quality. Forests and tree contribute to the reduction of water-related risks such as landslides, local floods and droughts and help prevent desertification and salinization. Fast-growing forest crops have potential for high water demand, which can lead to reduced water yields. In arid or semi-arid ecosystems, forests might not be the most suitable land cover to increase downstream water yield. ❶❷	
FOOD ACCESS	**Water and land rights** The lack of clear and stable land and water rights and tenure (and regulatory capacity) may contribute to conflict and competition for access. Land and water tenure (including customary and traditional user rights) can help protect rural livelihoods and provide incentives for responsible water use. ❶❷ **Economic water scarcity** A lack of investments in water infrastructure/ management and a lack of human capacity can inequitable access to water and economic water scarcity, and by extension, negatively impact on local food production. ❶❷	NO CLEAR TREND	**Food prices increase during water-related disasters** Water-related disasters put food access at risk due to supply shortages (e.g. floods and droughts) with subsequent spikes in food prices. ❶❷❹
FOOD UTILIZATION & NUTRITION	**Clean and safe water for food preparation** Equal and adequate access to safe and clean water is needed to prepare healthy and nutritious food. ❶❷❹	NO CLEAR TREND	NO CLEAR TREND

Table 3 (part 4 of 4)

Food and Water linkages

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS
STABILITY OF FOOD PRICES AND SUPPLY	**Virtual water footprint along the food production and supply chain** The virtual water content of agricultural products from relatively water/land-abundant to water/land-scarce areas can help to achieve the optimal use of land and water resources and ensure food supply in countries with low production. ❶❷❸❹	**Social water stress** Densely populated regions are at risk of consuming more water than what is sustainable. This can lead to water stress, affecting food supply and prices. ❹ **Water storage** Water storage capacity helps to mitigate variability in agricultural production. Siltation of rivers due to unsustainable land management practices causing sheet wash and gully erosion can reduce the productivity of land and loss of water storage capacity. ❶❷	**Climate change and agricultural water management** The climate is changing, affecting temperatures, precipitation patters and causing extreme weather events. Irrigators dependent on snow melt are even more vulnerable to changes in river flows. Agricultural water management, technologies and investments can help in mitigating the impacts of having less secure water availability for food production due to climate change. ❶❷

● synergy between nexus sustainability aspects
● trade-off between nexus sustainability aspects
● relevance to country typology

Table 4 (part 1 of 2)

Food and Energy linkages

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/RENEWABLE
FOOD AVAILABILITY	**Yield increase and income** Access to modern energy leads to higher yields, therefore an increased food availability and often (but not always) incomes. ❶❷❹ **Energy for irrigation and improved yields** Access to energy for irrigation can lead to stress, runoff and erosion, hence reduced yields in the long run. ❸❹	**Agricultural productivity** There is the risk that energy efficiency is achieved at the expense of productivity. ❹ **Energy efficiency and economic return** Reduction of use of non-renewable energy in agrifood systems has usually a positive effect on economic returns of food production in the long run. ❸❹ **Livestock production** The use of animal waste and manure for biogas production increases the overall energy efficiency of meat production, while providing a low- cost source of fertilizers that can help increasing yields in a sustainable manner. ❸❹	**Energy bill** Increase of renewables usually translates in a saving on the energy bill. ❸ **Bioenergy** Food crops use for bioenergy compete for food availability (although they can have positive effects on food access). ❸❹
FOOD ACCESS	**Increased yields on food prices** Access to modern energy for farming can decrease food price to consumers due to increased yields. ❶❷❹	NO CLEAR TREND	**Wood energy** Damage of forest land can affect livelihoods of local populations therefore access to food. ❶
FOOD UTILIZATION & NUTRITION	**Food processing technology** Access to modern energy enables the introduction of mechanization and technologies that can reduce food losses and waste. ❶❷	**Improved cooking efficiency** [3] Increase in efficient use of energy for cookstoves and technology for food preparation and conservation increases quality of food. This includes modern refrigeration, stoves with food not in contact with fuel and smoke, etc. ❶❷❹	NO CLEAR TREND

3 Improved cookstoves are defined on the basis of energy efficiency and safety/cleanliness

Food and Energy linkages

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/RENEWABLE
FOOD UTILIZATION & NUTRITION (cont'd)	**Cooking** Access to modern energy doesn't limit the amount of time that can be dedicated to cooking therefore increases the frequency of cooking. Access to modern energy decreases pressure on forest resources and forest damage. 1 2 **Renewables uptake at household level** Access to renewables at household level in off-grid areas allows better food conservation. 1 2 4		
FOOD STABILITY	**Energy subsidies and high/stable yields** Reliance on external energy subsidies helps to maintain a stable food production (through increased management of agricultural inputs: irrigation, greenhouses, soil preparation, etc.). 1 2 **Underground water pumping** The depletion of underground aquifers due to access to energy for pumping can put food stability at risk in the long run. 1 4	**New technologies and practices in agriculture** New technologies and practices can reduce the use of non-renewable energy in agrifood systems while maintaining a stable food production. 1 2 **Food transport** Transporting food for long distance usually implies a less energy efficient food chain (with associated GHG emissions) but can help to mitigate domestic food price volatility. 3 4	**Delinking the food and energy markets** The uptake of renewable energy in agrifood systems helps to decouple agricultural production from the energy market. 1 2 3 4

● (blue) = synergy between nexus sustainability aspects
● (brown) = trade-off between nexus sustainability aspects
● (grey) = relevance to country typology

The linkages matrices, or the resulting 3D matrix, is a basis for discussion, highlighting synergies and trade-offs, and once the 'hot topics' have been discussed and identified, the users know already which indicators (already available or at least agreed) can be used for that specific topic or 'nexus issue'. Therefore it can be used for a qualitative assessment, but the main purpose is to guide the assessment towards the relevant 'nexus issue' and therefore a quantitative assessment of the context nexus status though the use of a set of sustainability indicators. Based on the criterion of current (or forthcoming) availability of indicators at national level from different international organizations or initiatives, the following sources of data to measure the indicators have been considered:

a) FAO Statistical Yearbook / FAOSTAT Database, 2014

b) Indicators of Sustainable Development, UNDESA, 2007

c) World Bank Open Data, 2014

d) Energy Indicators for Sustainable Development, IAEA, UNDESA, IEA, Eurostat, EEA, 2005

e) The Global Bioenergy Partnership Sustainability Indicators for Bioenergy, GBEP/FAO, 2011

f) Asian Water Development Outlook, 2013

g) Poor People's Energy Outlook 2013, Practical Action, 2013

h) MEPI Index, UNIDO

i) UNECE Statistical Database, 2014

j) OECD Agri-environmental indicators, 2014

k) Access to Modern Energy: Assessment and Outlook for Developing and Emerging Regions, IIASA, UNIDO, GEF, 2012

l) FAO Aquastat, 2014

m) State of Food Insecurity (SOFI), 2013, FAO

n) Demographic and Health Surveys, USAID, 2014

o) Eurostat database, 2014

p) GEMSTAT-UNEP Water Quality Index to Assess Country Performance, 2014

q) European Environment Agency Waterbase, 2014

r) IGRAC Groundwater Resources Assessments, 2014

s) WHO/UNICEF Joint Monitoring Programme (JMP) for WASH, 2014

t) Transparency International Global Corruption Report, 2008

Sometimes more detailed data, more fit to the specific purpose, are collected by national authorities and are available in national registries. A selection of indicators taken from the sources above and organized by 'nexus issue' is reported in the Annex 1. They can be used directly and are usually available usually at national level. Along with existing indicators, a set of data of ideal indicators is also reported in the tables A.1, A.2 and A.3 (in italics).

Along with sustainability indicators directly relevant for water, energy and food, it is useful to contextualize also the sustainability status in relation to human resources. These relate to labour intensity requirement, which could include information on wages and employment, and capital intensity requirement, which can include information on capital availability as well as costs. The following indicators are proposed as examplesto assess these factors:

Labour

- Total economically active population in agriculture / total economically active population
- Rural population / rural and urban population
- Wages in non-agricultural activities / wages in agricultural activities
- Average earning in agricultural production / average earning in manufacturing
- Rate of unemployment (skilled/unskilled occupation)
- Yearly increase of labour cost in manufacturing

Cost

- ODA to agriculture / gross domestic product (GDP)
- Agricultural value added per capita / agricultural value added per agricultural worker
- Investment share in gross domestic product (GDP), possibly specific to the sector of the intervention
- Total economically active population in agriculture / net production value of agriculture

The measurement of these linkages through indicators is needed to quantify them. There are two ways to do this: using existing indicators and developing specific indicators when these are not available at the desired level or scale, or a rapid appraisal relying on existing indicators and making use of country typology (to derive benchmarks):

(i) Detailed nexus assessment

A long and precise quantitative assessment can be performed if time and resources permit. This is possible when more detailed data, more fit to specific nexus assessment purpose, are collected by national authorities and available in national registries, or when indicators can be quantified using specific tools (see section 4.5). These tools can be used for example for measuring the aspirational indicators in italics of tables A.1, A.2 and A.3, i.e. those indicators that cannot currently be measured because data needed to do so is currently not collected on a systematic basis.

(ii) Nexus rapid appraisal

Lack of data is often a key barrier for assessing nexus impacts. To overcome this constraint, it is proposed to build as much as possible on indicators that use data already collected at the national (or sub-national) level, and are available through international organizations. These indicators cannot always serve directly the intended purpose but sometimes data used to measure existing indicators can be used to build other ad-hoc nexus indicators.

As part of the nexus rapid appraisal, Table 5 contains a selection of suggested indicators (and relative weights) that are usually more relevant to a specific country typology. A combination of the information contained in table 5 and in Annex 1 can guide a rapid sustainability appraisal in terms of bio-economic pressure on the three nexus aspects as well as labour and capital, depending on the country typology.

However, an inclusive process would be more useful to understand internal and external constraints of the society. This information is needed to identify which aspects should be chiefly taken into account when designing/assessing a specific intervention in the country, and in turn the most relevant set of sustainability indicators that can be taken from those presented in tables A.1, A.2 and A.3.

An approach to quantify the context nexus status is presented in Box 4.

BOX 4 - QUANTIFYING THE CONTEXT NEXUS STATUS AND BENCHMARKS

In order to derive information from sustainability indicators to quantify the bio-economic pressure, (dynamic) benchmarks should be identified. Benchmarks should ideally be decided by local stakeholders (for example a neighbour country with similar characteristics, or a country of the same country typology as illustrated above, could be used as benchmark) and a simple methodology is proposed hereafter.

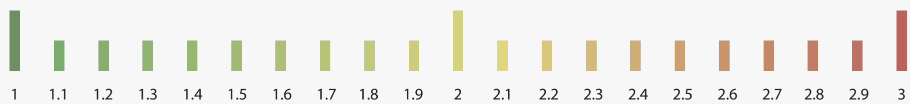
The list of countries used to calculate benchmarks for country typology (table 5), and the rationale, are reported in ANNEX 2.

The indicators of a number of countries within the same country typology are used to come up with a reference indicator, which is the arithmetic average. Then the actual measured indicator for the specific context under analysis is compared with the reference indicator and the following weights are assigned.

DIVERGENCE OF ACTUAL AND REFERENCE SUSTAINABILITY INDICATOR	ASSIGNED WEIGHT
The ratio between the actual indicator and the reference indicator is ≥|100| percent and the former is more sustainable than the latter	**1 (green)**
The ratio between the actual indicator and the reference indicator is 0 percent	**2 (yellow)**
The ratio between the actual indicator and the reference indicator is ≥|100| percent and the latter is more sustainable than the former	**3 (red)**

For values within ±100 percent from benchmarks, the weights are calculated following a continue number line between 1 and 3.

A colour corresponds to each weight assigned (1 to 3) and their arithmetic average gives the final result about the sustainability (or pressure) on one nexus aspect. The colours and the weights are used to determine the final colours following the colour scheme below (see section 4.7 for a practical application).



It is suggested to use two or three indicators for each cell of the 3D matrix (i.e. for each issue addressing one energy sustainability component, one water sustainability component, and one food security component). For example, according to the interlinkages matrices, if the 'nexus issue' to be addressed is about bioenergy, the indicators to be considered are at least those addressing interlinkages between:

- *Access to water resources for different uses* and *The energy produced and consumed is clean/ renewable*;
- *Sustainable use and management of water resources* and *The energy produced and consumed is clean/ renewable*;
- *Food availability* and *The energy produced and consumed is clean/renewable*;
- *Food Utilization & Nutrition* and *Access to modern energy services*;
- *Food Access* and *The energy produced and consumed is clean/renewable*.

The important added value of a *nexus rapid appraisal* lies in the fact that it is based as much as possible on indicators and information that are already collected by some international organization and therefore usually readily available. Furthermore, it can work with country typologies, making use of those indicators that are generally informative for the specific typology, but have not been selected by any consultative process and are not specific to a 'nexus issue'. These limitations constitute a trade-off between ease and rapidity of the assessment, and preciseness/usefulness for policy-makers in responding to stakeholder needs.

Table 5 (part 1 of 4)

Selected indicators already available at national level for the context analysis per country typology

COUNTRY TYPOLOGY:
DRY COUNTRY, AGRICULTURE-BASED ECONOMY

WATER	ENERGY	FOOD	LABOUR	CAPITAL
Freshwater withdrawal as % of total actual renewable water resources[4]	Share of households using traditional fuels	Average dietary energy supply adequacy	Wages in non-agricultural activities / wages in agricultural activities	ODA to agriculture / gross domestic product (GDP) (current USD / 1,000 USD)
PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **1**	PROPOSED WEIGHT: **1**
BENCHMARK: **34%**[5]	BENCHMARK: **80%**[6]	BENCHMARK: **124%**[7]	BENCHMARK: **1.6**[8]	BENCHMARK: **3.4**[9]
Rural population without improved drinking water sources	Total fossil energy consumption in agriculture / agriculture gross production value	Arable land per gross production value of agriculture	Rate of unemployment (skilled/unskilled occupation)	Total economically active population in agriculture / Net Production Value of agriculture
PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **1**	PROPOSED WEIGHT: **1**	PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **3**
BENCHMARK: **26%**[10]	BENCHMARK: **2.5 1,000 $/GJ**[11]	BENCHMARK: **1.15 (Ha/1,000 int.$)**[12]	BENCHMARK: **9.3 %**[13]	BENCHMARK: **1.32 people/1,000 int.$**[14]

4 This indicator captures the relation between water supply and demand. See FAO, 2008 for more information about the associated computation and conceptual problems.
5 FAO Aquastat. More recent data were used, in the period 2000-2003.
6 Traditional fuels considered are: charcoal, firewood and dung. The most recent data from USAID DHS surveys were used. Data was not available for Algeria, Syrian Arab Republic and Tunisia, and these countries were therefore excluded from the group.
7 2012 data, FAOSTAT, 3-year average.
8 2008 data, LABORSTA, calculated for all "Dry country, agriculture-based economy" for which data is available
9 Information on commitments of ODA for agriculture comes from FAOSTAT and are an average of the period 2009-2011, information on GDP comes from World Bank Statistics and refers to 2012, with the exception of GDP for the Syrian Arab Republic which refers to 2007
10 2012 data, World Bank Statistics
11 2010 data, FAOSTAT. Lesotho was excluded from the group (lack of data)
12 2010 data, FAOSTAT
13 Percentage of total labour force (modeled ILO estimate). 2012 data, World Bank Statistics
14 2012 data, FAOSTAT

Table 5 (part 2 of 4)

Selected indicators already available at national level for the context analysis per country typology

COUNTRY TYPOLOGY:
WATER RICH COUNTRY, AGRICULTURE-BASED ECONOMY

WATER	ENERGY	FOOD	LABOUR	CAPITAL
Area under agricultural water management as a % of irrigation potential PROPOSED WEIGHT: **2**	Share of households using traditional fuels PROPOSED WEIGHT: **2** BENCHMARK: **43%**[15]	Average dietary energy supply adequacy PROPOSED WEIGHT: **3** BENCHMARK: **112%**[16]	Wages in non-agricultural activities / wages in agricultural activities PROPOSED WEIGHT: **1** BENCHMARK: **3.38**[17]	ODA to agriculture / gross domestic product (GDP) (current USD / 1,000 USD) PROPOSED WEIGHT: **1** BENCHMARK: **1.5**[18]
Rural population without improved drinking water sources PROPOSED WEIGHT: **2** BENCHMARK: **25%**[19]	Total fossil energy consumption in agriculture / agriculture gross production value PROPOSED WEIGHT: **1** BENCHMARK: **2.3 1,000 $/GJ**[20]	Arable land per gross production value of agriculture PROPOSED WEIGHT: **1** BENCHMARK: **0.6 Ha/1, 000 int.$**[21]	Rate of unemployment (skilled/unskilled occupation) PROPOSED WEIGHT: **3** BENCHMARK: **5.2 %**[22]	Total economically active population in agriculture / Net Production Value of agriculture PROPOSED WEIGHT: **3** BENCHMARK: **1.0 people/1,000 int.$int.$**[23]

15 Traditional fuels considered are: Charcoal, Firewood and Dung. The most recent data from USAID DHS surveys were used. Data was not available for China, Korea DPR, Guatemala, Thailand, Tanzania, and these countries were therefore excluded from the group.
16 2012 data, FAOSTAT, 3-year average.
17 The following water rich country with agriculture-based economy were considered (chosen maintaining a good distribution over % of people working in agriculture): Kyrgyzstan, Peru, Tajikistan, Thailand and Sri Lanka
18 Information on commitments of ODA for agriculture comes from FAOSTAT and are an average of the period 2009-2011, information on GDP comes from World Bank Statistics and refers to 2012. Korea DPR was excluded from the reference group (lack of data)
19 2012 data, World Bank Statistics
20 2010 data, FAOSTAT. Korea DPR, Guatemala and Tanzania were excluded from the reference country group (lack of data)
21 2011 data, FAOSTAT
22 Percentage of total labor force (modeled ILO estimate). 2012 data, World Bank Statistics
23 2012 data, FAOSTAT

Table 5 (part 3 of 4)

Selected indicators already available at national level for the context analysis per country typology

COUNTRY TYPOLOGY:
AFFLUENT COUNTRY, NATURAL RESOURCE CONSTRAINT

WATER	ENERGY	FOOD	LABOUR	CAPITAL
Freshwater withdrawal as % of total actual renewable water resources PROPOSED WEIGHT: **2** BENCHMARK: **40%** [24]	Contribution of fossil energy to energy supply [25] PROPOSED WEIGHT: **3** BENCHMARK: **88%**	Net import of agricultural products, food and live animals per capita PROPOSED WEIGHT: **2** BENCHMARK: **13,52 3 (1,000 $ p.c.)** [26]	Average earning in agricultural production / average earning in manufacturing PROPOSED WEIGHT: **1** BENCHMARK: **1.42** [27]	Total economically active population in agriculture / Net Production Value of agriculture PROPOSED WEIGHT: **1** BENCHMARK: **0.096 (1,000/constant 2004-2006 int.$)** [28]
Share of monitoring sites in agriculture areas that exceed recommende r drinking water limits for nitrates, phosphorous and pesticides in surface water and groundwater PROPOSED WEIGHT: **3** BENCHMARK: **29%** [29]	Energy imports PROPOSED WEIGHT: **2** BENCHMARK: **80%** [30]	Change in cropland use over the last 10 years PROPOSED WEIGHT: **2** BENCHMARK: **-7.3%** [31]	Total economically active population in agriculture / Total economically active population PROPOSED WEIGHT: **3** BENCHMARK: **0.045** [32]	Investment share in gross domestic product (GDP), possibly specific to the sector of the intervention PROPOSED WEIGHT: **3** BENCHMARK: **22.3** [33]

24 FAO Aquastat. Singapore was excluded from the country group (lack of data). More recent data were used, mainly 2012.
25 2012 data, World Bank Statistics
26 2011 data, FAOSTAT
27 2008 or most recent data, LABORSTA. Republic of Korea and Singapore were excluded from the reference group (lack of data)
28 2012 data, FAOSTAT
29 Data for OECD countries were used instead due to lack of data for the reference countries, average 1990-2010, OECD Environmental Database
30 Net energy imports estimated as energy use less production, 2011 data, World Bank Statistics
31 2002-2011 data, FAOSTAT. Singapore was excluded from the country group
32 2013 data, FAOSTAT.
33 Gross fixed capital formation (% of GDP), 2012 data, World Bank Statistics. This benchmark is not sector-specific.

Table 5 (part 4 of 4)

Selected indicators already available at national level for the context analysis per country typology

COUNTRY TYPOLOGY:
EMERGING COUNTRY, EXPERIENCING STRONG POPULATION GROWTH

WATER	ENERGY	FOOD	LABOUR	CAPITAL
Total internal renewable water resources per capita	Fossil energy use per unit of GDP	Net import of agricultural products, food and live animals per capita	Total economically active population in agriculture / Total economically active population	Investment share in gross domestic product (GDP), possibly specific to the sector of the intervention
PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **2**
BENCHMARK: **7,757 m³/inh ab/year** [34]	BENCHMARK: **0.12 kg of oil equivalent / constant 2011 PPP $** [35]	BENCHMARK: **0.02 USD per capita** [36]	BENCHMARK: **0.28** [37]	BENCHMARK: **26%** [38]
Amount of food produced per unit of water consumed	Population using solid fuels	Change in forest area over the last 10 years / Total forest area	Wages in non-agricultural activities / wages in agricultural activities	Agricultural value added per capita / agricultural value added per agricultural worker
PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **2**	PROPOSED WEIGHT: **3**	PROPOSED WEIGHT: **3**
BENCHMARK: **1.19 m³/int.$** [39]	BENCHMARK: **66%** [40]	BENCHMARK: **-1.0%** [41]	BENCHMARK: **200%** [42]	BENCHMARK: **0.17** [43]

34 2012 data, Aquastat. Montenegro was excluded from the country group (lack of data)
35 2011 data, World Bank Statistics
36 2011 data, FAOSTAT
37 2012 data, FAOSTAT
38 Gross fixed capital formation (% of GDP), 2012 data, World Bank Statistics. This benchmark is not sector-specific.
39 This is a ratio between "Agricultural water withdrawal" for which we selected the last available data from Aquastat in the period 2000-2012, and "Gross Production Value (constant 2004-2006 1000 I$)" for which we calculated an average from FAOSTAT over the period 2001-2012
40 Traditional fuels considered are: charcoal, firewood and dung. The most recent data from USAID DHS surveys were used. Data was not available for China, Costa Rica, Guatemala, Jamaica, Malaysia, Mexico and Montenegro, and these countries were therefore excluded from the group.
41 Data refer to 2001-2011, FAOSTAT. Montenegro was excluded (lack of data)
42 Most recent data in the period 2006-2008 were used, FAOSTAT
43 2012 data, World Bank Statistics

This set of indicators is relevant to understand the context in which an intervention is supposed to be implemented and the level of stress (biophysical pressure) to which the environment and/or society is exposed. However, depending on the specific 'nexus issue', other indicators could be necessary for the context analysis. For example at national level they can include:

- Energy security considerations including energy mix and infrastructures
- Greenhouse gas emission of production and consumption

Fig.3 presents a visual representation in one single graph of the sustainability of water, energy, and food (the three main nexus factors) but also the situation regarding labour and capital in a given context.
The weights (or colours See box 4) can also be combined in a sustainability WEF nexus index.

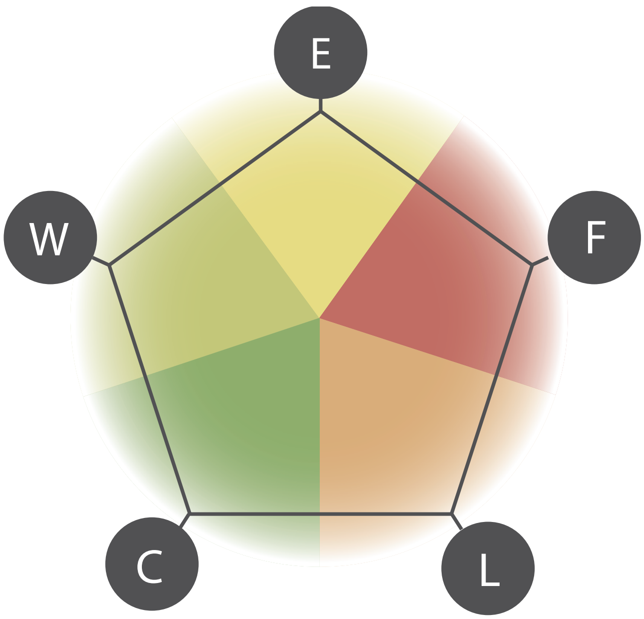
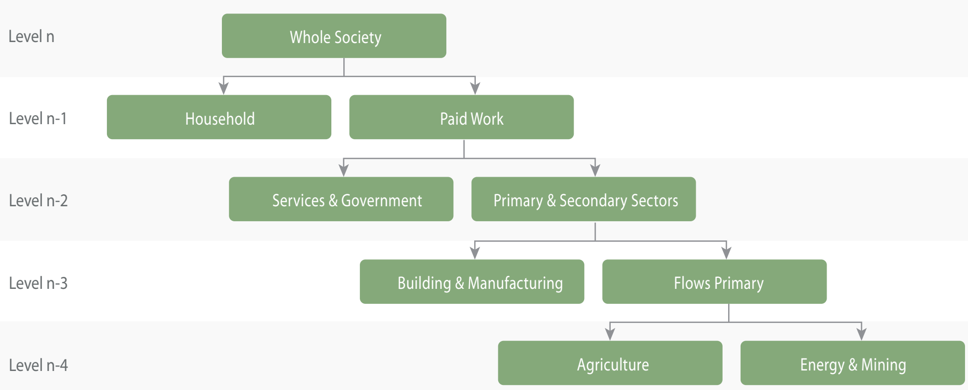


Figure 3

Visual representation of the bio-economic pressure of the context (or system) under analysis, using indicators intended for a specific nexus issue, or more rough country typology sustainability indicators. The colours are the result of the distance between the measured indicators and the benchmark indicators, for each sustainability aspect (sustainable water, sustainable energy, food security, labour and capital). Yellow=the sustainability of the context is similar to the reference, Green= the sustainability of the context is higher than the reference, Red= the sustainability of the context is lower than the reference.

Figure 4

Nested socio economic compartments



The context analysis can be carried out at different scales (national and sub-national) and levels. This requires using a standard accounting framework to analyse the (human) system under assessment, to organize the analysis of the society using the same 'societal compartments' (or categories of activity), nested in a specific way. Figure 4 shows one way of doing this[44].

If a multi-scale and multi-level analysis is structured in this way, by knowing the characteristics (i.e. specific indicators) of a societal compartment at a certain level (e.g. the amount of water or energy consumed per hour of work by the primary&secondary sectors in a country or village), and a sub- level (e.g. the same indicator for the agriculture compartment in just an area of the country, or for the group of fishermen and farmers in a village), it is possible to estimate other characteristics of the system. For example if one knows that in a country agriculture is using X energy power per worker and building&manufacturing Y energy power per worker, one can estimate the amount of power used for households, since it is possible to assume that the energy power range per person is typically within a certain range for a specific society typology. This is possible because the sum of funds and flow elements of a system are known, and also fund elements allocation is known[45].

44 More information can be found in "An Innovative Accounting Framework for the Food-Energy-Water Nexus", FAO, 2013

45 Funds are resources used but not consumed. They represent "what the system is" and "what the system is made of". Examples of fund elements are human beings, land, rivers and energy power installed. The idea of sustainability implies that these fund elements have to be maintained. They correspond to a certain extent to production factors (labour, capital, land) in economics. Flows, on the other hand, are those elements that are generated or inputs that are consumed by the system (or the socio-economic process). The analysis of flows tells us "what the system does". The proposed indicators (including those used to assess the performance of interventions – see section 4.6) use in as much as possible flows/fund ratios (e.g., energy input per hour of labour, water consumed per hectare of land in production). The flow/fund ratios guarantee the survival and reproduction of funds and therefore of the system and minimizing them translates into a lower impact on the natural and human systems.

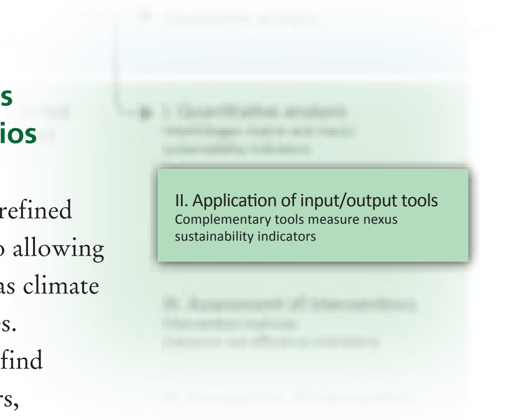
This allows for making up for missing data. For instance, one can derive indicators for households without measuring them directly (avoiding expensive and time consuming field surveys), but knowing just the characteristics of the whole society under assessment, some key categories of activities, ignoring less relevant ones and using typical ranges for other relevant categories.

The context information presented in this type of diagramme can then be combined with information about the performance of specific interventions (each intervention would fall under a specific 'nexus issue') as outlined in section 4.6. The resulting combination of information about nexus status of the context and impacts of the foreseen intervention can be used as a basis to discuss and evaluate the appropriateness/sustainability of a specific intervention or trade-offs between interventions – See sections 4.7. and 4.8.

At this stage it is up to the user to:

- Use the results of the context analysis illustrated above as a basis for nexus response, or
- Use another component to:
  – apply specific tools for finding and quantifying relevant information not already available, or
  – assess the efficiency of resource use by envisaged interventions in a nexus perspective.

4.5 Application of specific nexus tools to quantify impacts and draw scenarios



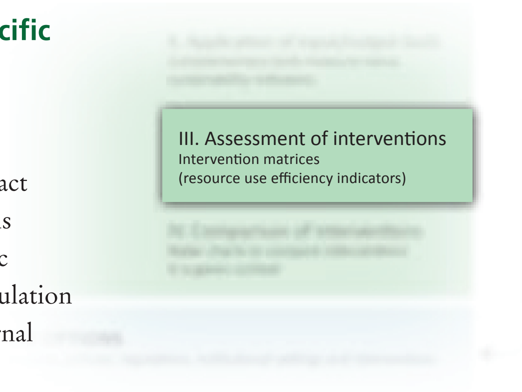
A number of tools are available to make more refined assessments of specific nexus interlinkages, also allowing for the consideration of external drivers (such as climate change), and trying to quantify critical variables. These tools can be also used to some extent to find missing data for measuring key nexus indicators, but some of them can also be used to develop possible scenarios, by estimating the effects interventions could have on the baseline.

Table A.5 (Annex 3) presents and compares some major available 'nexus tools' highlighting which WEF nexus sustainability component (or goal) they inform and which ecosystem or socio-economic information they consider. The time and resources needed for the application of specific tools can vary and are very context-specific. This compendium can already give insightful information of which nexus aspects or impacts can be assessed with which tools.

In particular, for each tool the following information is provided:

- Title of the tool;
- Nexus elements that are informed among Water, Energy, or Food. The tools give as an output some kind of information useful to assess the status (or the bio-economic pressure) on at least one nexus element;
- Output indicator. In which way (or unit) the information above is provided;
- Description of the tool. A short description of the characteristics of the tool and what it does;
- Geographical scope. At what level the indicator can be applied or has been applied;
- Type of tool. In terms of type of tools, three broad classes of tools are distinguished: input-output tools, where an input provided by the user is needed (or is suggested by the tool itself) in order to run a model and come up with a result; models that can be used as simulator on the basis of specific technical coefficients and level of inputs suggested by the model itself. The user can see how the result changes, changing the input parameters; information resources such as maps can be used by the user to derive directly the desired information (that can be used for a specific analysis/ assessment);
- Target users. The users that are expected to be the usual beneficiaries of the tool (e.g. decision- makers, policy-makers, technical experts, etc.);
- Natural system resources considered. The natural resources that are considered as input by the tool in terms of supply/demand/management. They include energy, water, land or another resource;
- Human system resources considered. The human resources that are considered as input by the tool in terms of supply/demand/management. They include money, human activity, workforce or another resource;
- Author of the tool.

4.6 Assessing the performance of specific interventions



Any intervention can have diverse and multiple consequences and is likely to have a higher impact where resources are already under pressure. This depends not only on the performance of specific interventions but also on the local context (population dynamics, state of natural resources, other external drivers, etc.).

Some key factors regarding interventions (or development opportunities) can be identified in the agriculture-energy domain and examples of these are illustrated in section 5. Every type of intervention is associated with some possible effects that it can have on the ecosystem and socio- economic aspects.

For consistency, all performance indicators should fulfil the following requirements:

- Account only for the impact of specific interventions (how the indicator is supposed to change before and after the intervention)
- Be expressed as percentage
- Increase as the impact of the intervention is higher[46]
- Be comparable to those used for the context analysis (they should apply to the same 'nexus issue')

Bearing the above in mind, the relevant indicators and weights applied in the overall performance should be determined in a consultative process. Table 6 proposes a basic set of indicators for the analysis of performance of interventions for the nexus that can be used to assess and compare interventions. They are consistent with those identified for the nexus context analysis.

46 Therefore, if an intervention requires more workforce for the same amount of produce the indicator will go up; if the intervention requires high capital per unit of ... the indicator will go up; if the amount of water use per unit of ... is higher the indicator will go up; if the energy produced per unit of ... if higher the indicator will go up

Table 6 (part 1 of 2)

A selection of development opportunities and suggested set of key performance indicators for each

INTERVENTIONS (or Development opportunities)	**SELECTED KEY INDICATORS FOR RESOURCES USE PERFORMANCE** (with the Nexus aspect they inform and proposed weights) W=water; E=energy; F=food; L=labour; C=capital; Δ="change in"
Bioenergy	Δ Water used / bioenergy produced (W, 3) Δ Water used for energy crops / cultivated land (W, 2) Δ Energy produced / agricultural land occupied (E, 3) Δ Agricultural land / bioenergy produced (F, 3) Δ Total man hours spent / bioenergy produced (L, 3) Δ n. of skilled jobs created / energy produced (L, 2) Δ Cost / energy produced (C, 3) Δ Income per worker / unit of land cultivated (C, 2)
Power irrigation	Δ Amount of water pumped / energy used (W, 1) Δ Amount of water pumped / fossil energy used (W, 3) Δ Water pumped / irrigated land (W, 3) Δ Energy used / irrigated land (E, 1) Δ Fossil energy used / irrigated land (E, 2) Δ Yield / water consumed (F, 2) Δ Land required by the pump / pumping capacity (F, 1) Δ Land required by the pump / energy generated (F, 1) Δ Income per worker / yield (L, 2) Δ Annual cost (capital, maintenance and operation) / amount of water pumped (L, 3) Δ Value of agricultural produce / annual cost (C, 3) Δ Annual capital and cost expenditure for equipment / working hours saved to irrigate (C, 1)
Hydropower	Δ Water used for additional livestock needed to compensate protein loss / total energy generated (W, 1) Δ Agricultural land expansion for additional livestock needed to compensate protein loss / total energy generated (E, 1) Energy generated / Δ season water flux of the river (E, 3) Δ Energy produced / area of reservoirs (E, 2) Δ Fish yield / energy generated (F, 2) Δ Hours for collecting firewood for energy / person who gained access to electricity (L, 2) Δ Working hours / unit food protein (or calorie) consumed (L, 2) Δ Energy cost / unit of irrigated land (C, 1) Δ Cost / unit energy consumed by people who gained access to electricity (C, 2)
Water desalination for agriculture	Δ Yield / water applied (W, 1) Δ Energy consumed / amount of desalinated water (E, 2) Δ Yield / fossil energy consumed (E, 3) Δ Land occupied by the plant / Water treated (F, 2) Δ Total hours saved from extracting and carrying water / land under cultivation (F, 2) Δ n. of skilled jobs / power installed (L, 2) Δ Income from agriculture / agricultural land (C, 3) Δ Cost / unit of treated water for farmers (C, 2) Δ Value of agricultural produce / annual operating and capital cost (C, 3)

Table 6 (part 2 of 2)

A selection of development opportunities and suggested set of key performance indicators for each

INTERVENTIONS (or Development opportunities)	**SELECTED KEY INDICATORS FOR RESOURCES USE PERFORMANCE** (with the Nexus aspect they inform and proposed weights) W=water; E=energy; F=food; L=labour; C=capital; Δ=”change in”
Energy subsidies for agriculture	Δ Pollutants in water resources / yield (W, 2) Δ Water used / agricultural land (W, 2) Δ Energy consumption / water used (E, 3) Δ Energy used / agricultural land (E, 1) Δ Total energy used / Yield (E, 2) Δ Yield / total water consumed (F, 1) Δ Yield per worker / subsidy (F, 3) Δ Amount of food harvested per worker / cost of agricultural inputs (F, 3) Δ Capital and cost expenditure for equipment / cost of workforce (L, 2) Δ Hours for extracting and carrying water / person (L, 3) Δ Hours for collecting traditional biofuels / person (L, 2) Δ Working hours / unit of land (L, 3) Δ Cost / water used for irrigation (C, 1) Δ Cost / energy consumed (C, 2) Δ Cost / irrigated land (C, 2) Δ Income due to food export (from the system) n. of workers (C, 3)
Food production facility	Δ Amount of desalinated water applied to the field / land where crops are grown (W, 1) Δ Amount of desalinated water applied to the field / yield (W, 3) Δ Fossil energy / amount of desalinated water (E, 3) Δ Energy / amount of desalinated water (E, 2) Δ Energy consumed / amount of crop produced (E, 1) Δ Reclaimed desert land / water produced (F, 2) Δ Fossil energy consumed / amount of crop produced (F, 3) Δ Land used for cultivation (e.g. algae cultivation) / biofuel produced (energy content) (F, 3) Δ Workers / energy generated (L, 2) Δ Working hours / land (L, 1) Δ Workers / amount of vegetables produced (L, 2) Δ Income per worker / yield (L, 3) Δ Annual operating cost / freshwater produced (C, 2) Δ Capital cost / freshwater produced (C, 1) Δ Operating cost / total energy produced (C, 1) Δ Annual capital and operating cost / value of agricultural produce (C, 3)
Other	Set of indicators measuring resource use efficiency to be developed ad-hoc with stakeholders, depending of the type of the intervention

By assigning weights to performance indicators, stakeholders and the assessment team will rank these on the basis of which aspects they feel should be given more importance in the overall performance.
Eventually, each intervention will be assessed for its impact on the five nexus resource factors: Water, Energy, Food/Land, Labour (including employment and/or wages) and Capital (including investment and/or cost) thanks to a selected set of weighted performance indicators. Box 5 provides more details on how to achieve this.

BOX 5 – HOW TO QUANTIFY THE PERFORMANCE OF AN INTERVENTION AND DEVELOP THE ASSOCIATED RADAR CHART

- A set of indicators is selected, which link the amount of a resource consumed (or provided) and another resource (e.g. water, energy power, land, agriculture produce, worker), therefore expressing the use intensity of a resource (e.g. productivity). More details can be found in section 4.4.

- The indicators are measured on the basis of the specific information of the project. These are normally provided by the project developer and should be part of any feasibility study and project impact assessment.

- Ideally two or three performance indicators should be selected for each row or column (i.e. for each nexus aspect). Some indicators related to two nexus aspects can be classified under either aspect, depending on the emphasis that the assessor wants to give. For example, an indicator 'energy produced on change of seasonal water flux of the river' can be a performance indicator for energy or water. If water impacts are more important than energy impacts for the intervention, then this will be considered a 'water' indicator.

- The indicators are expressed as percentage change (hence the Δ symbol), taking as reference:
  – the situation before the intervention (e.g. if an intervention consists of installing a modern drip irrigation system, replacing an older surface irrigation system or hand-made irrigation, the reference to be used should be the same indicator applied to the old system) or, in alternative,
  – a typical intervention that was developed in a similar context.

- The indicators value can be positive or negative, is expressed as percentage, and goes up as the change of the resource use density goes up. Each indicator is weighted from 1 to 3, depending on weights assigned by stakeholders. However, weights for typical nexus agriculture interventions are proposed in table 6.

- If the performance under one nexus aspect is given by multiple indicators, a weighted arithmetic average is calculated, and this is then reported on a scale from 0 to 5 using the thresholds on the side:

≥ +100%	5
50%	4
0%	3
-50%	2
≤ -100%	1
n/a	0

- A high score of the indicator (or the index resulting from the combination of multiple indicators) indicates the intervention as a high impact on the sustainability of the specific nexus component, while a score close to 1 means that the impact is low, and actually the intervention is alleviating pressure on the specific nexus component. 0 means that the intervention was not assessed against that specific nexus component.

- Indicators' directionality is adjusted so that the indicator increases as the impact on the specific resource increases. Therefore an indicator would go up for example if the amount of water, energy, land consumption is increasing, more workers are employed by the intervention, more investments or costs are associated with the intervention and vice versa.

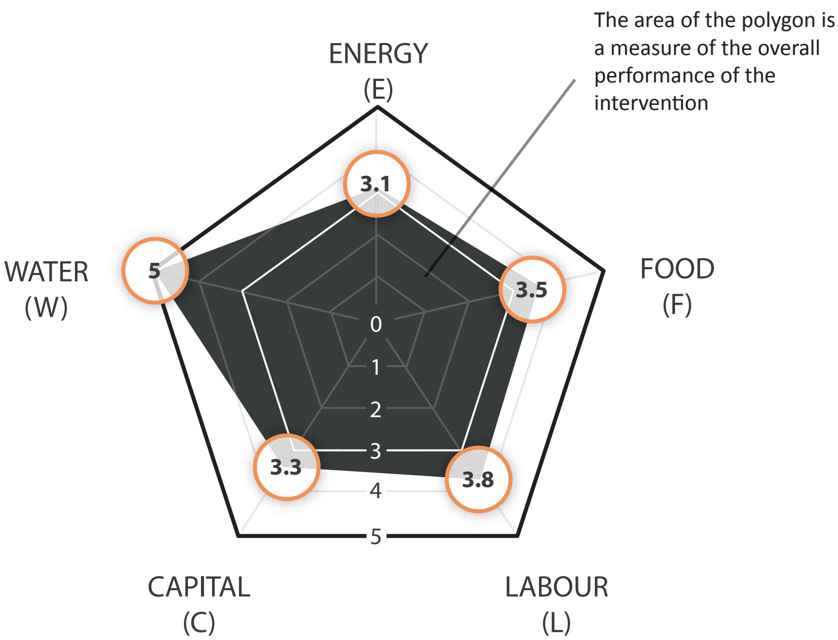
The impact indicators related to the same resource factor can be combined in a single index as illustrated in Figure 5. The results for all resource factors can be visualized in a radar graph and the area of the diagramme is a measure of the overall performance of the intervention. The smaller the size of the polygon, the smaller the impact of the intervention on the nexus aspects.

4.7 An example of *nexus rapid appraisal* in practice

This section quickly shows the type of considerations that can be made on the basis of the nexus rapid appraisal, how the assessment of interventions is presented, and how these can be combined.

Figure 5

Radar diagramme visualizing the performance of an intervention against five resource factors (energy, water, food/land, capital, labour



The examples apply to two case studies presented in more detail in Chapter 5: Case study 6: *On-grid wind energy for water desalination for agriculture* and Case study 5: *The Sahara Forest Project*. For further information about the specific case study, please refer to the relevant sections in Chapter 5.

For the quantitative analysis of the context nexus status, we chose the simplest way, which is using the country typology as part of the nexus rapid appraisal. Since the intervention illustrated in case study n. 6 takes place in Canary Islands (Spain), we assessed the nexus status of Spain in comparison with the selected "*Affluent country, with natural resource constraints*" group, using the indicators and weights proposed in Table 5. The results are shown in table 7.

Table 7

Nexus context indicators and parameters used to calculate the score for each context status indicator, and overall score per nexus aspect (using case study n.6)

CONTEXT SUSTAINABILITY INDICATOR	**CONTEXT** (Spain)	**REFERENCE CONTEXT** (Affluent country group)	**DIVERGENCE FROM THE REFERENCE**	**ASSIGNED WEIGHT**	**SCORE**	**SCORE** (combined per nexus aspect)
Freshwater withdrawal as percentage of total actual renewable water resources (most recent data were used)	29%	40%[47]	-27%	2	1.73	1.99 (water)
Share of monitoring sites in agriculture areas that exceed recommender drinking water limits for nitrates, phosphorous and pesticides in surface water and groundwater	34%	29%	+17%	3	2.17	
Contribution of fossil energy to energy supply (percentage, 2012)	76%	88%	-14%	3	1.86	1.89 (energy)
Energy imports (Percentage of net energy imports estimated as energy use less production, 2011)	75%	80%	-6%	2	1.94	
Net import of agricultural products, food and live animals per capita (1,000$ p.c., 2011)	7.986	13.523	-159%	2	0.41	0.96 (food)
Change in cropland use between 2002 and 2011 (%)	-3.8%	-7.3%	-49%	2	1.51	
Average earning in manufacturing / average earning in agricultural production	2.44	1.42	+72%	1	2.72	2.07 (labour)
Total economically active population in agriculture / Total economically active population, 2013	0.038	0.045	-15%	3	1.85	
Total economically active population in agriculture / Net Production Value of agriculture (people/constant 2004-2006 1,000 int. $, 2012)	0.035	0.096	-64%	1	1.32	1.94 (capital)
Investment share in gross domestic product (GDP), 2012	19.2%	22.3%	+14%	3	2.14	

47 See footnotes in table 5 about the assumptions made and data used to calculate these benchmarks
48 Gross fixed capital formation (% of GDP)

For example, to derive the overall score for water:

- The first water indicator was calculated for Spain using the most recent data about "Freshwater withdrawal as % of total actual renewable water resources" from FAO Aquastat.
- The benchmark for this indicator from Table 5 was used (country typology: Affluent country group. Spain is part of the same country typology).
- For the specific context (Spain), the actual indicator is 27 percent lower than the benchmark, meaning that, for this indicator, this context is more sustainable than the average of the countries of the same typology used for the benchmark.
- To this indicator, a weight '2' was assigned, reflecting the relevance of this indicator to inform water sustainability aspects. The weight was taken from those suggested in Table 5; however, they can be modified by the assessor and the emphasis that needs to be given to a sustainability aspect.
- The score of the single indicator proposes the same "divergence from the reference" (or from the benchmark) from a scale from -100 percent to +100 percent, to a scale from 1 to 3 (2 corresponds to 0 percent).
- The combined score for water is the weighted average of all single indicator scores under the same nexus aspect. The calculation for the first indicator is therefore a weighted average of the water indicators: (1.73*2+2.17*3)/(2+3)=1.99.
- For all values below 1 a green colour (1) is assigned in the graphical visualization, and for all values above 3 a red colour (3) is assigned.

Applying the conversion into colours as explained in Box 4, we obtain the diagramme below (Figure 6). This figure shows that the context (Spain in this case) is performing quite well in terms of pressure on nexus resources. The overall score of energy, water and food sustainability (on the basis of the indicators selected, and the reference country typology used as benchmark) is better than the average, with the only exception of the labour sustainability aspects considered (in this case because of the important salary difference between agriculture and manufacturing sectors).

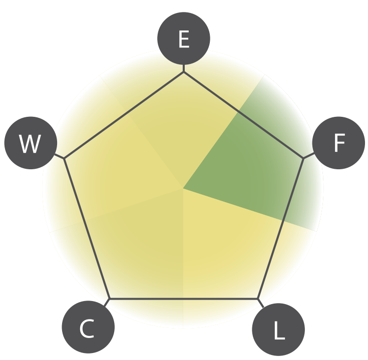


Figure 6

Sustainability assessment of the context for case study n.6. In this case the assessment was based on the suggested indicators, measured at country level, comparing them with the country typology benchmarks (Nexus Rapid Appraisal).

Moving on to intervention assessment, the following performance indicators can be used for the "On-grid wind energy for water desalination for agriculture", selected on the basis of the limited information collected for the case study and the relevance:

Table 8

Nexus performance indicators and parameters used to calculate the score and overall score per nexus aspect (using case study n.6)

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	X	X	X	X
ENERGY	Δ Energy consumed / Amount of desalinated water	X	X	X
FOOD/ LAND	Δ Yield / water applied Δ Land occupied by the plant / water treated		X	X
LABOUR	Δ Direct jobs created / amount of desalinated water	Δ No. of skilled jobs / power installed		X
COSTS	Δ Cost / unit of treated water for farmers		Δ Income from agriculture / agricultural land	

The selected performance indicators are measured and each of them is assigned to a resource, meaning that they will contribute to the overall scoring under that specific resource. Furthermore, a weight is assigned to each indicator on the basis of their relevance, from 1 (less relevant) to 3 (more relevant). Since this is an example, a number of assumptions have been made to estimate the reference values used to measure the change. The indicators (ideally more than one) under each of the five resources considered can then be combined in one single score as illustrated in box 5 in section 4.6.

The calculations presented in this section are just aimed at explaining how the *nexus rapid appraisal* works. They are not very accurate as information on the intervention performance is based on the information received for the case study, while in reality they should be provided by the project proponent as part of a project feasibility study and project impact assessment. Likewise, also the reference values chosen should be taken from similar and comparable projects, or a typical value for resource-use efficiency for the same purpose should be considered (e.g. if the specific intervention is using the water produced to grow tomatoes, a typical value for water use efficiency in a local tomato plantation should be used as reference).

Table 9

Parameters used to calculate the score of each performance indicator (case study n.5)

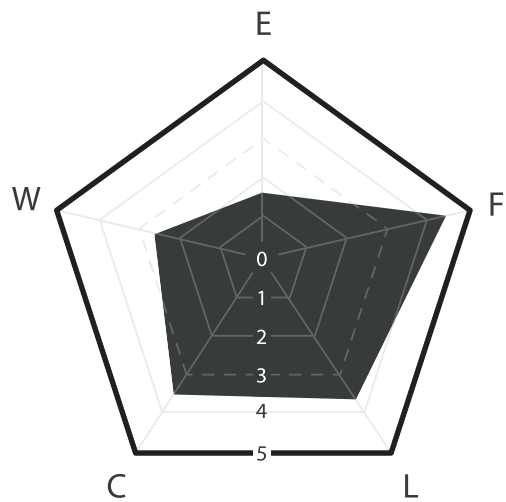
PERFORMANCE INDICATOR OF THE INTERVENTION	ACCOUNTED FOR UNDER WHICH RESOURCE	ACTUAL VALUE IN THE CASE STUDY	WEIGHT ASSIGNED BASED ON THE RELEVANCE	Δ VALUE OF THE INDICATOR	SCORE	REFERENCE VALUES AND ASSUMPTIONS MADE
Δ Energy consumed / amount of desalinated water	E	2.20 kWh/m^3	2	-66%	1.68	Typical energy intensity considered: 6.5 (the UK Thames Water Desalination Plant is 6.8 - http://currenteventsii.yuku.com/topic/22791/Desalination-world-countries-making-fresh-water-ocea#.U5BPwnJrz3c)
Δ Yield / water applied	W	+180%	1	-12%	2.76	Tomatoes yield increases 180%. Compared with similar non-irrigated to irrigated tomatoes cultivations in the area (201%). Similar amount of water applied
Δ Energy consumed / amount of desalinated water	F	11.11 m^3 of water treated per m2 of land occupied	1	+75%	4.5	Typical land occupation of a desalination plant is 45 m^3/m^2, calculated on the basis of the recent plant installed in El Prat, Barcelona (Spain)
Δ No. of skilled jobs / power installed	L	0.00467	1	- 32,143 %	1	Assumption: 1.5 MW of power is used for desalination plant out of 2.64 MW The average jobs/power in Spain is around 1.5 KW p.c.
Δ Direct jobs created / amount of desalinated water	L	0.0014 person/ m^3	2	424%	5	Desalination of 430 Mm^3 of water per year created 315 are skilled jobs in Israel (http://www.il.boell.org/downloads/Friends_of_the_Earth_2011.pdf)
Δ Income from agriculture / agricultural land	C		3	+2,000 %	2.6	Typical income increase comparing irrigated and non-irrigated cropping http://r4d.dfid.gov.uk/PDF/Outputs/RIPPLE/wp- 14-income-diversification.pdf
Δ Cost / unit of treated water for farmers	C	0.55 €/m^3	2	+358%	5	Assuming before the interventions the farmers were using groundwater for irrigation. Cost of underground water pumping for irrigation: 0.12€/m^3 (Spain average)

The scores of each performance indicator are then combined into one single performance score for each nexus aspect (or resource considered). The results are shown in the table and the spider chart below.:

Figure 7

Overall performance of the intervention against the five resources considered and overall score per nexus aspect (using case study n.6)

NEXUS ASPECT	OVERALL PERFORMANCE SCORE
Water (W)	2.76
Energy (E)	1.68
Food/land (F)	4.5
Labour (L)	3.67
Capital (C)	3.56



The results show that the specific intervention "On-grid wind energy for water desalination for agriculture" has a very low impact on energy resources (it is using renewable energy and energy is used efficiently), has a very low impact on water resources (it is using no freshwater and the treated water is transformed efficiently into food), while it has a high impact on food/land (in this case because the area occupied by the plant was considered, and land use is not efficient) and it is using labour and capital quite efficiently. All these 'efficiency considerations' are done from a nexus resource perspective, meaning how much of the specific resource is needed per unit of one or more of the other resources (e.g. how much energy per unit of water, how much money per unit of water, how much labour per unit of energy, etc.).

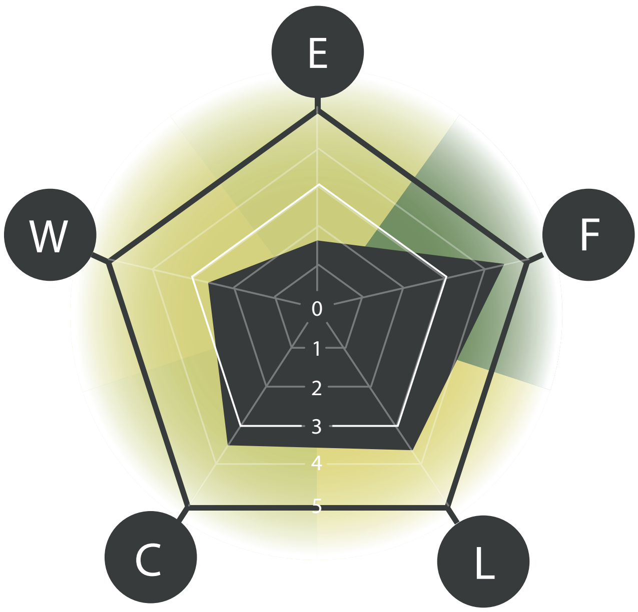
The overall performance of the intervention could be combined into one single index, which corresponds to the area of the polygon on the spider chart. For example, in this case the overall performance is **25.6**.

It should be borne in mind that the performance of an intervention is also a function of the indicators chosen. This means that two performances can be compared only when the same indicators (and weights) have been considered.

The two sets of information about the 'nexus status of the context' and the 'performance of the intervention' are then visualized in one single graph as shown below.

Figure 8

The performance of case study n.6 set against the sustainability of the context



The diagramme shows that this intervention is having a high impact on the land resource. Considering the context as 'Spain', the overall sustainability in terms of food/land is good, and therefore one can be ready to accept such trade off in terms of land resource use. However, in a context of already stressed land resources (as it may be the case in an island), the analysis would provide a different result. The choice of the scale of the analysis always depends on who is doing the analysis and what level of analysis they are interested in. However, as already mentioned, data for the nexus rapid appraisal are usually available at country level, and an ad-hoc study would be necessary to apply the nexus assessment at a different scale.

A similar methodology is now applied to assess the intervention illustrated in case study n.5: *The Sahara Forest Project*. This intervention takes place in Qatar, which falls also under "Affluent country, with natural resource constraints". In this case, the assessment of the context sustainability changes, as illustrated in Table 10.

Table 10

Sustainability indicators considered score for each nexus aspect (using case study n.5). Simplified table.

CONTEXT SUSTAINABILITY INDICATOR	DIVERGENCE QATAR/ REFER ENCE	ASSIGNED WEIGHT	SCORE (COMBINED PER NEXUS ASPECT)
Freshwater withdrawal as percentage of total actual renewable water resources	630%	2	8.30 (water)
Share of monitoring sites in agriculture areas that exceed recommender drinking water limits for nitrates, phosphorous and pesticides in surface water and groundwater	n/a	3	
Contribution of fossil energy to energy supply	+12%	3	-0.99 (energy)
Energy imports	-765 %	2	
Net import of agricultural products, food and live animals per capita	+87%	2	1.45 (food)
Change in cropland use over 2002-2011	-198%	2	
Average earning in agricultural production / average earning in manufacturing	+52%	1	1.49 (labour)
Total economically active population in agriculture / Total economically active population	-86%	3	
Total economically active population in agriculture / Net Production Value of agriculture	+69%	1	1.66 (capital)
Investment share in gross domestic product (GDP)	-68%	3	

Applying the suggested set of indicators and weights (Table 5), Qatar appears to perform well in all sectors, with the exception of water.
For assessing the intervention illustrated in case study n.5, the indicators in table 11 were considered.

Table 11

Parameters used to calculate the score of each performance indicator (case study n.5). Simplified table.

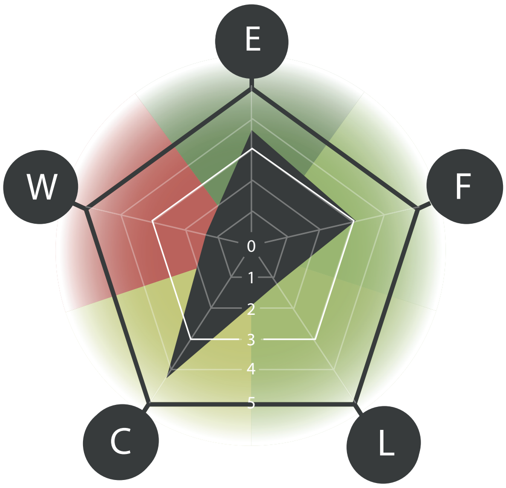
PERFORMANCE INDICATOR OF THE INTERVENTION	ACCOUNTED FOR UNDER WHICH RESOURCE	WEIGHT ASSIGNED BASED ON THE RELEVANCE	Δ VALUE OF THE INDICATOR[49]	SCORE (COMBINED PER NEXUS ASPECT)
Δ Amount of freshwater used / land where crops are grown	W	1	-13 %	1.45
Δ Amount of freshwater consumed / yield	W	3	-99 %	
Δ Land occupied by desalination plant / fresh water produced	E	2	+479 %	3.62
Δ Total energy produced / amount of crop produced	E	2	+13.491 %	
Δ Fossil energy consumed / amount of crop produced	F	1	-100%	3.0
Δ Capital cost / freshwater produced	F	2	+99.9 %	
Δ Operating cost / total energy produced	F	3	+74%	
Δ Energy consumption / amount of desalinated water	L	2	+4.235%	1.2
Δ Land occupied by power plants / Energy produced	L	2	-38%	
Δ Workers / energy generated	C	1	-30%	4.24
Δ Workers / amount of vegetables produced	C	1	-77%	

49 The reference values used are not provided in the simplified version of the table. They have been calculated on the basis of a literature and web review, with a number of underlying assumptions given the illustrative

The overall diagramme resulting from the nexus assessment is showed in Figure 9

Figure 9

The performance of case study n.5 set against the sustainability of the context



The results of the nexus rapid appraisal show that this intervention performs very well in the Qatar context. Indeed, the intervention is not using capital resources (high capital and operating costs) and energy resources efficiency (a large amount of renewable energy – which could be used for other purposes – is needed for desalination and the amount of energy produced per unit of land is low). This is acceptable as the context is not under stress in terms of energy and capital. On the other hand the intervention has an outstanding performance regarding water (water is transformed into food very efficiently and the amount of freshwater used is low) and employment aspects (few people are needed to produce the energy needed and the vegetables); and water is particularly under stress in the context of Qatar.

This example shows how such intervention looks very suitable for the Qatar context (and probably also for other countries with similar characteristics) and the nexus trade-off between high capital and energy needs, would be probably accepted in that specific context.

A similar intervention in a context like the one presented in figure 6 (Spain) appears less suitable, and the trade-offs may not be acceptable for the stakeholders, since they would add pressure on capital and energy in a context which is not water-constraint.

The overall performance of the intervention illustrated in case study n.5 is **15.4** (given by the area of the polygon), meaning that resources are used more efficiently than in the previous example (according to the indicators and weights chosen).

4.8 Comparison of interventions

The assessment of single interventions and of nexus context status can be combined in a single diagramme to highlight where interventions are having a high impact on nexus components that are already at stake (Fig. 10).

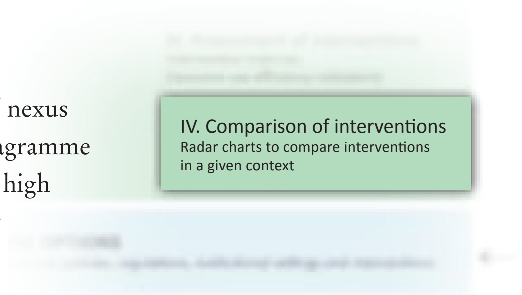
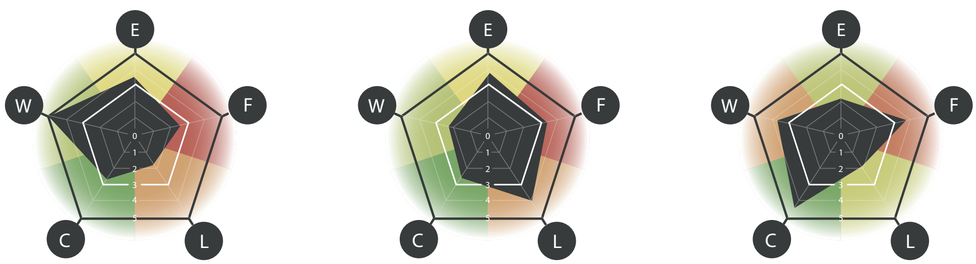


Figure 10

The three examples of visual representations above highlight which interventions are having a high impact on nexus aspects already under stress. They refer to the same country/context.



A. SOLAR IRRIGATION IN REGION a

B. HYBRID DIESEL-SOLAR IRRIGATION IN REGION a

C. MINI-HYDRO IN REGION a

The *nexus assessment* does not suggest which interventions are better than others in absolute terms but just highlights the trade-offs and on which aspects the intervention is adding pressure to nexus sustainability components already not sustainable or at risk of becoming not sustainable. Of course the interventions which have a high impact on nexus aspects which are already under pressure should be avoided.

Again, it should be reminded that both indicators used to measure sustainability aspects and intervention performance should usually be chosen by a participatory process which involves the affected stakeholders. As a result, two nexus context assessments of the same system could appear slightly different because of the weights that different stakeholders gave to different sustainability aspects, and the sustainability indicators chosen.

For example the three diagrammes of Fig. 10 refer to the same country/context, but the indication of context sustainability may change on the basis of the specific 'nexus issue' analysed. For example, in this case, the context analysis of an intervention dealing with irrigation will likely use a different set of sustainability indicators than an intervention dealing with hydropower. This problem is absent when working with a predefined set of sustainability indicators, like the ones presented in Table 5, however the nexus context analysis may be less relevant for the specific intervention to assess.

On the other hand some interventions have always the same performance independently of the context where it is rolled out (e.g. the performance of an irrigation system is the same in terms of energy used per unit of water pumped, cost, employment or energy per unit of land, independently from the context. It may change in terms of food produced or Δ with what was there before).
Decision-makers have two options to avoid adding pressure to a nexus aspect already under stress: they can:

- Choose the specific intervention that has a limited impact on a nexus aspect already under pressure, ready to accept higher impacts elsewhere (e.g. on capital resources need), or

- Consider corrective measures to improve the current bio-economic pressure or sustainability of the society. These should be discussed in a consultative manner and this is an important added value of the *nexus assessment* to trigger the intersectoral discussion.

The *nexus assessment* can be used as a basis to engage in further stakeholder discussion, and move into the identification of *Response options*.

CHAPTER 5

CASE STUDIES

This section illustrates some interventions that touch upon water, energy and food/land at the same time, in a direct or indirect way. The intervention types illustrated can be attributable to the following topics:

- Powered irrigation
- Bioenergy from energy crops
- Energy policies for farmers
- Hydropower
- Resource efficient food production
- Water desalination for agriculture
- Bioenergy from degraded land

At the end of each case study, a table presents some suggested key indicators that can be used to assess the performance in terms of resource use efficiency, of each intervention typology.

The case studies assess the performance of specific technical or policy interventions in regard to their resource uses. They look at both natural and socio-economic resources, focusing on water, energy, food/land/soil, labour and capital cost. Each intervention is assessed for its impact on resource use efficiency, productivity and sustainability (mainly quantity, quality, flow and timing).

The case studies highlight synergetic solutions that take into account the interconnected nature of water, energy and food issues by design. They do not look at how and to what impact interventions can be upscaled.

They do not explicitly address alone how these different interventions contribute to the achievement of broader development goals, nor do they address trade-offs and conflicts between user/interest groups. This can be done as a next step in the assessment

5.1 Case study n.1 – Solar steam irrigation

Case study information kindly provided by Futurepump Ltd (www.futurepump.com).

IN ORDER TO MEET GROWING DEMANDS FOR FOOD, MORE IRRIGATION IS NEEDED THROUGH ENHANCED FLEXIBILITY, RELIABILITY AND TIMING OF IRRIGATION. THIS CASE STUDY ILLUSTRATES AN EXAMPLE OF CHEAP OFF-GRID IRRIGATION PUMPS USING SOLAR ENERGY, WHICH CAN BE USED IN REMOTE AREAS. THEIR IMPACT ON ENERGY RESOURCES IS NEGLIGIBLE, AND AT THE SAME TIME, THEY ALLOW HIGHER AGRICULTURAL YIELDS AND A PRODUCTIVE USE OF WATER. THE PAYBACK TIME OF THIS SIMPLE TECHNOLOGY, WHICH IS DESIGNED FOR APPLICATION IN REMOTE AREAS WHERE FOSSIL FUELS ARE USUALLY EXPENSIVE, IS PARTICULARLY SHORT. ANOTHER DIRECT BENEFIT IS THE TIME LOCAL FARMERS SAVE BY NOT HAVING TO MOVE WATER AROUND.

As in most developing countries, a large part of the population is dependent on agriculture for living with 69 percent of the total labor force involved in agriculture in 2013 (FAOSTAT, 2014). This puts a burden on natural resources in Kenya, especially on water. Farmers in Kenya face a number of challenges from unreliable rainfall to high and volatile energy prices, low crop yields, and lack of access to modern farming technology. According to estimates, there are 2.9 million smallholder farmers in Kenya and only six percent of the farmland is irrigated. Lack of access to energy for irrigation is one of the main factors, which limits the productivity of small farms that rely on rainfed agricultural systems for income generation. Different forms of manual pumping technologies, like treadling pumps, rope and washer pumps, exist. However, they are labour-intensive and physically exhausting. Manual pumping is also only appropriate where water tables are shallow and is almost impossible, where water tables are deep. Diesel or petrol-powered engine pumps offer an alternative, but they also pose environmental risks and have recurring fuel and maintenance costs along with a limited lifespan of 3-5 years. This means that the long-term cost associated with using diesel or petrol powered engines is higher and volatile depending on the price of the fuel. Irrigation and energy use are interdependent,

Figure 11

Traditional irrigation practices in Kenya

© Leonora Enking, retrieved from flickr

as most modern irrigation technologies require substantial amount of energy to run. This in turn could contribute to an increase in yields. Small-scale irrigation systems based on renewable energy could provide a viable alternative to exhaustive manual pumping and environmentally polluting fossil fuel powered generators.

The sunflower solar powered water pump was first developed by the PRACTICA foundation in 2004. The project was later supported by the International Development Enterprises (iDE) and Bill and Melinda Gates Foundation in 2007. Future Pump Ltd joined the partnership, tasked with mass manufacturing, marketing, sales and distributing the product in 2011, and also received support from the Renewable Energy and Energy Efficiency Partnership (REEEP). The Sunflower Pump is an effective and a simple renewable-powered irrigation device, which uses concentrated solar energy to produce steam to run a small steam engine to pump water. Initial field trials were carried out in Ethiopia in 2011 to test the feasibility and performance. In 2013 and 2014 field trials were also performed in Kasikeu in Kenya. Ten pumps were installed at pilot farms on a loan-finance basis. A range of agricultural holdings (cultivating a variety of crops) were chosen in order to provide as much variation in usage as possible. The system has the potential to displace fossil fuel irrigation pumps globally. It presents a practical solution to farmers, who are irrigating manually or not at all, and for small commercial farmers looking for alternatives to expensive fossil fuel pumps.

An added benefit of the solar pump is that it frees children and women from the time-consuming task of manually pumping and carrying water. Additional indirect benefits include encouraging small businesses in manufacturing, assembly, repairs and sales since the sunflower pump can be serviced locally which results in employment generation.

THE PROBLEM TO BE ADDRESSED

The steam pump addresses the problem of the lack of effective and efficient water pumping technology for smallholder farmers. It brings key benefits in terms of access to water for irrigation, which has direct benefits like increased agricultural yield and indirect benefits such as more free time for kids and women to perform other productive activities instead of pumping and carrying water manually. The project does not negatively affect land usage or energy usage as it requires a negligible amount of space to set up and harnesses renewable energy. The key risk that can arise from the use of automated water pumping systems, like Sunflower, is the possibility of over pumping. Locally intensive and continuous groundwater withdrawals are at risk of exceeding rates of natural replenishment, which in the long run may have negative consequences for local and global food production. Although groundwater abstraction provides an invaluable source of ready irrigation water, it has proven to be difficult to regulate.

Future Water Pump Ltd used essential data gathering to analyse the efficiency of the solar thermal systems as well as cost benefits in comparison to other water pumping technologies available such as fossil fuel power generators, diesel and gasoline pumps and PV pumps. The pilot study in Kenya was done in the town of Kasikeu, Makueni County, Kenya. This is around 120 km south east of Nairobi.

The initial trials were based on available spatial data about ground water levels, solar irradiation in Kenya and surveys on smallholder incomes. One of the main indicators that determines the efficiency and functionality of a water pump is the depth to groundwater. For the pilot study, these data were derived from the study conducted by McDonald (2012) coupled with onsite surveying. In addition to this, direct normal irradiance (DNI) also substantially affects the performance of a solar powered water pump. DNI is defined as the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays of the sun. This was estimated based on the data[50] by DLR, UNEP and SWER via Openei.org. In addition to this, the diameter of the collecting disk also determines the total amount of solar thermal energy produced. Through the pilot study it was estimated that with the collector area of 3 m^3 a total of 12,000 litres of water could be pumped in a day from a 7.5 m depth well. This can irrigate around 0.2 hectares, assuming a crop irrigation requirement of 5 litres/m^2/day. The cost benefits for the farmers as compared to diesel pumps are substantial. To assess the potential benefits of using the Sunflower Pump, essential indicators include capital expenditure over a period of 20 years, m^3 of water pumped per day, amount of water required to irrigate a 1 Ha plot and crop water requirement. While the initial cap ex on a Sunflower pump is higher than that of diesel pump, it does not require fuel or lubricants to run, which makes the total operational cost significantly lower. The average daily running cost of diesel pump to withdraw 70 litres of water per day comes to 1.4 USD over a period of 20 years against 0.3 USD for Sunflower Pump for the same duration of time. This directly translates into an average yearly benefit of $400 to the farmer. In addition to the cost savings, this technology helps in displacing fossil fuel, mainly diesel, on a yearly basis. In a typical dry season in Kenya, a 3000 m^2 field requires around 21 m^3 of water per day for irrigation. To pump this amount of water for growing season comprising of about 150 days using a diesel powered pump would require 197 litres of diesel/year.

Given the CO_2 intensity of diesel fuel to be 2.8 kg/l, this would translate into 521 kg of CO_2 per year per generator. This is an added advantage of these solar steam pumps besides decoupling irrigation from the fossil fuel usage.

50 http://www.futurepump.com/solar-dni-in-kenya.html

KEY FACTS

Pumping capacity	Up to 20,000 l/day
Pumping depth capacity	0 to 15 m (ideally 5 m)
Initial capital ex	400 USD
Potential displacement (per pump) of fossil fuel/ CO_2 emissions	197 l of diesel or 521 Kg of CO_2/year
Avoided fossil fuel cost in comparison with a traditional diesel pump (per ha or kl)	800 USD/ha or 11.5 USD/kl
Area irrigated by one pump assuming a requirement of 70 m^3 of water per day per hectare	0.25 ha
Yield increase for cucumber, tomato, kale and lettuce in Kenya after introduction of active irrigation	2.5-3.3%
Land needed to displace diesel	65.6 l/m^2

Figure 12

The solar pump in operation in a field in Kenya (left) and 3D model (right)

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

This technology is a cost effective and convenient way to provide smallholder farmers, who currently do not have efficient water pumping systems or who depend on expensive and polluting diesel powered pumping systems with clean and affordable pumping systems. The case shows that it is commercially viable and practically possible to harness solar power, especially in regions with high solar irradiance.

From this assessment it is clear that solar powered pumps can go a long way in providing decentralized pumping in off-grid areas for the expansion of irrigation and hence cultivated areas, which directly translates into increased income for smallholders due to increased and/or more stable yields. The Sunflower Pump is able to provide water yields in the range of 5,000 – 20,000 litres/day and can operate at the pumping depths of 0 - 15m. It has a low capital cost of around USD 400, which can be offset by savings on fossil fuels, depending on local prices and availability of fossil fuels. With a lifespan of 20 years, the financial break-even point is usually reached after two years after which the investment starts to pay off. There should, however, be some mechanisms in place to access microcredits. Furthermore, technical skills are required for maintenance over time. In places where mostly women and children spend hours to manually pump and carry water (as there is a lack of automated pumping systems), the solar pumps can provide an alternative, allowing for time for leisure, education or paid work. Moreover, the introduction of solar powered pumps can also create local employment through local manufacturing, reselling and service industry.

In this case study, the inter-linkages between water, energy and food targets are substantial. The example of Sunflower Pump demonstrates that a sustainable usage of energy can have an effect on water usage, which in turn can augment food production capacity compared to traditional diesel or gasoline pumps. Water availability for irrigation has a drastic effect on crop yields. In a recent study (Wang'ombe & van Dijk, 2013) on potato cultivation in Kenya, it was recorded that irrigation increased the per hectare yield of potato from 11.7 tonnes to 13.8 tonnes. In another study (FAO & IAEA, 2013) done on cucumber, tomato, kale and lettuce, it was observed that drip irrigation increased the yields of these crops by 2.5 to 3.3 percent. Nevertheless, the risk of continued abstraction of non-renewable groundwater, dropping aquifer levels and deteriorating water quality can present a challenge to local and global food production. The sunflower pump follows a sustainable participatory model of development by ensuring local participation and has direct benefits for the smallholder. Additionally, it also validates the usefulness of decentralized energy systems for rural villages, which do not have access to grid.

Table 12

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	×	×	×	×
ENERGY	Δ Amount of water pumped/ energy used Δ Amount of water pumped / fossil energy used	×	×	×
FOOD/ LAND	Δ Water pumped / land irrigated Δ Yield / water consumed Δ Land required by the pump/pumping capacity (F)	Δ Energy used / irrigated land Δ Land required by the pump / energy generated	×	×
LABOUR	Δ Total hours saved from extracting and carrying water / pumping capacity	Δ Total hours saved from extracting and carrying water / energy capacity installed	Δ Total hours saved from extracting and carrying water / land irrigated Δ Income per worker / yield	×
COSTS	Δ Annual cost (capital, maintenance and operation) / amount of water pumped		Δ Value of agricultural produce / annual cost	Δ Annual capital and cost expenditure for equipment / working hours saved to irrigate

5.2 Case study n.2 – Ethanol production

Case study information kindly provided by PANGEA (www.pangealink.org).

WHEN MANAGED SUSTAINABLY, BIOFUELS, SUCH AS ETHANOL CAN PRODUCE NET ENERGY, DISPLACE FOSSIL FUELS, AND IMPROVE AND DIVERSIFY FARMERS' INCOME, WHILE MINIMIZING THE IMPACT ON WATER. THIS CASE STUDY ILLUSTRATES ONE EXAMPLE OF ETHANOL PRODUCTION TO BE EXPORTED FROM THE SYSTEM. THE MAIN AIM OF THE PROJECT IS TO IMPROVE THE LOCAL ECONOMY BY GENERATING INCOME (WHICH IN TURN, CAN IMPROVE FOOD SECURITY) AND SUBSTITUTE FOSSIL FUELS WITH A RENEWABLE LOW-CARBON ALTERNATIVE.

Silversands Ethanol is a company producing ethanol from sugar beets in South Africa, with past uses including gel for clean cooking and fuel for ethanol-powered buses. It was the first to set up a fuel ethanol plant in South Africa, as well as the first ethanol plant to use maize, sorghum and tropical beet in the country. The Silversands Ethanol factory has the capacity to produce one million litres per year, based on a 24-hour-per-day run for 220 days per year. The sugar beet feedstocks grown on a nearby farm are transported from the farm to the mill in small trucks. Farming operations cover 2,000 hectares altogether, of which the company owns 700 hectares, with the rest comprising communal land farmed on a share crop or rent agreement with local farmers. The sugar beet is grown on 15 to 30 hectares of this farm depending on demand. The annual production of sugar beet on the farm is 124 metric tonnes per hectare, with 113 litres of ethanol produced per tonne of sugar beet (Tricorona, 2012). Waste wood collected from the farm, plus some electricity from the South African grid is used to fuel the process, and steam and animal fodder are produced, the latter at around 10 tonnes per hectare. No electricity is produced from co-generation. After being made into gel fuel, the ethanol is sold to restaurants and households that use paraffin for cooking and heating. The ethanol was also sold to the Johannesburg metro bus company for the buses they ran in conjunction with Scania. Small trucks deliver the ethanol, carrying 3,000 litres at a time. None of the ethanol is exported.

Figure 13

Cover lagoon digester prior to gas production

© Silversands Ethanol

THE PROBLEM TO BE ADDRESSED

Ethanol production initially came about as the Silversands Ethanol farm needed an alternate market for their maize crop. For two years maize prices were so low that they could not afford to sell the crop at prices lower than production cost. Therefore, they began using the maize as feedstock for ethanol production. As the price environment of maize changed they sought more efficient crops to produce ethanol from to remain competitive. Sugar beet was established as a crop that could be grown well in the South African climate. One hectare of maize can produce about 4,000 litres of ethanol, whilst in comparison one hectare of sugar beet can produce about 14,000 litres. An additional push to make the switch to sugar beet came in the aftermath of the food-versus-fuel debate, which saw the South African government deciding not to register biofuel plants using food crops. Therefore, Silversands Ethanol transitioned from the original first grade maize, to third grade maize, and now to solely sugar beets (Food & Beverage Reporter, 2009). Concerns about human health, air quality and climate impacts of traditional cookstoves using biomass and charcoal as fuel also encouraged Silversands Ethanol to develop and produce ethanol gel for clean cookstoves.

The greatest foreseen risk in this case was the competition for the land that would normally be used for food production. However, this was not such a problem due to all the underutilized land in the area, which was in addition to the original driver; finding a use for the food crops when market prices were too low. Silversands Ethanol selected farmland that was already being cultivated, thereby reducing its impact on the environment, biodiversity and habitats. It also met the sustainability criteria of the EU Renewable Energy Directive. The Directive stipulates that biofuels should not be grown on land with high biodiversity and high carbon stock, such as wetlands, and continuously forested areas. The Silversands Ethanol business was privately financed by the shareholders of the company. The farmers benefitted from the new market for sugar beet crops as the demand for these crops was higher than their other crops, resulting in better incomes. Prior to this, the farmers did not produce crops on the land because the price for rice crops was too low for them to make profit. The sugar beet was a new crop and Silversands Ethanol had a share crop agreement with the other farmers, with them growing the sugar beet crops on their land and sharing the profits. Exact figures for the water impact of the business do not exist, but no impact on the supply or quality of the water to the farm or to the local area has been observed. Silversands Ethanol has said that there were no shortages of water on the farm or in the local area. They still use the same water supply without any problems in the water availability or quality in the local community.

A study performed by Tricorona (2012) assessed the impact of Silversands Ethanol's ethanol production on the climate. In this study, Tricorona followed the methodology of the Renewable Energy Directive 2009/28/EC on the promotion of the use of energy from renewable sources. The Renewable Energy Directive (RED) includes default values and typical values for a large number of biofuels based on crop production methods. Typical values are estimations of how large the greenhouse gas (GHG) emission savings are for a normal production of the fuel, using the specified crop and production method, while default values refer to a "worst case" scenario. Producers may apply the default values to their production or assess their own actual data, applying the RED methodology.

For sugar beet ethanol, the greenhouse gas emission savings default value is 52 percent. Therefore, without the company even using actual data, sugar beet ethanol fulfils the RED criteria.

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

Silversands Ethanol's GHG emission savings are 78 percent according to the RED calculation methodology, better than both the EU RED default value of 52 percent for emissions savings from sugar beet ethanol as well as its typical value of 61 percent. The main reason for this is that natural gas is used for steam production in the RED default calculation, whilst Silversands Ethanol collects waste wood from the farm as fuel for the steam production, therefore reducing GHG emissions. Sugar beet crops need 530 mm of water to mature a crop, which is equal to the annual rainfall in the region. However, when rain is not readily available, irrigation is needed during the dry spells. Sugar beet's water efficiency is around 60 m^3/GJ compared to sugar cane's water efficiency of 110 m^3/GJ for ethanol production (Gerbens-Leenes, Hoekstra & Vander Meer, 2009). The fact that the sugar beet ethanol production is located in an area with surplus unused land means that it does not impact on land availability and food security. According to Strydom (2009) Silversands Ethanol created 31 jobs in 2009 for previously unemployed people in the region. The jobs created were for unskilled, semi-skilled and skilled workers. Silversands Ethanol employed unskilled workers and trained them to construct the factory, with further training on how to run the ethanol factory. Most of the jobs provided on the farm were for unskilled workers carrying out field work. These jobs did not exist before, and so they had a positive impact on the income of the people hired in the local community. The price of the ethanol produced is higher than that of alternative fuels such as diesel. However, if Silversands

Figure 14

Silversands Ethanol's sugar beet plantation

© Silversands Ethanol

KEY FACTS

Water consumption: 0.53 m^3 of water per hectare per year

Biomass produced: 124 tonnes of sugar beets per hectare per year

Ethanol biofuel produced: 113 litres per tonne of sugar beets; around 14,000 litres per hectare per year

Overall water efficiency (water productivity): 60 m^3/GJ of ethanol

Animal fodder: 10 tonnes/hectare/year

Local impact on land availability and food security: negligible

Overall GHG emissions savings of ethanol produced compared to gasoline: 66 g CO_2eq/MJ; 78 percent GHG emission saving

Ethanol can increase the capacity of their ethanol production, their ethanol price will be the same as diesel prices or even a little cheaper.

This example demonstrates the importance of identifying the energy, water and food security impact of business operations in a particular region or area. The incentives for a nexus approach include economic efficiency, resource efficiency, and improved livelihood options (Bazilian et al., 2011). The business improved the farmers' livelihoods, as there was greater demand for the sugar beet crops than their previous crops. In addition, the company had a share agreement with the farmers where they grew the sugar beet crops, ensuring they received a share of the profits. The integrated assessment of the energy, water and food impact of the company shows that their ethanol production provides significant GHG savings, as well as adhering to the requirements of the EU Renewable Energy Directive (RED). The use of sugar beets as feedstock by Silversands Ethanol makes use of the most water-efficient crop for ethanol production, as well as being a crop well suited to the area. The use of underutilized excess land in the area ensures that the sugar beets and ethanol production have no negative impact on land availability and food security in the region.

Table 12

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	×	×	×	×
ENERGY	Δ Water consumed / bioenergy produced	×	×	×
FOOD/ LAND	Δ Water consumed for energy crop / cultivated land	Δ Energy produced / agricultural land occupied Δ Agricultural land / bioenergy produced	×	×
LABOUR		Δ Total man hours spent / bioenergy produced Δ n. of skilled jobs created / energy produced	Δ Income per worker / area of plantation	×
COSTS		Δ Total operating cost / energy produced		Δ Capital and cost expenditure for equipment / cost of workforce

5.3 Case study n.3 – Electricity subsidies for farmers in Punjab

THE EFFECT OF ELECTRICITY SUBSIDIES FOR FARMERS IN PUNJAB OVER THE LAST DECADES IS A WELL-KNOWN AND DOCUMENTED CASE STUDY. ACCESS TO CHEAP ELECTRICITY PROVIDED A BENEFIT TO FARMERS IN THE SHORT RUN (INCREASING YIELDS, THROUGH PUMPED IRRIGATION), BUT NEGATIVELY IMPACTED WATER AVAILABILITY AND QUALITY AS WELL AS SOIL QUALITY, DUE TO AGRICULTURE INTENSIFICATION. ULTIMATELY, FARMERS ARE STRUGGLING TO MAINTAIN PROFITS FROM AGRICULTURAL PRODUCTION AND AT THE SAME TIME ARE OVER-EXPLOITING NATURAL RESOURCES.

Punjab is a northern state in the republic of India. It lies on the Indo-Gangetic planes, making it one of the most fertile areas in India. Agriculture is the largest economic activity in Punjab with 62 percent of the total state population living in rural areas out of which close to 7.7 percent live below the poverty line. A total of 6.59 million hectares of land is under the cultivation of food grains in Punjab accounting for 5.5 percent of total agricultural land in India for food grains. Punjab is the second largest producer of rice in India comprising of around 11 percent of total rice production in India and the second largest producer of wheat having a share of 17.4 percent in the total wheat production in India (MoA, 2013). Due to the importance of agriculture in the state, substantial investment in agricultural technology has been made since 1960. This has resulted in 98 percent (Singh, Dhaliwal, & Grover, 2012) of the agricultural land in Punjab being irrigated by the end of 2010-2011. As a result Punjab has a food grain yield of 4258 Kg/Ha, which is amongst the highest in India. Being a part of the republic of India, a majority of the local produce of wheat and rice is procured by the government of India based on the minimum support price. The public procurement programme plays an important role in ensuring food security in India along with providing farmers with fair price for their produce. The rising population in India is putting an ever increasing pressure on agriculture to produce more food by, either increasing the land coverage or by increasing yields. The net sown area of the country has risen by about 20 percent since independence and has reached a point where it is not possible to make any appreciable increase.

Figure 15

Electric pump bringing water from deep underground to irrigate fields in Punjab, India

© Columbia Water Center, retrieved from flickr

Thus, the majority of excess demand for food would need to be met by increases in yields. This puts additional pressure on available input resources for agriculture like water and electricity and may also have a negative impact on soil fertility due to excessive use of fertilizer and tillage.

THE PROBLEM TO BE ADDRESSED

About 80 percent of the Punjab's geographical area is cultivated with cropping intensity of more than 180 percent[51]. Therefore, agriculture in the state is dependent upon heavy requirement of water. The state's surface water resources are limited, and owing to increase in population during the last 50 years, are fully utilized.

Therefore, to meet the ever-growing demand for agriculture, industry and the population, dependency on groundwater has been increasing enormously. Between 1970-71 and 2005-06 the number of tube wells has increased from 0.19 million to more than 1.15 million (Vashisht, 2008). As a result of over pumping of groundwater coupled with declining average rainfall per year, the water table has declined in most part of the state.

From 1982-87, the water table in Central Punjab was falling an average of 18 cm per year. That rate of decline accelerated to 42 cm per year from 1997 to 2002, and to a staggering 75 cm during 2002-06 (Perveen et al., 2011). The over pumping of groundwater is also directly related to the energy subsidies provided by the government to the farmer, which encourages intensive agriculture and consequent impact on underground aquifers.

At the same time, these subsidies are essential to keep the pumping of water and hence agriculture economically feasible, adding to the net economic benefit to the farmer.

Figure 16

A crop field in Punjab, India

While the state of Punjab is now a leading producer of wheat and rice, this was not always the case. The shift from traditional crops, like barley or cotton, to monoculture of rice-wheat system was driven by forces such as price policy, technological change, market infrastructure and low cost of irrigation. Subsidies in various agricultural inputs like electricity, fertilizers and other agricultural equipment acted as a catalyst for agricultural production. In various parts of the state, subsidies have gradually increased over the years. Hence it should be acknowledged that the shift from traditional diversified crops to wheat and rice was due to various food security policies and factors like subsidies and minimum support price, and was not a response to the actual economic returns to the state. In effect, the actual agricultural subsidies provided to the sector increased from around 18 million USD in 1980-81 to around 1 billion USD in 2009-10 (Kaur, 2012). More specifically these subsidies primarily include subsidies on fertilizers and electricity. The electricity subsidies in Punjab have increased from almost 7 million USD in 1980-81 to a staggering 276 million USD in 2009-10. This roughly translates into a subsidy of approximately 2 USD per hectare in Punjab. The subsidized electricity provided by the state has reduced the marginal cost of irrigation in Punjab. A negative externality arising from such a policy is over-irrigation of lands resulting in inefficient use of electricity and underground water resources. The canal system, which irrigates nearly one-third of the total area in Punjab, is limited to five districts of Amritsar, Ferozepur, Faridkot, Bathinda and Muktsar in Punjab. Additionally, the total area under canal irrigation had been declining every year. In 1990-91, the area under canal irrigation was 1.66 million hectares, but fell to less than 1 million hectares in 2000-01. At present 1.1 million hectares are under canal irrigation, which is around 36 percent of the total irrigated area in the state. The move from traditional crops to primarily wheat and rice in Punjab has had a negative effect on groundwater level, especially since paddy is an extremely water intensive crop. It could be argued that the present grim groundwater condition in the state is essentially the result of faulty production practices leading to excessive and irrational use of water. Other factors include restricted availability of surface water, heavily subsidized power supply to the agriculture sector resulting in disproportionate installation of tube wells by farmers.

KEY FACTS

Between 1970-71 and 2010-11:

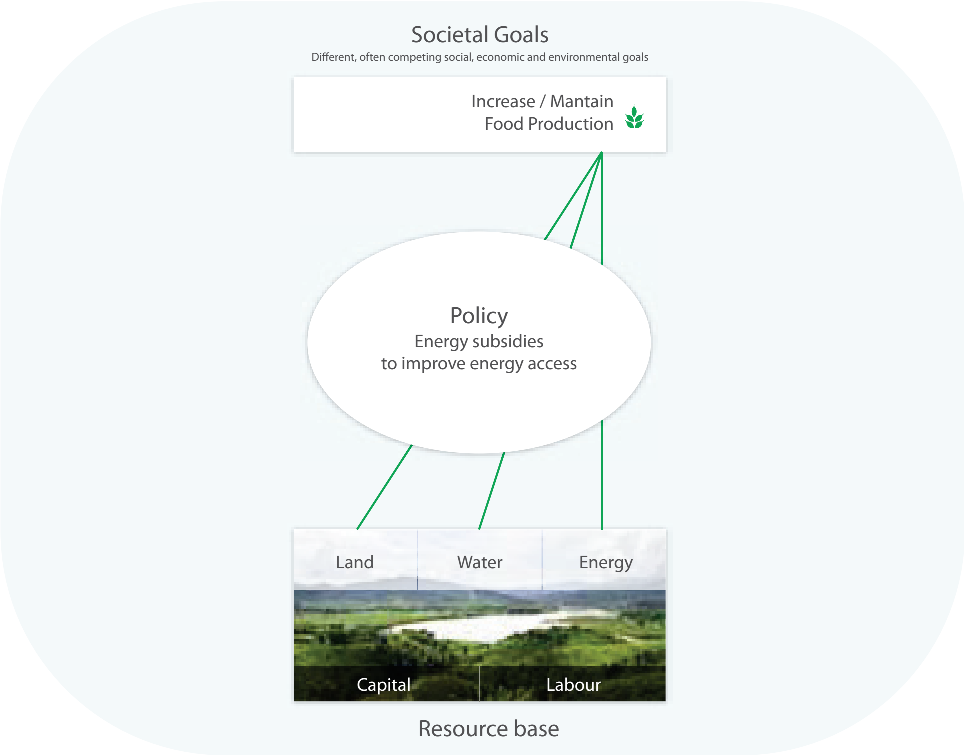
- Electricity subsidy in Punjab increased from USD 6.8 million to USD 275 million between 1980-81 and 2009-10 (assuming 1 USD equals 59 INR)
- The minimum support price for wheat increased from 44,862 USD/tonne to 690,651 USD/tonne
- The minimum support price for rice increased from around 8.6 USD/tonne to around 174.5 USD/tonne
- The percentage of gross cropped area for rice increased from 6.87 percent to 35.85 percent
- The percentage of gross cropped area for wheat increased from 40.49 percent to 44.53 percent
- Yield for wheat increased from 2,505 kg/ha to 4,693 kg/ha
- Yield for rice increased from 2,044 kg/ha to 3,824 kg/ha
- Labour use for wheat decreased from 184 hours/ha to 178 hours/ha
- No. of tube wells increased from 0.192 million to 1.38 million, which corresponds to 4.7 to 33.2 /1,000 Ha
- The water table was falling an average of 18 cm/year in the 80s, accelerated to 42 cm/year in 1997-2002 and to a staggering 75 cm in 2002-2006
- Average energy consumption for wheat in Punjab was 18,816 MJ/ha and for rice it was 30,298 MJ/Ha (1998)

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

The situation in Punjab exemplifies the importance of the inter- linkages between water, energy and food and the effect one sectorial policy can have on other sectors of the economy. This reinforces the need to take into account all three nexus dimensions. Due to intensive farming over the last decades, the yield per hectare of wheat and rice in Punjab has increased manifold. However, the rising population in India would pose a challenge to food security. Dropping water tables could further aggravate the challenge of providing food security as water and energy are intricately interlinked and required to assure food security. Hence, a policy shift in one of the three areas can have a severe impact on the other as exemplified by the effect of energy subsidy on groundwater level in Punjab. In the long run, energy subsidy would further reduce groundwater levels which in turn would severely impact grain production in Punjab.

Figure 17

Relevant nexus relations as currently considered



To ensure faster and more sustainable agricultural development, it is essential to maintain groundwater balance. To this end, the role of subsidies becomes of paramount importance as they can have distortionary effects on the cropping pattern, variations in inter-regional development and on agricultural inputs like water and energy. Additionally, heavy subsidies to agriculture sector means less energy available to manufacturing and service sectors at higher prices. This also has a restricting effect on the development of manufacturing industry resulting in potential loss in employment and state revenues.

In the specific case of Punjab, the government is seeking to diversify the cropping pattern from primarily wheat-rice cultivation to other fruits and less water intensive crops. The change in cropping pattern can also be brought about through various policy measures like establishing a higher minimum support price for other crops which may encourage farmers to diversify cropping pattern. This may, however, also have a negative impact on food security unless the displaced amount of food grain is cultivated elsewhere in the country. Moreover, changes in cropping patterns alone may not have a substantial effect on lowering of water table. A gradual decrease in energy subsidies would play a stronger role in slowing down of water extraction rate in farms, although at the cost of making agriculture more expensive for the farmers. Hence, along with diversifying crops and a cap on subsidies, a concrete public procurement programme for other crops would be more practical. The case of electricity subsidies is a more complex one. While energy subsidies have been increasing, the number of hours of subsidized electricity has been decreasing every year. Due to this, the farmers are dependent on diesel generators or tractors to fulfill their water demand resulting in substantial spending on fossil fuel even though the electricity is subsidized.

A clear assessment of the current state of natural resources, like water and soil quality as well as energy required in agriculture and their interrelations would be required in making informed policy decisions. The gross value added per unit hour of paid work in agriculture in Punjab is around 1 USD/hour, which is substantially less when compared to other sectors of the economy. Therefore, subsidies in various agricultural inputs make agriculture economically feasible for the farmers. On the other hand, a removal or decrease in subsidies could discourage farmers from producing high water intensity crops, thereby slowing overexploitation of groundwater. Reducing subsidies may also make electricity less expensive for other sectors, and may result in an increase in demand for labour and capital. As of now, the government of Punjab is encouraging farmers to install solar powered water pumps by subsidizing the cost of such systems. The obvious benefit of such a strategy is the reduction in energy used by submersible pumps and also a decrease in fossil fuels since a large number of water pumps are run by diesel based generator. However, while such a strategy would be good from a sustainable energy perspective, it would have a minimal or no impact on groundwater extraction since the amount of water being extracted would remain the same. Additionally, most farmers stick to wheat and rice since the government guarantees minimum support price and marketing for these grains. A similar programme for other crops exists but the profit from other crops could be up to 50 percent less. A more active and profitable minimum support price and marketing infrastructure for other crops would further encourage farmers to cultivate other less water intensive crops having a direct impact on groundwater levels

Table 14

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	×	×	×	×
ENERGY	Δ Energy consumption / water used	×	×	×
FOOD/ LAND	Δ Water consumption / agricultural land Δ yield / total water consumed Δ Pollutants in water resources / yield	Δ Energy used / agricultural land Δ Total energy used / yield	×	×
LABOUR	Δ Hours for extracting and carrying water / person	Δ Hours for collecting traditional biofuels / person	Δ Working hours / unit of land Δ Yield per worker / subsidy Δ Amount of food harvested per worker / cost of agricultural inputs	×
COSTS	Δ Cost / water used for irrigation	Δ Cost / energy consumed	Δ Cost / irrigated land Δ Income due to food export (from the system) / n. of workers	Δ Capital and cost expenditure for equipment / cost of workforce

5.4 Case study n.4 – Hydropower dams in the Mekong river basin

THIS CASE STUDY ADDRESSES A SENSITIVE ISSUE AS ENCOUNTERED IN SEVERAL REGIONS OF THE WORLD: THE COMPETITION FOR WATER RESOURCES BETWEEN THE ENERGY SECTOR, AGRICULTURE, AND OTHER PRODUCTIVE SECTORS. IN PARTICULAR, IT HIGHLIGHTS THE IMPORTANT, AND OFTEN UNDER-ESTIMATED IMPACTS THAT A HYDROPOWER PLANT CAN HAVE ON LOCAL LIVELIHOODS AND ON FISH CATCHMENTS, REQUIRING A SIGNIFICANT INCREASE IN PROTEIN PRODUCTION FROM OTHER SOURCES (E.G. INCREASED LIVESTOCK PRODUCTION, CROPPING OR FOOD IMPORT).

The Mekong River is one of the world's largest rivers flowing through China, Myanmar, Thailand, Lao PDR, Cambodia, and Viet Nam. The river is rich in biodiversity and provides water for agriculture, fisheries and energy supply to millions of people. Particularly in the Lower Mekong Basin (LMB), the livelihoods of around 60 million people (ICEM, 2010) depend on the river system as source of food and income generation. Fish and other aquatic animals, such as freshwater crabs, shrimp or turtles, are the main source of dietary protein. Broadly, there are three types of fish habitats in the Mekong basin: i) the river, ii) rainfed wetlands outside the river-floodplain zone, and iii) large water bodies outside the flood zone, including canals and reservoirs.

Recognizing the importance of the Mekong River for these countries, the Mekong River Commission was established in 1995 as the inter-governmental agency that works directly with the governments of Cambodia, Lao PDR, Thailand and Viet Nam to sustainably manage the shared water resources. With the growing population and economic growth in the region, the demand for electricity is increasing rapidly, and is expected to grow at 6-7 percent annually to 2025. As a response, hydropower development has been promoted as a way to provide electricity access to the millions of household in the region. From 1993 to 2005, the economic growth and the requirement of energy increased by an annual rate of about 8 percent in the LMB region (ICEM, 2010). The total foreign direct investment

Figure 18

View of a dam construction site on the Nam Ou

© Challenge Program on Water and Food, retrieved from flickr in order to build the 12 dams is expected to be in the range of USD 18-25 billion (ICEM, 2010).

To satisfy the rising demand of electricity, LMB countries have plans for a total of 12 hydropower dams on the free flowing main stem of the lower Mekong River in Southeast Asia and 77 other dams in the Mekong Basin as a whole. The total estimated hydropower potential in the Mekong Basins is 53,000 megawatts (MW) (ICEM, 2010). To date, 17 hydro schemes on tributary rivers have been completed, totaling more than 1,600 MW, or 5 percent of the total estimated hydropower potential of the Mekong River. The proposed 12 dams on the main stem of the LMB would produce additional energy of 14,697 MW. This represents 23-25 percent of the national hydropower potential of the four LMB countries. The economic value of hydroelectric power currently generated from the Mekong is estimated at USD 235 million per year (MRC, 2005).

THE PROBLEM TO BE ADDRESSED

While the proposed hydropower dams would bring significant benefits in terms of energy access and security, they would also have drastic impacts on the hydrology of the river, and as a consequence, on downstream fisheries and agricultural land. If built, the dams are likely to alter the hydrological regime, and as a consequence, the availability of water throughout the year and across boundaries. If combined with planned large-scale irrigation projects, the dry season flow is likely to increase by 70 percent in Thailand and Lao PDR, but only by 10 percent in Vietnam's Mekong Delta (Pech, 2013). The advantages upstream come with an increased risk of dam operational floods, replacing natural floods and increasing river water levels downstream from a reservoir. Substantial economic losses would occur for farmers in the lower deltas of the Mekong as sediment loads are expected to decrease. Reductions in associated nutrient loads are estimated at 20-65 percent, requiring substantial investments to replace fertilizer inputs to maintain current production levels (Pech, 2013).

The Lower Mekong River contributes significantly to regional employment as well as to regional food security. Around 60 million people (12 million households) live in the LMB countries, out of which around 80 percent rely directly on the river system for their food and livelihoods. The per capita freshwater fish consumption of the LMB has been estimated at 33.7 kg/person/yr (Orr et al., 2012). The region's fisheries industry, integral to the livelihoods of 60 million people, could be severely affected due to a decline in the availability of fish in the Mekong basin. The construction of twelve main stem dams would result in blocked migratory paths, reducing total fish resources by around 16 percent by 2030 as well as a loss in biodiversity. In addition, the amount of annual protein loss by 2030 would be equivalent to 110 percent (ICEM, 2010) of the current annual livestock production of Cambodia and Lao PDR. A decline in fish availability would mean drastic changes in the diets of the people in the LMB region, shifting from aquatic proteins to land-based proteins like livestock, cattle and poultry. These require significant amounts of resources like land and water to produce and market. This may result in changes of cropping patterns, unsustainable development of livestock sector and increased pressure on natural resources - in order to substitute for the lost proteins. A change in the dietary patterns of around 60 million people – moving from heavy consumption of fish protein to a more rainfed, land-based production of protein – would have serious repercussions.

In addition, building dams would also have uncertain impacts on biodiversity, soil nutrients, ecology and people's livelihoods. Around 106,942 people will suffer direct impacts from

KEY FACTS

The impact of 12 dam construction as follows (based on ICEM, 2010 and Orr et al., 2012):

Food Security	Energy Security	Water footprint	Socio-economic benefits	GHG Emissions
Economic loss of USD 476 million/year 54% loss of riverbank gardens 20% of affected agricoltural lands would be permanently lost through inundation or clearing would be inundated Loss of 16% fish resource which is a 360,000 Ton Loss of 7,962 ha of paddy Loss of 22,475 ton of rice/yr	6-8% of projected demand by 2025 Decrease dependance on hydrocarbon based electricity Decrease in import of oil and gas Increased government revenue from power export and taxes Increase in irrigable area and agricoltural productivity in some areas	Increase in water usage for live stock and food production 7% more water required for livestock production Increased irrigation to 17,866 ha of paddy	Direct job creation expected to generate an estimated USD 7.9 billion in wages Proposed FDI in the 12 proposed mainstream projects between 2010 and 2030 is an estimated USD 18-25 billion 6,942 people directly impacted and another 2 Million high risk of indirect impact of reservoir	GHG off-set potential of equivalent to around 52 million tonnes CO_2eq/yr by 2030

the 12 LMB mainstream projects, losing their homes and land and requiring resettlement. More than two million people in 47 districts living within the proposed reservoirs, the dam sites and immediately downstream of the 12 LMB mainstream projects are at highest risk of indirect impacts from the LMB mainstream projects. Such human displacement could result in loss of employment and has an impact on the local and regional labour market.

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

According to the ICEM report published in 2010 the combined effects of dams already built on tributaries and the loss of floodplains to agriculture is expected to reduce fish catch by 150,000 to 480,000 tonnes between 2000 and 2015. In LMB countries around 47–80 percent of animal protein for local residents comes from freshwater fisheries, and 90 percent of this is from capture fish. The per capita freshwater fish consumption of the LMB has been estimated at 33.7 kg/person/year for each of the 60 million people in the Basin (Orr et al., 2012). The 12 mainstream dams represent 6-8 percent of the projected LMB power demand for 2025.

According to ICEM, 90 percent of total electricity in LMB is generated from fossil fuels (natural gas, coal, and oil products). The region as a whole imports about 22 percent of the energy carriers used in electricity generation, and fossil fuel imports for power generation are expected to rise. The official 2025 forecasts estimate LMB regional energy demand to be 820 TWh/year, of which the LMB mainstream projects could competitively supply 65 TWh/year. At the same time, dams would reduce fish catchment in lower basin, which would translate into low supply of animal proteins in LMB countries due to their heavy reliance on fish proteins. In order to substitute this loss of fish proteins, the LMB countries would need to increase livestock production in order to compensate for the decrease in fish catch and protein substitution.

Figure 19

Tributary to the Mekong River, Mekong Delta, Vietnam

Remko Tanis, retrieved from flickr

However, livestock development is a land and water intensive process. In a recent study (Orr et al., 2012), it was calculated that to replace fish protein with domestic livestock protein would require between 13 and 27 percent more pasture land, around 4-7 percent more water, exerting even more strain on forests and water resources. In terms of availability and cost of alternative protein sources, these may be significantly higher since more water and land would be required to grow crops or for livestock development to substitute for the loss of fish proteins. To this end, one of the negative externalities of building dams additional to reduced fish supply, would be the increase in water footprint in agriculture and livestock in LMB countries. The increased pressure on water resources would comprise both green and blue water. The higher pressure on land resources includes grazing land for buffalo, cattle or goat and farms for poultry. It has been estimated that in all LMB countries a substantial increase in pasture land would be required for protein substitution. In Cambodia for example this may be in the order of 25 to 55 percent, and 9 to 190 percent in Laos.

Around 60 million people in the MRB consume on average 27 kg of fish per year and once the dams plans are completed, the decrease in fish availability would result in the need of additional resources for livestock and agricultural expansion. This may in turn result in substantial increase in food prices and, as there is still substantial poverty in LMB countries, even a little increase food prices would jeopardize efforts to ensure food access and availability. Therefore, a proper integrated assessment is required to understand how hydropower would affect food security and changes in water usage. This would help the decision-makers to make informed policy decisions, which would take into account the socio-economic as well as environmental aspects.

Table 15

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	X	X	X	X
ENERGY	Energy generated / Δ season water flux of the river Δ Water consumption for additional livestock needed to compensate protein loss / total energy generated	X	X	X
FOOD/ LAND		Δ Energy produced/ area of reservoirs Δ Fish yield/energy generated Δ Agricultural land expansion for additional livestock needed to compensate protein loss / total energy generated	X	X
LABOUR		Δ Hours for collecting traditional biofuels / person who gained access to electricity	Δ Traditional biofuels / person who gained access to electricity Δ Working hours / unit food protein (or calorie) consumed	X
COSTS	Δ Cost / water consumed for farming	Δ Cost / unit energy consumed by people who gained access to electricity	Δ Energy cost / unit of irrigated land Δ value of agricultural produce/annual cost	

5.5 Case study n.5 – The Sahara Forest Project

Case study information kindly provided by The Sahara Forest Project (www.saharaforestproject.com)

THIS CASE STUDY ILLUSTRATES HOW AN INTEGRATED FOOD PRODUCTION FACILITY GROWS HIGH-QUALITY AND DIVERSE FOOD PRODUCTS IN DESERT AREAS, MINIMIZING ENERGY AND FRESHWATER NEEDS. THE FACILITY IS TECHNOLOGY- INTENSIVE, BUT THE EXPERIENCE COULD BE REPLICATED IN COASTAL AREAS OF OTHER DRY COUNTRIES.

The world is facing considerable challenges in providing food, water and energy security while at the same time tackling the effects of climate change and desertification. The challenges are inextricably linked and, it is in this context that the Sahara Forest Project has developed a solution designed to utilize what we have enough of, to produce what we need more of, using deserts, saltwater and CO_2 to produce food, water, and clean energy.

The Sahara Forest Project has designed a technological system where waste from one technology is used as resource for another. With three core technological components, saltwater-cooled greenhouses, solar power technologies and technologies for establishing outside vegetation in arid environments. The project is established as two entities: a foundation and a private limited company. The foundation is set up to promote the concept of restorative growth, defined as "re-vegetation and creation of green jobs through profitable production of food, freshwater, biofuels and electricity", and to be a creative playground for early-stage concepts and launching of new initiatives. The Sahara Forest Project company is set up as a Norwegian company with the purpose of creating profitable innovation and environmental solutions within the food, water and energy sector.

The project has set out to establish groups of interconnected economic activities in different low lying desert areas around the world. The simple core of the concept is an infrastructure for bringing saltwater inland. Through this infrastructure the Sahara Forest Project aims to make electricity generation from solar power more efficient, operate energy- and water-efficient saltwater-cooled greenhouses for growing high value crops in the desert, produce freshwater for irrigation or drinking, safely manage brine and harvest useful compounds from the resulting salt, grow biomass for energy purposes without competing with food cultivation, and revegetate desert lands.

In addition to its commodity outputs of food, energy and salt, the system also provides climate benefits by sequestering CO_2 in the facility's plants and soils, and by pushing back the accelerating process of desertification through the revegetation of desert areas.

Over the last five years the concept has been developed with an initial focus on implementation in Jordan and Qatar. A fully functional Sahara Forest Project pilot facility is built in Qatar through a partnership with Yara International ASA, and Qatar Fertilizer Company (Qafco).

THE PROBLEM TO BE ADDRESSED

The biggest technical challenge is not with any of the individual components, but in bringing all the technologies together in a well-integrated system where the waste-stream from one technology becomes a resource for another component. A key success factor in addressing this challenge was the establishment of an interdisciplinary team of experts that joined forces to cross traditional borders between different technologies and professions towards the establishment of a truly integrated technological system.

Potential environmental risks identified during the planning and implementation of the Qatar pilot facility included pollution of soil or groundwater with salt via leakages from the saltwater infrastructure, or spillage of the thermal oil used in the Concentrated Solar Power (CSP) system. These risks were addressed through design (e.g. concrete, fully lined ponds for saltwater) and regular maintenance and inspections during operations. No spillages occurred during the pilot's operations.

Potential disruption of existing local ecosystems were avoided by working closely with local ecologists to design facilities in ecosystem conscious ways (e.g. preserving wide thruways for native species, siting buildings to avoid destruction of vegetation stands), and by ensuring the revegetative benefits of the project outweighed any destructive activity during construction.

The first feasibility study for the Sahara Forest Project concept was presented at The UN Climate Summit in 2009 (COP 15 in Copenhagen). Three years later the first pilot facility was opened in Qatar and was showcased at the UN Climate Conference in 2012 (COP 18 in Doha). Through five years of studies, field testing and pilot operations a solid foundation is now in place for enabling the roll-out of the Sahara Forest Project.

Figure 20

View of the CSP panels and greenhouse of the SFP pilot plant in Qatar

KEY BASELINE FINDINGS REGARDING HORTICULTURE AND AGRICULTURE IN JORDAN

Growers in Jordan rely on extraction of dwindling groundwater resources: in 2007, 15 percent of water used was drawn from non-renewable sources and demand continues to increase. Over-extraction leads to water salinization in many areas.

Horticulture in Jordan and similar developing countries in the MENA region is conducted primarily using soil-based methods in simple tunnel greenhouses that offer minimal control of water, nutrients, or pests.

Horticulture and agriculture in Jordan and similar countries are highly vulnerable to pest infestations due to lack of passive protection (e.g. enclosures, non-soil growth mediums), absence of capital for chemicals, and single-crop dependence.

SOLAR TECHNOLOGIES IN THE MENA REGION

For concentrated solar power (CSP) plants, wet cooling is significantly more efficient than dry air cooling; it results in the production of 7-10 percent more electricity for the same infrastructure and operational investment.

Wet cooling using freshwater in traditional cooling towers is not an acceptable option in many sunny arid regions where water is scarce.

Dry air cooling is implemented in projects in the MENA region, but its inefficiency in some cases requires natural gas boosters to improve production during hot periods.

PV panels and CSP mirrors suffer from extensive dust soiling and require frequent washing with distilled water.

Solar technologies still seek traction in the MENA region.

Feasibility studies carried out in Jordan and Qatar have sought to establish baselines of regional agricultural and horticultural practices, regional norms for the solar industries, and land and water resources.

In Qatar, the Sahara Forest Project Pilot Facility brings together a combination of promising environmental technologies:

- Qatar's first operational facility for Concentrated Solar Power.

KEY FACTS

Total land occupied by the facility: 1 hectare

Total land occupied by the seawater-cooled greenhouse: 600 m^2

Water use: 2-3 m^3/day (in the greenhouse during crop production)

Nutrient-rich runoff water which can be recycled and used as fertilizer: 1.5 m^3/day

Desalination water efficiency: 2-2.5 units of seawater are required for every one unit of freshwater produced

Amount of freshwater desalinated with CSP: 10 m^3/day (Backup freshwater during nighttime hours, commissioning and maintenance downtime)

Peak PV power: 40 KW

Employment created: more than 20 full-time jobs (a management team of four on-site experts, two off-site managers, a skilled electrician and 9 unskilled workers in addition to back office)

Worker wages: Fair wages. The company reports to the foundation, in line with SFP's ethical guidelines. Freshwater usage in greenhouse for highly productive crop: 4.6 litre/m^2/day

Crop yield: 25 kg/m^2 (through 12 weeks of production) or >75 kg/m^2/year

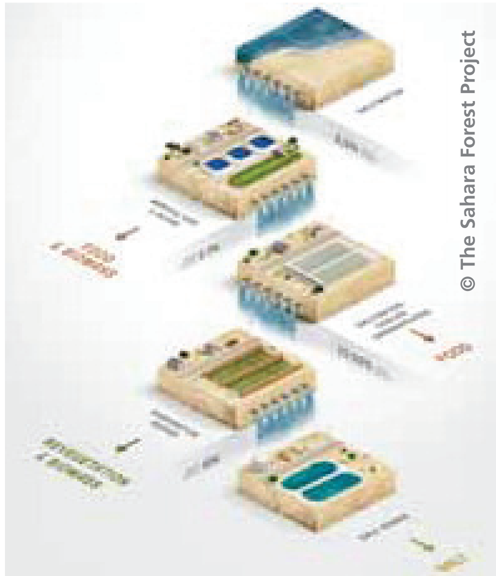
GHG emissions: The major carbon emission attributable to future facilities will be the embodied emissions in the materials used to construct the facility and the fertilizers used in its operation, and in the transport of materials, inputs, and products to and from the site location. Major carbon emission savings at future facilities can come from:

- the production of freshwater and energy with zero-carbon PV or CSP, rather than carbon intensive natural gas, fuel oil, or grid electricity;
- the storage of carbon in desert soils through soil improvement and revegetation;
- the replacement of freshwater for cooling the greenhouse and CSP (which might otherwise be generated through, or force generation of other water through, fossil fuel-powered desalination) with seawater;
- potentially, the production of low carbon algal biofuels and animal feeds.

- Saltwater-based greenhouses utilizing saltwater cooling as the basis for cultivation of traditional crops.
- Evaporative hedges and areas for cultivation of crops and useful desert plants.
- Facilities for cultivation of salt tolerant plants, halophytes.
- A state of the art facility for cultivation of algae that is the first one of its kind in Qatar and the wider region.

Figure 21

The SFP system



WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

2.3 litre/plant/day are used in the greenhouse and produce up to 25 kg/m^2 of cucumber crops, indicating yields at 75 kg/m^2/year for baby cucumbers. The yields obtained in the pilot stage in Qatar are competitive with leading European greenhouse operations. The use of seawater for evaporation in greenhouse pad and fan cooling system reduces total water use of the system by more than 50 percent compared to traditional freshwater systems, and vegetable production is possible in greenhouse 12 months of the year despite summer heat.

However, water use at the facility varies seasonally. Freshwater usage is 2-3 m^3 per day in the 600 m^2 greenhouse during crop production periods, with generation of an additional 1.5 m^3/day of nutrient-rich runoff water. This water can be recycled for use in the greenhouse or, as at the pilot, used as needed to irrigate and fertilize external crops.

Cooling for CSP using the seawater infrastructure (the greenhouses, evaporative hedges and outdoor vegetation) provides near 100 percent of theoretical max wet cooling efficiency. 2-2.5 units of seawater are required for every one unit of freshwater produced through desalination. The waste brine from desalination then serves as the cooling brine for the greenhouse, CSP, and external evaporative hedges. The 600 m^2 greenhouse required 2-3 m^3 of brine each day, while the five external hedges evaporate the remaining brine to near saturation.

So far 19 desert plants and vegetable and grain crops were successfully cultivated outdoors throughout the year in areas with saltwater based evaporative hedges. The plants cultivated include barley, rocket (rucola), *Cymbopogon commutatus* (a silt plant, Vernacular names: incense grass), *Panicum turgidum* (a sand binding grass, Vernacular names: thamam/ ithmam), *Lycium shawii*, (Vernacular name: desert thorn), species of Atriplex (Vernacular names: orache). A variety of desert species with a range of applications, from grazing fodder to bioenergy feedstocks to habitat provision to soil rehabilitation and improvement were cultivated. These include: The flowering halophyte *Limonium axillare* (Vernacular name: sea lavender, the legume *Cassia italic* (Vernacular names: senna) in addition to traditional woody desert species such as Ziziphus and Acacia and medicinal crops such as Aloe vera.

The SFP technologies operated successfully throughout the summer, proving that there are significant comparative advantages using saltwater for the integration of food production, revegetation and energy production.

The seawater-cooled greenhouse is demonstrated to support production of high yields of high quality vegetables year round even in harsh desert environments. The cooling provided by the seawater system can lower temperatures by up to 15 °C on hot and dry summer days, and enables commercial-level vegetable yields with irrigation rates no higher than those in commercial operations in the milder climates of Europe.

Annual production of high quality cucumber crops is estimated to be at least 75 kg/m^2/year; this is extrapolated from a 15-week crop yield at the Qatar pilot of 25 kg/m^2 and the demonstrated ability of the greenhouse to support crops year round. At this production level the greenhouse will be profitable in operation.

With eight hectares of greenhouse production the Sahara Forest Project would match yearly import of cucumbers to Qatar, and with 60 hectares of greenhouse production the Sahara Forest Project would match the yearly import of cucumbers, tomatoes, peppers and aubergines to Qatar (in Qatar more than 90 percent of the national food consumption is covered by import).

Figure 22

Vegetables grown in the desert

Utilization of the saltwater infrastructure to provide wet cooling to Concentrated Solar Power systems was tested at the Qatar pilot, where it provided cooling to a thermal desalination system run on heat gathered by a parabolic trough solar collector. This system in operation showed that cardboard evaporative pads erected as outdoor "hedges" approach the theoretical maximum efficiency for evaporative wet cooling. This proves the potential for using a saltwater cooling infrastructure to simultaneously cool greenhouses, electricity turbines and desalination units, as well as other systems that require cooling such as pack houses, algae ponds, or offices.

This cooling can increase the electricity production efficiency of the CSP by up to 10 percent, which makes a big difference to the bottom line. Moreover, the waste heat taken out of the CSP or other systems can be put to good use, using the greenhouse roofs to distill seawater into freshwater. Making these systems work as interconnected units is a challenge, and significant re-engineering work was required to make the pilot operation a success. At larger scales, a similar learning process can be expected.

By establishing a commercially viable way to bring saltwater into the desert, this intervention also creates opportunities for a wide range of businesses to develop alongside it. These include salt extraction, traditional desalination, algae production, halophyte cultivation, mariculture, bioenergy and more.

Current models of production and single-focus technology solutions neglect and/or waste many resources that can be utilized to achieve restorative growth. Saltwater, desert land and CO_2 are all available in abundance, as are valuable industrial and agricultural wastes full of energy and nutrients. Integrated systems, such as that of the Sahara Forest Project, create synergistic benefits out of waste streams and enable economically viable utilization of unconventional resources such as seawater.

Technology solutions at the food-energy-water nexus cannot stand alone without support from local and regional farming, and industrial and academic communities. The Sahara Forest Project's studies and operations to date have succeeded because of extensive collaboration with local, regional, and international experts and a high level of buy-in from communities and partners. Integrated systems like the Sahara Forest Project make winning such buy-in easier. They significantly change the traditional picture presented by large single-purpose industrial facilities, which create only a limited number of jobs in specialized fields and can compete with local communities for scarce resources such as freshwater. Instead, the combined facility creates a net benefit to the local community, producing food and freshwater that can be used locally in addition to the exported energy, while creating a large number of jobs suitable for a wide variety of backgrounds, from engineers to scientists to growers to agricultural workers.

Table 16

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	X	X	X	X
ENERGY	Δ Fossil energy / amount of desalinated water Δ Energy / amount of desalinated water	X	X	X
FOOD/ LAND	Δ Amount of freshwater used / land where crops are grown Δ Amount of freshwater consumed / yield Δ Reclaimed desert land / water produced	Δ Fossil energy consumed / amount of crop produced Δ Land used for cultivation (e.g. algae cultivation) / biofuel produced (energy content) Δ Energy consumed / amount of crop produced	X	X
LABOUR		Δ Workers / energy generated	Δ Working hours / land Δ Income per worker / yield	X
COSTS	Δ Annual operating cost / freshwater produced	Δ Cost / energy produced	Δ Annual capital and operating cost / value of agricultural produce	Δ annual capital and cost expenditure for equipment / working hours saved

5.6 Case study n.6 – On-grid wind energy for water desalination for agriculture

Case study information kindly provided by the Canary Islands Institute of Technology (www.itccanarias.org)

THIS CASE STUDY ADDRESSES WATER DESALINATION FOR AGRICULTURE, USING RENEWABLE ENERGY SOURCES. DESALINATION IS AN INCREASINGLY HOT TOPIC, WHICH NEEDS LARGE AMOUNTS OF ENERGY TO PROVIDE IRRIGATION WATER IN COSTAL DRY AREAS. LARGE ENERGY CONSUMPTION ALLOWS GROWING NEW (HIGHER-VALUE) CROPS, THEREBY IMPROVING FOOD AVAILABILITY AND ACCESS. GHG EMISSIONS DUE TO DESALINATION CAN BE OFFSET BY USING RENEWABLE POWER.

The Canary Islands are located 1,800 km southwest off the south of Spain, and approximately 100 km west off the African continent. The archipelago has no fossil fuel local resources, nor does it have abundant fresh water natural sources. This is the case particularly in the eastern islands. However, there is plenty of wind, sun and seawater surrounding the islands, so it would only makes sense to consider the production of desalinated water, using locally available renewable resources.

THE PROBLEM TO BE ADDRESSED

On the other hand, the progressive lack of rainfall, the contamination of natural water resources and the increase of local and tourist populations have led to a relevant reduction in the quantity and quality of the natural water sources during the last decades. Desalination technologies provide an alternative source of water to meet growing demands.

The principal water demand comes from the agricultural sector, which has a long tradition in the archipelago (mostly focused on fruits and vegetables). The guarantee of a reliable and good quality water supply at competitive costs for this sector in the eastern islands is only possible by producing desalinated water (in some islands, there is almost a 100 percent dependence on desalination for the water supply).

Figure 23

Wind farm view with traditional saline ponds

KEY FACTS

Total land occupied by the plant: 450 m^2

Amount of desalinated water: 5,000 m^3/day (1.5 Mm^3/year)

Irrigated agricultural land: 150 ha

Energy intensity per unit of desalinated water: 2.2 kWh/m^3

Energy intensity per unit of irrigated land: 2.85 kWh/m^2

The plant is entirely powered with renewable energy (grid-connected wind turbines)

Cost of water for farmers: 0.5-0.6 €/m^3, which is largely offset by the income due to commercialization of the new crops available

Cost of the plant: around 1.1 M€

Operating cost: 150,000 €/year

Direct jobs created: 7 skilled jobs

CO_2 emissions avoided thank to renewables: 6,000 tCO_2/year

Figure 24

Pressure vessels racks of the RO plant

Canary Islands Institute of Technology (ITC)

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

The location of crops in windy areas, close to the shore, is a clear advantage to consider the combination of electricity generation from wind power and water production from desalination plants. The Canary Islands Government has been a pioneer in creating a specific regulation addressed to promote the simultaneous implementation of a wind farm associated with the energy consumption of a local industry. First, local industries were public water companies on the eastern islands (Lanzarote and Fuerteventura) that owned SWRO (seawater reverse osmosis) desalination plants. These were some of the first wind farms to be installed in the early 90s. According to regional legislation, the nominal power of the desalination plant must be at least 50 percent of the installed wind power, and the annual balance of electricity consumed by the SWRO unit must be 50 percent or more of the electric energy generated by the wind farm.

An illustrative example of the canary "water - renewable energy" nexus is the initiative of a local agriculture cooperative (SOSLAIRES CANARIAS S.L.) which installed a 5,000 m^3/d SWRO plant associated to a grid-connected 2.64 MW wind farm (4 x 660 kW wind turbines) in "Playa de Vargas" (East of Gran Canaria Island), with a total investment of EUR 5.2 million (wind farm 46 percent, SWRO plant 21 percent); both installations were commissioned in 2002. The desalination plant occupies around 450 m^2 and is able to produce up to 1.5 million of cubic metres per year for the irrigation of more than 150 hectares. The water produced is of high quality (slightly over 400 ppm) and the plant has an excellent specific energy consumption (approx. 7.9 MJ/m^3, equivalent to 2.85 kWh/ha of irrigated land). The annual electric energy balance (wind energy production minus energy consumption due to water production) is positive, avoiding the emission of more than 6,000 tonnes CO_2/year.

Seven technicians compose the management and technical staff for the tasks related to the wind farm and desalination plant. This personnel cost is around 150,000 €/year.

Thanks to the water quality and the constant water supply, the diversification of crops and ratio of productions has changed drastically. Before this investment, tomatoes were the only crop. Now more than fifteen types of vegetables (gourds, beans, kidney-beans, cucumbers, etc.) are being cultivated. Although the cost of the desalinated water is higher than the existing (low quality) groundwater, the income increment has been significant for the farmers.

Figure 25

Crops watered with desalinated water (inside and outside greenhouses)

The facility produces and sells water to local farmers, assuring the profitability of the system. The wind energy produced is entirely sold to the island energy operator. The regular water cost for the farmer, taking into account the wind energy sale benefit, has resulted in 0.5 to 0.6 €/m^3.

Besides the seven direct jobs which have been created in SOSLAIRES for the technical and management tasks, more than 350 people have been linked to the project in different stages, including farmers.

The 'nexus' has been one of the key themes in the research and development of the Canary Islands Institute of Technology (ITC). The ITC has developed and tested prototypes of different renewable energy driven desalination systems, operating in off-grid mode, since 1996. The ITC facilities in Pozo Izquierdo (Gran Canaria Island) are an ideal platform for testing renewable energy desalination systems thanks to the local excellent conditions: direct access to seawater, annual average wind speed of 8 m/s, average daily solar radiation of 6 kWh/m^2. Up to 18 different combined systems of renewable energy generation and desalination processes have been tested, including small scale (18 m^3/d) and medium scale (350 m^3/d) wind powered desalination systems. A theoretical techno- economic analysis of an off-grid wind farm coupled to a variable operation SWRO plant for a daily demand of 5,000 m^3/d was performed for two locations (Pozo Izquierdo in Gran Canaria, and Tan- Tan in Morocco). The main results are very promising since expected water costs are under 1.6 €/m^3.

Table 17

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	×	×	×	×
ENERGY	Δ Amount of desalinated water / energy consumed	×	×	×
FOOD/ LAND	Δ Land occupied by the plant / water treated Δ Yield / water applied	Δ Yield / fossil energy consumed	×	×
LABOUR	Δ Direct jobs created / amount of desalinated water People that have been linked to the project at different stages / amount of desalinated water	Δ Total hours saved from extracting and carrying water / energy capacity installed Δ n. of skilled jobs / power installed	Δ Total hours saved from extracting and carrying water / land under cultivation Δ Income from agriculture / agricultural land	×
COSTS	Δ Cost / unit of treated water for farmers		Δ Value of agricultural produce / annual operating and capital cost	Δ Capital and cost expenditure for equipment / cost of workforce

5.7 Case study n.7 – Bioenergy from degraded soil

Case study information kindly provided by PANGEA (www.pangealink.org).

DEGRADED OR CONTAMINATED SOIL CAN BE THE RESULT OF SEVERAL PRODUCTIVE ACTIVITIES, SUCH AS THE MINING SECTOR OR NON-SUSTAINABLE AGRICULTURE. WHEN THE SOIL IS NO LONGER SUITABLE TO GROW FOOD, AN ALTERNATIVE IS TO USE IT TO GROW ENERGY CROPS, WHICH CAN CONTRIBUTE TO SOIL RESTORATION OVER TIME. THE COMBINATION OF BIOENERGY CULTIVATION WITH SUSTAINABLE BIOENERGY CONVERSION PROCESSES SUCH AS BIOGAS CAN MINIMIZE WATER CONSUMPTION, WHILST PRODUCING NET ENERGY AND RESTORING LAND. THIS CAN BE DONE THROUGH FERTILIZER CO-PRODUCTION.

South Africa is faced with a rapid increase in waste due to rapid urbanization, population growth and higher living standards along with the associated increases in consumption. This is in addition to economic activity in industry, agriculture and mining, which also contribute to the waste.

Selectra is a South African company working within the water, waste and energy nexus, promoting biological solutions and treatments developed by the Slovenian EKO GEA. The EKO GEA system feeds and protects the microbial populations required in all biological processes, from crop and soil agriculture to waste treatment and elimination. In 2012, Selectra developed a system to cultivate plants on severely impacted mine land, which has little or no economic value give the high incidence of heavy metals and other pollutants, as well as the low pH-levels of the treated soils. The initial trials with sugar beet and sorghum showed that it is possible to establish energy crops on impacted land after pH correction and biological stimulation using the EKO GEA process. In 2013, Selectra signed a pilot project agreement with VIASPACE to test the suitability of a fast-growing perennial grass that can be used in a number of downstream processes such as low-carbon thermal electricity generation, production of environment-friendly pellets for energy, and as a feedstock for bio-methane and cellulosic biofuels production.

THE PROBLEM TO BE ADDRESSED

Mining in Africa is a major driver of growth with the continent producing more than sixty metal and mineral products, and hosting around 30 percent of the world's total mineral reserves (African Development Bank, 2012). Mineral waste is that which is generated during the extraction, beneficiation and processing of minerals and is presented in liquid or solid form. These wastes include the soils excavated to reach the rock mass (where the minerals are usually located) that has no economic value and must be withdrawn to reach the ore. The mill tailings, a mixture of fine particles and water, produced at the concentration plant are another form of waste. On top of this, other negative effects are due to mine waters pumped to the surface, sediments produced by clarification of waters from the mine or the mill, and the sludge produced by the treatment of contaminated water, especially acidic waters.

Selectra's mining programme is driven by the need to address mining impacts in Gauteng, South Africa, which has 379 mine residue areas, covering 32,086 hectares (Department for Agriculture and Rural Development, South Africa, 2012). These mine residue areas have negative effects on the environment in terms of landscape and visual amenity, contamination of land, air, surface water and groundwater, local flora and fauna as well as on the health of local populations.

Selectra addresses the impacts of derelict land on local populations, restoring the land by growing energy crops. Pollution plumes are first controlled and then reversed. The intervention does not affect local food security as the energy crops are grown on mine-impacted land not suitable for food or feed production. The plants take up contaminants and heavy metals through phyto-accumulation, an interaction between the soil, microbes and plants.
Initially, the giant grass was planted to evaluate its performance in the mine and was used as a windbreak to prevent both dust from spreading and soil erosion; it can also adapt to its surroundings and thrive in poor quality soil. This particular type of grass was chosen because of its high yielding characteristics, its ability to flourish under harsh conditions and for the fact that it does not directly compete with food crops. After use, re-growth is significantly faster than the initial harvest because the plant establishes an excellent root system, (Sample, 2013) and once the grass has been established it can be harvested at 0.9-1.5 m tall for biogas production every 45-60 days.

The energy output or energy yield per hectare per year of the specific grass is high, leading to lower cost biomass for energy production, biofuels and biomaterials (ibid). At around 1 m tall, the grass can produce an annual yield of 375 metric tonnes per hectare, and a biogas plant can use a 70 hectare plantation to generate 3 MW of energy, which could translate into 1 MW electricity, 1 MW of heat and 1 MW energy loss.

Figure 26

Degraded land due to mining operations

KEY FACTS

Occupied land area: 70 hectares

Land use efficiency: 100 ha/MW of actual useful energy produced

Energy generated: up to 1MW; 71,000 GJ/year

Grass yield: 375 metric tonnes per hectare

Energy power potential: 3 MW over 70 Ha

Energy produced per unit of land: 42 KWh/ha/year

Water desalination efficiency (freshwater produced/water used): 500 litres of freshwater; 10,000 litres of total water used (=5 percent)

Amount of water used: 2,000 litres/ha/year

Water quality: Discard water is used for irrigation of crops along with the digester inorganic residues

Water used for irrigation: 800 mm per season

Soil quality improvement: Soil is currently Class III to Class VI –Expectations are to improve to Class II and in some instances to Class I

Fertilizer use: residues for the digester are spread onto surrounding fields

Jobs created: 10 well paid full-time jobs

Total capital expenditure for the project: around 5 million USD

Heat/electricity produced per litre of freshwater: 0.1 kW of heat/electricity per litre of fresh-water Energy produced per worker: 100 kW

In the mine tailings footprint, the grass is particularly useful as the subsurface root system adds organic matter and helps create soil from the crushed rock, returning the soil back to its fertile state by absorbing heavy metal contaminants from the soil and contributing to remediation. The feedstock produces electricity via direct combustion or anaerobic digestion which produces biogas and can replace fossil fuels.

Additional outcomes for the project include job creation through the involvement of local farmers, as well as the provision of an environmentally sound and green method to restore mine tailings and generate carbon neutral electricity for local homes and businesses.

WHAT AN INTEGRATED ASSESSMENT HIGHLIGHTS

A nexus-relevant intervention is used to create an opportunity presented by mine residue areas, reducing or reversing environmental impacts. To assess the potential efficiency and sustainability of the pilot project, nexus indicators were considered, and included information on efficiency of energy conversion and distribution, contaminant discharges of liquid effluents per energy produced, and soil acidification. Further, a potential risk was linked to access to water resources, specifically the total amount of water used, if activities are established in an area with limited fresh water.

The total energy input used for running the plant, is generally 10-15 percent of energy produced. The energy produced can be up to 1 MW. This plant requires 200,000 litres of water on an annual basis to operate and, within this freshwater used around 5 percent of total dilution water is required. The system recycles 95 percent of the water from digestate back to the dilution tanks and the remaining 5 percent of this water is discarded to surrounding fields after treatment.

From this it is clear that the sustainable conversion of energy crops grown on degraded land is possible with high inputs, plus limited use of water, and with no direct competition with food production.

The plant is able to create three separate products: energy (sold to partners and local communities), clean water and fertilizers (which in turn can provide a benefit for food security). However, there are trade-offs associated with the process that must be considered. For example, what will happen once contaminated soil will be returned to their fertile state? Then the debate over fertile land will begin: will this land be reserved for partner mining companies or sold to locals for additional farming?

This example shows an application, which solves a 'waste problem' by using limited external energy and water on contaminated soils.

Figure 27

Giant grass grown on mine impacted land and nursery

Table 18

Suggested indicators to assess the performance of the type of intervention

	WATER	ENERGY	FOOD/LAND	LABOUR
WATER	X	X	X	X
ENERGY	Δ Energy (electricity and heat) produced/Amount of wastewater treated Δ Total water consumed/ amount of energy generated	X	X	X
FOOD/ LAND	Δ Plant area/ treated water Δ Total wastewater/ treated water Δ Treated water/ land irrigated	Δ Energy consumed / Land Δ Energy (biogas) supplied/ household	X	X
LABOUR		Δ Hours for collecting firewood for energy/person Δ Jobs created/ energy generated	Δ Working hours/ unit of land Δ Income per worker/yield	X
COSTS		Δ Cost/treated water	Δ Cost/energy generated	X

CHAPTER 6

SUMMARY AND WAY FORWARD

This report presents a concept of the Water-Energy-Food Nexus and devises a systematic way to carry out a *nexus assessment* in a participatory way.

The nexus assessment approach is proposed. It consists in a stepwise methodology to assess the nexus context status, and also the performance of different technical and policy interventions against the country status. The *nexus assessment* can also be run independently in a non-participatory manner through a *nexus rapid appraisal* and, for this purpose, a number of key indicators and information sources are proposed.

The information set generated by the *nexus assessment* helps decision-makers in four ways:

1. **Help decision-makers within government, companies or development agencies in addressing nexus issues in a stepwise, robust and yet cost effective way**
   As decision-makers can use a pre-existing framework like the FAO Nexus Approach, they can prepare better for the increased need of integrated cross-sectoral assessments. By understanding how main interactions between water, energy and food systems take place and what tools can be applied to better quantify these interactions, decision-makers can better understand the analytical patterns and how they link to other relationships within the Nexus Approach.

2. **Assist decision-makers to assess and compare different response option**
   Decision-makers can apply the *nexus assessment* to evaluate potential projects or policy interventions to support nexus considerations against the deployment context. The assessment can also be done in a more rough and rapid way (*Nexus Rapid Appraisal*) relying as much as possible on existing data and indicators, and information usually provided by the project proponents.

3. **Support decision-makers in identifying inter-disciplinary teams of experts that have the right abilities to carry out an integrated analysis of the impacts and sustainability assessments**
   This is fundamental for assessing cross-sectoral and inter-disciplinary issues that may require a particular standard of expertise. For a full-fledged *nexus assessment*, specific skills may be required to run each analytical tool, and inter-disciplinary skills are required to make the specific results ‘talk to each other’.

4. **Help plan nexus related interventions and related identifying training need**
   The *nexus assessment* can provide the basis for an in-country training planning.

The application and use of the *nexus assessment* is subject to the availability of data and the right technical expertise. It is therefore important that countries or relevant actors identify experts, define training needs and consider the required data sources and consider how this may affect the time frame for implementation of the tools. While the use of several specific models permits a better quantitative identification of the many relationships between natural resources, food security, and human resources, it is suggested to focus only on the most relevant relationships. A context analysis and a matrix highlighting the interlinkages between water, energy and food systems can help with this. Users may select the tools they use as well as the scope of the analysis (including multi-scale and multi-level analysis) in order to reflect the policy priorities (e.g. of the country).

The results of the *nexus assessment* can be used to compare the impacts of different interventions on water, energy, food, employment and capital costs, or to see how the same intervention performs in different contexts. All this allows for flexibility for the assessor to prioritize and give importance to the indicators and the 'nexus' interlinkages they deem more relevant on the basis of their own targets and aims, through a *weighting system*.

The Nexus Approach, its analytical components and the *nexus assessment*, is a flexible instrument that can be integrated and complemented as necessary. The selection of specific tools to quantify sustainability indicators will depend on the user's or country's priorities and strategies and also on the priorities of the society in which the approach may be applied.

The case studies presented in this report are linked to agriculture-related interventions, such as irrigation for agriculture or biofuels. However, the same framework concept and the linkages among sustainability aspects can be adapted to other sectors (it would require the identification of ad-hoc relevant issues, adaptation of the nexus matrices and an ad-hoc metric). Moreover, the main nexus aspects considered (water, energy, food/land, employment and capital) can be modified to accommodate other aspects deemed relevant such as for example climate change/emissions. Furthermore, the user can decide to detail as preferred the type and number of indicators that inform about a specific nexus component, detailing a specific issue further and focusing on a specific side of the problem. With these additions, analysis and conclusions on the theme at hand can be drawn out further.

For example, information on the effects of climate change in the context component, along with information on the performance on emissions of an intervention, can be specifically evaluated if climate change is a relevant nexus component to be investigated. In the same line, if the main focus is rural development and employment, an emphasis could be given to the set of indicators directly informing these two aspects in the choice and weights of indicators.

Key stakeholders are invited to engage in the assessment process, making the different goals, targets and strategies of different actors explicit and trying to reconcile these. Ideally, this will raise awareness of the interlinked nature of global resources systems to be considered in decision-making processes. This is particularly important when 'silo' approaches have led to unsustainable policy and development decisions. The Nexus Approach provides an innovative and flexible framework to systematically assess cross-sectoral interactions. The *nexus assessment* is an interesting tool for analysis and for triggering more inter-disciplinary work.

In sum, the proposed *nexus assessment* helps "walking the talk" regarding nexus promotion. It is innovative in many ways:

- it provides a stepwise process to address policy-making and intervention in a nexus manner,
- it combines quantitative and qualitative assessment methods,
- the indicators it proposes have been selected on the basis of available international datasets in case one wishes to carry out a rapid nexus context appraisal, as second best option to generating context specific information
- last but not least, it considers it is essential to link intervention assessment to context status as a key condition to assess the sustainability and appropriateness of interventions. The approach shows how to do this in practice.

Given its innovative character, the proposed approach should be considered work in progress, to be improved as lessons from its implementation will be drawn.

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ANNEX 1 – SELECTED INDICATORS FOR NEXUS LINKAGES

The three tables below contain a list of indicators or data collected to build indicators that have been measured or are envisaged to be measured by a number of international organizations. They are usually available at national level but not always.

These sustainability indicators deal with energy and water sustainability and food security components. In particular, the information contained in the three tables can be combined ideally in a 3D matrix so that each cell is relevant for one specific combination of one water sustainability aspect, one energy sustainability aspect and one food security aspect.

The indicators are also grouped by 'nexus issue', consistently with tables 2-4 in chapter 4.

The indicators (or the data used to build them) are taken from the following sources, while those in italics are relevant (ideal) indicators that do not come from a specific source:

a) FAO Statistical Yearbook / FAOSTAT Database, 2014 (http://faostat.fao.org/)
b) Indicators of Sustainable Development, UNDESA, 2007 (www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf)
b) World Bank Open Data, 2014 (http://data.worldbank.org/indicator)
d) Energy Indicators for Sustainable Development, IAEA, UNDESA, IEA, Eurostat, EEA, 2005 (www-pub.iaea.org/MTCD/publications/PDF/Pub1222_web.pdf)
e) The Global Bioenergy Partnership Sustainability Indicators for Bioenergy, GBEP/FAO, 2011 (www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf)
f) Asian Water Development Outlook, 2013 (www.adb.org/sites/default/files/pub/2013/asian-water-development-outlook-2013.pdf)
g) Poor People's Energy Outlook 2013, Practical Action, 2014 (http://practicalaction.org/ppeo2014)
h) MEPI Index, UNIDO (www.un-energy.org/measuring-energy-access and http://www.mdpi.com/2071-1050/5/5/2060)
i) UNECE Statistical Database, 2014 (http://w3.unece.org/pxweb/)
j) OECD Agri-environmental indicators, 2014 (www.oecd.org/tad/sustainable-agriculture/agri-environmentalindicators.htm)
k) AAccess to Modern Energy: Assessment and Outlook for Developing and Emerging Regions, IIASA, UNIDO, GEF, 2012 (www.iiasa.ac.at/web/home/research/researchPrograms/Energy/IIASA-GEF-UNIDO_Access-to-Modern-Energy_2013-05-27.pdf)
l) FAO Aquastat, 2014 (www.fao.org/nr/water/aquastat/data/query/)
m) State of Food Insecurity (SOFI) 2013, FAO (www.fao.org/publications/sofi/2013/)
n) Demographic and Health Surveys, USAID, 2014 (www.statcompiler.com/)
o) Eurostat database, 2014 (epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes)

p) GEMSTAT-UNEP Water Quality Index to Assess Country Performance, 2014 (www.gemstat.org/queryrgn.aspx)
q) European Environment Agency Waterbase, 2014 (www.eea.europa.eu/data-and-maps#tab-datasets)
r) IGRAC Groundwater Resources Assessments, 2014 (www.un-igrac.org)
s) WHO/UNICEF Joint Monitoring Programme (JMP) for WASH, 2014 (www.wssinfo.org/)
t) Transparency International Global Corruption Report, 2008 (www.transparency.org/research/gcr/gcr_water_sector)

Table A.1 (part 1 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and sustainable water objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant for all sustainable energy components
ACCESS TO WATER RESOURCES FOR DIFFERENT USES	**Water pumping and groundwater management** Annual freshwater withdrawn (% of total freshwater withdrawals sector wise (agriculture, domestic, industry) [b] Actual renewable groundwater resources (m^3/capita/year) [l] Total groundwater abstraction/ Exploitable groundwater resources [l] Groundwater quality [q, p] Salinity levels in groundwater sources [r] *Annual freshwater withdrawn disaggregated by energy source* *Dependency on groundwater for agriculture and other uses (as percentage of total water use)* *Number of farmers dependent on groundwater for agriculture activities / Total population of the country* **Energy for clean drinking water** Composition of final energy use for cooking in rural and urban households (electricity, LPG, kerosene, coal , biomass) [k]	**Energy efficient water technologies** I. Productivity of irrigated agriculture [f] II. Independence from imported water and goods [f] III. Resilience (percentage of renewable water resources stored in large dams) [f][52] IV. Productivity (financial value of industrial goods relative to industrial water withdrawal) [f] V. Consumption rate (net virtual value of industrial goods relative to water withdrawals for industry) [f][53] VI. Utilization of total hydropower capacity [f] VII. Ratio of hydropower to total energy supply [f] [54] Weighted share of people using different water pumping technology [55] [g]	**Dams and hydropower** Utilization of total hydropower capacity [f] Ratio of hydropower to total energy supply [f] Total dam capacity (national) in km^3 [l] Primary production of renewable energy (total and disaggregated by hydro) [o] **Bioenergy production** Water withdrawn for the production and processing of bioenergy feedstock, including: Volume of water for the production and processing of bioenergy feedstock per unit of bioenergy output, disaggregated into renewable and non-renewable water sources [e] Transport energy intensities [d] Bioethanol and biodiesel production (ktoe) [j] Primary production of renewable energy (total and disaggregated by biomass and renewable waste) [o]	% of people with access to improved water access (piped water supply) [c] Access to improved sanitation (%)[56] [c] Hygiene (age-standardized disability-adjusted life years per 100,000 people for the incidence of diarrhea) [c] Improved water source, rural and urban (% of rural /urban population with access) [c] Annual freshwater withdrawals. Total and disaggregated by agriculture, domestic, industry) [c]

52 I, II and III are components of the *Agricultural water security sub-index* of the *Asian Water Development Outlook (AWDO) 2013*. It measures how countries are ensuring the productive use of water to sustain their economic growth in food production, industry, and energy. The AWDO team developed sub-indexes for each of the three sectors, using three main indicators that characterize water security. Each sub-index is evaluated on a scale of 1–10, with 1 being insecure and 10 being secure. The mean scores for each sub-index give the total economic water security of the country's economy. The maximum score for the index is 30 (10 points for each of the 3 sub-indexes that make up the index). A factor for resilience is incorporated into each of these sub-indexes to indicate the intra and inter-annual rainfall variability and water resources storage. (ADB, 2013)
53 IV and V are components of the *Industrial water security sub-index* of the *Asian Water Development Outlook 2013*
54 VI and VII are components of the *Energy water security sub-index* of the *Asian Water Development Outlook 2013*
55 According to the multi-tier framework for mechanical power developed for the Poor People's Energy Outlook 2013
56 Used to build the Household water security index of the Asian water development outlook 2013

Table A.1 (part 2 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and sustainable water objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant for all sustainable energy components
ACCESS TO WATER RESOURCES FOR DIFFERENT USES (cont'd)	Source of drinking water (disaggregated by piped water, well water) [n] Time to water source [n]: - Water within 15 minutes; - Median time to water **Water desalination** Desalinated water produced in km^3 per year [I]			
SUSTAINABLE USE AND MANAGEMENT OF WATER RESOURCES	**Water for power generation** Amount of cooling water required for conventional power plants (nuclear and fossil-fuelled) **Hydropower production** Utilization of total hydropower capacity [f] Ratio of hydropower to total energy supply [f] Resilience (percentage of renewable water resources stored in large dams) [f] **Irrigation systems** Area equipped for power irrigation (HA) [I] % of area equipped for irrigation power irrigated [I] **Water pollution by fossil energy use** Contaminant discharges in liquid effluents from energy systems measured in Kilograms (kg) or milligrams (mg) per liter [d] Oil discharges into coastal waters measured in Tonnes [d]	**Irrigation systems** Area equipped for power irrigation (HA) [I] % of area equipped for irrigation power irrigated [I] Area under agricultural water management (Hectare and %) [I] Irrigation potential (Land area that can be irrigated) [I] % area equipped for full control irrigation actually irrigated [I] Area equipped for full irrigation by type of irrigation (surface, sprinkler, localized) [I] *Energy for transporting water for agriculture / area equipped for power irrigation* **Management of water by utilities** *% water distribution losses by water utilities* **Water productivity in agriculture** Cubic meters of water used per unit of value added (in US $) by economic activity [b]	**Energy recovery from biomass, organic waste and wastewater and water quality** Total produced municipal waste water, m^3 [I] Total treated municipal waste water, m^3 [I] Direct use of municipal wastewater, m^3 [I] Direct use of treated municipal wastewater for irrigation purposes, m^3 [I] Agricultural land area under certified organic farm management(Ha) [j] Share of agricultural land area under certified organic farm management, % [j] *No. of biogas plants / agricultural land* *Total usage of organic manure in agriculture coming from biodigesters / agricultural land* **Fossil fuel pollutants** Renewable energy share in national energy and electricity generation [d] Total amount and percentage of increased access to modern energy services gained through modern bioenergy (disaggregated by bioenergy type), bioenergy, disaggregated into modern bioenergy and traditional use of biomass (Bioenergy used to expand access to modern energy services) [e] *Amount of renewable energy used to expand access to modern energy services* *Geothermal energy produced / average temperature increases of concerned underground aquifers* *Amount of water required for cleaning and cooling / size of solar plant / TARWR* **Bioenergy competition with food and water use** Pollutant loadings attributable to fertilizer and pesticide application for bioenergy feedstock production, in kg of N, P and active ingredient per ha per year and as percentages of total N, P and pesticide active ingredient loadings from agriculture in the watershed [e]	Total freshwater withdrawals, million m^3 [I] Agricultural, Industrial, and municipal water withdrawn as a % of total water withdrawn [I] Water pollution as % of BOD emissions - total and disaggregated by sector [c] % of total actual renewable water resources (TARWR) [e] % of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources [e]

Table A.1 (part 3 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and sustainable water objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant for all sustainable energy components
RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS	**Technologies for resilience to water-related disasters** *% of people with access to water purification and storage technologies*	**n/a**	**Energy for irrigation systems** Area equipped for irrigation drained [l] % of total cultivated area drained [l] Percentage of area equipped for full control surface irrigation drained [l] **Hydropower and Flood Risks** Total dam capacity (national) in km^3 [l] Resilience to Water-Related Disasters [f][57] Reservoir Flood Control Index [MK12, CGIAR]	Improved sanitation facilities (% of population with access) [c] Investment in water and sanitation with private participation (current USD) [c] No. of people affected by water related diseases [l]
Indicators or indicator components relevant to all sustainable water components	Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy Measured as a % of population [d] Share of household income spent on fuel and electricity (IAEA). Measured as % [d] % population with access to electricity [c] Energy use (kg of oil equivalent per capita) [c]	GDP per unit of energy use (constant 2011 PPP $ per kg of oil equivalent) [c] Industrial energy intensity [d] Agricultural energy intensity [d] Service/commercial use intensity [d] Household energy intensity [d]	Renewable energy as a share in electricity and energy [d] Fossil fuel energy consumption (% of total) [c] Contribution of renewables to energy supply [j] Share of renewable energy in gross final energy consumption [o]	

57 It is a composite indicator that includes evaluation of three types of water-related shock—floods and windstorms, droughts, and storm surges and coastal floods—by assessing

- Exposure (e.g., population density, growth rate);
- Basic population vulnerability (e.g., poverty rate, land use);
- Hard coping capacities (e.g., telecommunications development); and
- Soft coping capacities (e.g., literacy rate).

Table A.2 (part 1 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable water and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE WATER MANAGEMENT	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS	Indicators or indicator components relevant for all sustainable energy components
FOOD AVAILABILITY	**Water allocation by sector** Total water withdrawal (Km^3/year) by agriculture, industry and municipal [l] Agricultural, industrial and municipal withdrawal as % of total water withdrawal [l] **Livestock production** Livestock total per hectare of agricultural area (livestock total number/ha) [a] Bacterial numbers and the presence of coliform organisms (fecal coliform presence) (site-specific) [q, p] *Feed-water productivity and feed conversion efficiency by animal type, product and production system* **Inland fisheries and aquaculture** Change in freshwater fish production (aquaculture and capture, tons/yr) [a] Levels of ph (site-specific) [p] Levels of alkalinity (site-specific) [q, p] *Concentration of nitrogen and phosphorous (point-source of intensive production units)*	**Availability of freshwater resources for agriculture** Precipitation in volume (long-term average, mm/ yr) [l] Internal renewable water resources (long-term average, m^3/yr) [l] Total actual renewable water resources (m^3/yr) [l] Total actual renewable water resources per capita (m^3/yr) [l] Dependency ratio [l] Per capita total renewable water resources (m^3/person/ year) compared to thresholds of 500, 1000, 1700 m^3/person/year [l] **Crop production** % of the cultivated area equipped for irrigation [l] Value of irrigated output as share of total agricultural output (USD, differentiated by crop) [a] Value of irrigated output as multiple of value of rain-fed output (USD, differentiated by crop) [a] Freshwater withdrawal as % of total actual renewable water withdrawal [l] Total groundwater abstraction/ Exploitable groundwater resources [l] Brackish/Saline Groundwater at Shallow and Intermediate Depths (BSG) [r] Area salinized by irrigation of total harvested irrigated crop area in ha [l] % of salinized soils by irrigation of total arable land [l] % of area equipped for full control surface irrigation drained [l] Use of agricultural pesticides and fertilisers (nitrogen, phosphate, potash) on arable and permanent crop area [a] Share of monitoring sites in agricultural areas that exceed recommend drinking water limits for nitrates, phosphorous and pesticides in surface water and ground water [j] Share of major ions, metals, nutrients, organic matter and bacteria in watershed [q, p] *% catchment under cropping of intensive agriculture* *Irrigated added value / agricultural water use ($/cap/m^3)* *Number of farmers dependent on groundwater for agriculture activities / Total population of the country* **Livestock production** *Concentration of nitrogen, ammonia and phosphorous (point-source of intensive production units)* *Concentration of antibiotics in watershed (site-specific)* *Cropland drainage effluent contamination for major feed crops (nitrate, phosphate and pesticides) of acceptable levels* **Groundwater resources** Actual renewable groundwater resources (m^3/capita/year) [l] Actual groundwater entering and leaving the country (m^3/yr) [l] **Wastewater resources** Direct use of treated municipal wastewater for irrigation purposes[l]/ Total treated municipal waste water (km^3/year) [l] Direct use of treated/ untreated municipal wastewater for irrigation (km^3/year) [l] Direct use of agricultural drainage water (km^3/year) [l] Produced municipal wastewater (m^3/yr) [l] Treated municipal wastewater (m^3/yr) [l]	**Water stress due to agriculture** Total freshwater withdrawals by irrigated agriculture, million m^3 as share of total freshwater withdrawals, million m^3 [j] - Surface and groundwater withdrawals for agriculture as % of total actual renewable water resources [l] Agricultural water security index[f]: i. Productivity of irrigated agriculture ii. Independence from imported water and goods iii. Resilience (percentage of renewable water resources stored in large dams) Area salinized by irrigation (ha) [l] **Dependency on food imports** Dependency ratio, as total volume of external water flows over total volume of water produce/year [l] Cereal import dependency ratio [a] Depth of food deficit [m]	Average value of food production [m] Average dietary energy supply adequacy[m] Import Quantity Index of Agricultural products [a] Change in cropland use [a] Area of land/soils under sustainable management [a]

Table A.2 (part 2 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable water and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE WATER MANAGEMENT	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS	Indicators or indicator components relevant for all sustainable water components
FOOD AVAILABILITY (cont'd)		**Water desalination for irrigation** Desalinated water produced (km^3/year) [l] Desalinated water used for irrigation (km^3/year) **Land use** Runoff co-efficient (mean annual or monthly precipitation) [l] Net recharge rate (mm/yr) of groundwater as proxy of effects of land management on groundwater [r] Erosion rate or sediment load in a river/ upstream drainage areas [a] Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production [e] **Water-forestry interactions** Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production [e], including the following (amongst others): (a) arable land and permanent crops, permanent meadows and pastures, and managed forests (b) natural forests and grasslands (including savannah, excluding natural permanent meadows and pastures), peat lands, and wetlands		
FOOD ACCESS	**Economic water scarcity** Rural population with access to water supply (as proxy of infrastructural water scarcity) [s] *Share of investments in irrigation as share of total public spending/ ODA*	n/a	**Food prices increase during water-related disasters** Domestic food price index [m] *Percentage of water expenditure as total of household expenditure* *Domestic food price index of key food and non-food commodities (e.g. staple food, cooking and heating fuel, energy costs for machinery, water)* **Water governance** Global corruption report in the water sector [t]	

Table A.2 (part 3 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable water and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO WATER RESOURCES FOR DIFFERENT USES	SUSTAINABLE WATER MANAGEMENT	RESILIENT SOCIETIES AND ECOSYSTEMS TO WATER-RELATED DISASTERS	Indicators or indicator components relevant to all sustainable water components
FOOD UTILIZATION & NUTRITION	**Provision of clean and safe water for food preparation** % of population with access to improved water source (urban and rural) [c,s] % of population with access to an improved sanitation facility [b,s] Population affected by water borne disease [l] Number and % of population which is undernourished [l] *% of population using improved water technologies and improved sanitation facilities) coupled with data on sufficient household food consumption* *Household dietary diversity and number of meals taken a day* *Existence of water safety plans* *Incidence rate and prevalence of food- and water-borne diseases (possibly by gender)* *Average household water usage/day*	n/a	n/a	
STABILITY OF FOOD SUPPLY AND PRICES		**Social water stress** Renewable water resources per capita (m^3) adjusted by HDI [based on l] Relative social water stress index [u] Share of food expenditure for the poor [m] **Water storage** Total dam capacity (national) (km^3) [l] Total dam capacity per capita [l] Total exploitable water resources disaggregated by total regular and irregular renewable surface and ground water [l] Water storage capacity per person, including volume of renewable groundwater per capita	**Climate change and agricultural water management** Precipitation variability [c] Total agricultural water managed area/ total area of agriculture [l] % area equipped for irrigation actually irrigated [l] Area equipped for irrigation by type of irrigation (surface, sprinkler, localized) [l] Area that is potentially irrigable [l] *Food price volatility/area of water under active water management*	Domestic food price volatility [m] Per capita food production variability [m] Per capita food supply variability [m]

Table A.3 (part 1 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant to all sustainable energy components
FOOD AVAILABILITY	**Yields increase and income** Energy used in agriculture and forestry [a] Agricultural machinery, tractors in use in agriculture [c, a] Direct on-farm energy consumption, toe [j] Direct use of fossil fuel energy in agriculture per unit of value of output [a, a+j] *Yield increase / amount of modern energy used for farming* **Energy for irrigation and improved yields** Energy for power irrigation in agriculture per agriculture production [a] Energy consumed in fisheries per fish product production [a]	**Agricultural productivity** Change in yield/amount of modern energy used for farming [a] Agricultural energy intensities [d] Energy used in agriculture per gross agriculture production [a] **Energy efficiency and economic return** Economic value of food products/Reduction of use of non-renewable energy in agriculture [a] **Livestock production** Size of' 'Animal waste to energy' systems in the country (as total energy and manure produced)	**Energy bill** End-use energy prices by fuel and by sector [d] Economic value of agricultural products [a] Energy imports, net (% of energy use) [c] Pump price for gasoline and diesel (US$ per liter) [c] Direct on-farm energy consumption, Ktoe, per agricultural produce [a, a+j] *Amount of energy produced by decentralized rural energy systems /population without access to modern energy* **Bioenergy** Woodfuel production by volume and value [i] Land use and land-use change related to bioenergy feedstock production [e], includes i. Total area of land for bioenergy feedstock production, and as compared to total national surface ii. Agricultural land and managed forest area iii. Percentages of bioenergy from: (a) yield increases, (b) residues, (c) wastes, (d) degraded or contaminated land iv. Net annual rates of conversion between land-use types caused directly by bioenergy feedstock production, including the following (amongst others): (a) arable land and permanent crops, permanent meadows and pastures, and managed forests (b) natural forests and grasslands (including savannah, excluding natural permanent meadows and pastures), peat lands, and wetlands Percentage of land – total and by land-use type – used for new bioenergy production [e] Bioethanol and biodiesel production (ktoe) [j] Energy imports, net (% of energy use) [c] Pump price for gasoline and diesel (US$ per liter) [c] Total Jobs in Bioenergy sector [e], disaggregated by: (a) skilled/unskilled (b) indefinite/temporary. **Renewables** *% of renewable energy used in agriculture as a proportion of total energy used in agriculture*	Average value of food production [m]

Table A.3 (part 2 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant to all sustainable energy components
FOOD ACCESS	**Increased yields on food prices** Agricultural machinery, tractors in use in agriculture [c] [a] Share of household income spent on fuel and electricity [d] *No. of increased business hours due to access to modern energy*	n/a	**Wood energy** Forest area damaged by human: forest operations and other (forests, other wooded lands, Total forest and other woodlands) [i] Change in forest area over the last 10 years as a % of total forest area [a]	Share of Food expenditure for the poor [m] Domestic food price index [m] Depth of food deficit [m] Prevalence of food inadequacy [m] Cropland per Gross production value of agriculture [a]
FOOD UTILIZATION	**Food processing technology** Household energy use for each income group and corresponding fuel mix [d] *Reduction of food loss /amount of modern energy used for food processing* *Changes in the amount of food processed/monetary value of post-harvest technologies that use modern energy* **Cooking** Forest area damaged by human: forest operations and other [i] Population using solid fuels (%) [i] **Share of households using traditional fuels (disaggregated by fuel) [n]** *Frequency of cooking of main staple crops* *Number and % of households having biogas from digesters for cooking or solar cooking systems in rural areas* **Renewables uptake at household level** Bioenergy used to expand access to modern energy services [e] Total Volume of removals from forests [i] Woodfuel from forests in volume [i] MEPI Index [h] *Share of modern energy for food drying and storing* *Number and % of household having cooling technology to preserve food*	**Improved cooking efficiency** Number and % of household having access to modern cooking energy (LPG, Gas) [n]	n/a	% of people with access to improved water access (piped water supply) [f] Access to improved sanitation (%) [f]

Table A.3 (part 3 of 3)

Summary table of data and indicators for specific nexus issues linking sustainable energy and food security objectives (indicators in italic are possible indicators currently not collected)

	ACCESS TO MODERN ENERGY SERVICES	EFFICIENT USE OF ENERGY	THE ENERGY PRODUCED AND CONSUMED IS CLEAN/ RENEWABLE	Indicators or indicator components relevant to all sustainable energy components
FOOD STABILITY	**Energy subsidies and high/ stable yields** *Variation of production of the 4 main crops/modern energy used in agriculture* **Underground water pumping** Percentage of agricultural land classified as having moderate to severe water erosion or wind risk [j] *Amount of water pumped for agriculture / cost of electricity, diesel, gasoline used in water pumping*	**New technologies and practices in agriculture** Agriculture, value added (% of GDP) [c] *Economic value of food products / Reduction of use of non-renewable energy* **Food transport** *Energy associated with transport of a national food basket*	**Delinking the food and energy markets** *Percentage of renewable energy used in agrifood systems* Change in consumption of fossil fuels and traditional use of biomass [e] , includes: i. Substitution of fossil fuels with domestic bioenergy measured by energy content and in annual savings of convertible currency from reduced purchases of fossil fuels [e] ii. Substitution of traditional use of biomass with modern domestic bioenergy measured by energy content [e]	Domestic food price volatility [m] Per capita food production variability [m] Per capita food supply variability [m]
Indicators or indicator components relevant to all food security components	Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy [d] Energy use (kg oil equivalent) per $1,000 GDP [i]		Fossil fuel energy consumption (% of total) [c] Primary production of renewable energy (total and disaggregated by hydro, wind, solar, biomass and renewable waste, geothermal) [o]	

ANNEX 2 – BENCHMARKS FOR COUNTRY TYPOLOGIES

Table A.4 summarizes which countries have been considered to estimate the benchmarks per country typology and the assumptions behind this choice.

Table A.4

COUNTRY TYPOLOGY	COUNTRIES CONSIDERED	RATIONALE
Agriculture-based economy, dry country	Burkina Faso, Ethiopia, Ghana, Kenya, Pakistan, Lesotho, Morocco, Algeria, Tunisia, Syrian Arab Republic	According to FAOSTAT, in 2011 the renewable water available per capita in these countries was < 1,500 m^3/inhabitant/year and the percentage of active population working in agriculture was more than 20 percent of the total active population. The countries have been chosen with a good distribution of the percentage of active population working in agriculture over total population.
Agriculture-based economy, water rich country	Nepal, United Republic of Tanzania, Angola, China, Thailand, Guatemala, Tajikistan, Peru, Democratic People's Republic of Korea, Kyrgyzstan	According to FAOSTAT, in 2011 the renewable water available per capita in these countries was > 1,500 m^3/inhabitant/year and the percentage of active population working in agriculture was more than 20 percent of the total active population. The countries have been chosen with a good distribution of the percentage of active population working in agriculture over total population.
Affluent country, with natural resource constraints	Singapore, Japan, Lebanon, Republic of Korea, United Kingdom, Jordan, Jamaica, Israel, Armenia, Italy	According to World Bank statistics, in 2011 all these countries were net energy importers and, according to FAOSTAT, they all employed more than 20 percent of active population in non-agriculture activities, and they were net importers of agricultural products in 2011. The countries have been chosen maintaining a good distribution of the percentage of net import value over gross production value of agricultural products.
Transition country, experiencing strong population growth	Guatemala, Malaysia, Costa Rica, India, Indonesia, Mexico, Morocco, China, Jamaica, Montenegro	According to FAOSTAT, in these countries in 2011 the percentage of active population working in agriculture was between 35 and 90 percent of the total active population and, according to World Bank statistics, they all had a yearly population increase >0.5 percent between 2003 and 2012. The countries have been chosen with a good distribution of the average population increase.

These groups of countries have been used to calculate the benchmarks reported in table 4. The same groups could be used to calculate other ad hoc benchmarks. Maintaining always the same groups of countries with similar characteristics is useful for the *Nexus Rapid Appraisal* (see section 4.4).

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ANNEX 3 – COLLATION OF SPECIFIC NEXUS TOOLS TO QUANTIFY IMPACTS AND DRAW SCENARIOS

	NEXUS ELEMENTS INFORMED[58]	OUTPUT INDICATOR	DESCRIPTION OF THE TOOL	GEO-GRAPHICAL SCOPE	TYPE OF TOOL[59]	TARGET USERS	NATURAL SYSTEM RESOURCES THAT ARE CONSIDERED[60]	HUMAN SYSTEM RESOURCES THAT ARE CONSIDERED[61]	AUTHOR
NEXUS 1.0 TOOL	**E-F-W**	• Water requirements (m^3) • Local energy requirements (kJ) • Local carbon emissions (tonne CO_2) • Land requirements (ha) • Financial requirements (QAR) • Energy consumption through import (kJ) • Carbon emissions through import (tonne CO_2)	The tool allows the user to create different scenarios with varying food self- sufficiencies, water sources, energy sources, and countries of import.	National (Qatar)	IO	Decision-makers; technical experts	E: Energy sources for water usage are used as input (e.g. Diesel, natural gas, etc). Energy used to extract (treat) water is also specified as input, categorized by source - Diesel, Natural Gas, Wind, Solar Thermal, Geo Thermal, Nuclear, Biomass); Tillage & Harvest Energy Sources are also specified (Gasoline, Diesel and LPG) W: Source of water (by share) can also be supplied (Ground water, Desalination (RO), Desalination (MSF), Desalination (MED), Treated Waste Water (TWW) L: Includes choices of crops to calculate the land requirement (ha) O: Based on a given scenario it can calculate the total carbon emission (tonne CO_2). Additionally it also calculates the Carbon emissions through import (tonne CO_2)	–	Qatar Environment and Energy Research Institute (QEERI)

58 W=Water, E=Energy, F=Food
59 In terms of type of tools we distinguish three broad classes:
IO=input-output tools, where an input from the user is needed (or is suggested by the tool itself) in order to run the model;
MD=modeling tools, where the tool can be used as simulator on the basis of determined technical coefficients and level of inputs;
IR=information resources such as maps that can be used by the user directly to derive the information or the information can be fed into another analysis.
60 W=Water, E=Energy, L=Land, O=Other
61 C=Capital, L=Labour, O=Other

	NEXUS ELEMENTS INFORMED[58]	OUTPUT INDICATOR	DESCRIPTION OF THE TOOL	GEO-GRAPHICAL SCOPE	TYPE OF TOOL[59]	TARGET USERS	NATURAL SYSTEM RESOURCES THAT ARE CONSIDERED[60]	HUMAN SYSTEM RESOURCES THAT ARE CONSIDERED[61]	AUTHOR
INTERACTIVE COMPETE MAPS	**E-F**	Percentage of total land. Also, if the conversion factor of a particular energy feedstock is known, in theory Joules/ Hectare or kWh/hectare could be calculated	Gives information about land usage in eight African countries using PFD maps with layers. The user can get an idea about the current state of land usage and plan location of the bioenergy plant. Additionally, it also provides good practices for Bioenergy Production in semi-arid and arid Sub-Saharan Africa	Regional (Africa)	IR	Decision-makers; technical experts	E: Identifies land for Bioenergy feedstock (residues and crops) in arid and semi-arid regions of Africa W: Maps the reach of perennial rivers within the map L: Identifies land (a) suitable for biomass production for energy, (b) suitable for biomass production for other uses, and; (c) filtering out land that is not available or not suitable for inclusion in future bioenergy land use scenarios	O: identifies social constraints in African countries for example presence of refugee camps and protected monuments and sites	Competence Platformon Energy Crop and Agroforest ry Systems for Arid and Semi-arid Ecosystems – Africa (COMPETE)
2050 PATHWAYS CALCULATOR	**E-F-W**	Allows users to develop their own combination of levels of change to achieve an 80 percent reduction in greenhouse gas emissions by 2050, while ensuring that energy supply meets demand • Water exploitation index (WEI) which is the total water used for energy generation as a percentage of natural river flow	The tool provides trajectories for various user defined scenarios of resource usage. For each sector of the economy, four trajectories have been developed, ranging from little or no effort to reduce emissions or save energy (level 1) to extremely ambitious changes that push towards the physical or technical limits of what can be achieved (level 4).	National (United Kingdom)	MD	Policy-makers, Energy Industry experts, Educational Institutions	E: Looks at various combinations (trajectory) of Bioenergy, Wind, Solar, Nuclear, Hydro, Gas and Coal fired plants as well as other energy intensive sectors such as heating & cooling, transport etc. in the economy to see its effect on country level and sectoral GHG emissions W: Focuses on hydropower and rainfall catchment L: Various scenarios where different proportions of total land dedicated to energy crop is done and corresponding derived energy from them is calculated O: Calculates the total GHG emission in the UK from all sources and aims to reduce them by 80 percent by 2050	C: The MARKAL model is used for cost optimization. O: Develops an air pollution health impact index for various scenarios	UK Departme nt of Energy and Climate Change (DECC)

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LEAP (LONG RANGE ENERGY ALTERNATIVES PLANNING SYSTEM) **WEAP** (WATER EVALUATION AND PLANNING SYSTEM)	**E-F**	• Water Demand (litres) • Water supply (litres) • Water pumping (m3) • GHG emissions/ TWh or tons of GHG emissions • Energy supply in TWh through various generation technologies	LEAP-WEAP together can analyse the relation between water usage and energy generation and how water and energy policies individually can affect both water and energy systems. In particular, WEAP can model the demand and supply situation at a range of spatial and temporal scales. It can also be used to evaluate the impact of water management measures like wastewater reuse and climate change adaptation. It considers agricultural, municipal and also ecological water usage	Sub-national or regional level	IO	Decision-makers; technical experts	E: Data about energy demand in household/ industry/transport and commercial sector can be input and edited in LEAP to track energy consumption, production and resource extraction in all sectors of an economy. It can be used to account for both energy sector and non-energy sector GHG emission sources and sinks. W: Input data in WEAP varies according to the kind of analysis to be done. • Schematics, maps, etc. of the river basin you wish to model • Demand data (municipal, domestic, industrial, irrigation, livestock, etc.) • Drivers (e.g., population, irrigated area, etc.) and projections of those drivers for scenarios • Withdrawal, either total or per activity (e.g., per person, per hectare) • Consumption (percentage of withdrawal not returned) and routing of any return flow • Monthly variation • Loss and reuse • Demand-side management policies, either current or possible future policies • Priorities and preferences for supply (e.g., who has first claim on river water, and for demands connected to multiple supplies, which is their preference or ratio of withdrawals) • Transmission link data - Information on links between supply and demand • Pipeline capacity • Costs (may include the cost of the supply as well as the transmission cost, or be viewed as a price the consumer has to pay) • Water losses • Hydrology • River gauge flows as monthly time series data • Diversions • Instream or downstream (i.e. out of the basin study area) flow requirements If using runoff model, precipitation and temperature time series data: • Groundwater • Storage capacity • Initial storage • Maximum withdrawal • Natural Recharge • Gains from and losses to adjacent rivers • Reservoirs • Inflow (if not on a river) • Initial and total storage capacity • Volume-elevation curve (to calculate evaporation or for hydropower) • Monthly evaporation rate • Levels of reservoir storage (inactive zone, buffer zone, conservation zone, flood control zone) • Hydropower: max and min turbine flows, tailwater elevation, efficiency, etc. • Other supply sources (imports, transfers, desalinization, etc.) • Surface water quality and wastewater treatment facilities • Pollution generation by sectors • Percent removal of pollutants by treatment process • Routing of wastewater or treated wastewater • Pollutant decay rates • Flow-stage-width curves for river reaches • River water temperature time series data for each reach	–	Stockholm Environment Institute (SEI)

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DIAGNOSTIC TOOLBOX FOR INVESTMENT IN AGRICULTURAL WATER MANAGEMENT (AGWA)	**E-F-W**	Various indicators including: • Agricultural share in GDP (%) • Economically active population in agriculture over total economically active population (%) • Rural population over • Total population (%) • Cultivated land (ha) • Crop yield for three major staples and two main food crops in terms of food production (tonnes/ha) Need to Invest index composed of: • Prevalence of undernourishment (%) • Electricity dependency ratio • Average dependency ratio for three major staple crops (%) • Rural population over Total population (%) • Non-equipped area for full control irrigation • over total cultivated land (%) • Population without access to electricity over total population (%) *Investment Potential Index* (Measures the country's potential in developing water resources for irrigation and hydropower) composed of: • Percentage of irrigation potential equipped for full control irrigation (%) • Water requirement ratio (%) • Percentage of area equipped for full control irrigation actually irrigated (%) • Share of exploited hydropower potential over total hydropower potential (%) • Share of renewables in electricity production (%) *The Institutional and Policy Index* • Irrigation projects budget in agricultural public budget (%) • Irrigation projects budget in total public budget (%) • Irrigation projects budget in total donor budget (%) • Hydropower projects budget in energy public budget (%); • Hydropower projects budget in total donor budget (%); • Hydropower projects budget in total public budget (%).	AgWA is a set of instruments that supports actions that boosts sustainable use of water for agricultural and energy production. It primarily has 3 modules: 1. Context tool which aims to understand potential contribution of sustainable use of water and energy resources for agricultural production and livelihood improvement 2. Institutional and policy tool which maps country and regional level institutions, actors, laws and policies 3. Financial tool which provides project based estimates of investment needs in agricultural and hydropower projects	Project level	IO	Decision-makers; technical experts	E: Installed capacity of the hydropower facility measured in Megawatts W: Understand potential contribution of sustainable use of water and energy resources for agricultural production and livelihood. The unit of analysis are irrigation and hydropower projects at a country level L: • Total hectares of land • Dominant food and cash crop, • Yields (tonne/ha) for the main crops • Retail prices for the main crops • Average production cost for the main crops, including maintenance • Hectares of land under irrigation or rehabilitated by crop O: The context dimension of indicators also take in to account the impact on GHG and climate change	C: The financial tool within the tool box provides reliable estimates of investment in agricultural water and hydropower projects O: Nutritional outcome and Water-related diseases are qualitatively addressed	FAO

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STRATEGIC ASSESSMENT FRAMEWORK FOR THE IMPLEMENTATION OF RATIONAL ENERGY (SAFIRE)	**E**	• Market penetration • Net employment creation • Pollutant emissions (six types) • Value added • Import dependency • Capital expenditure External costs • Government expenditure (national version only)	SAFIRE: an engineering-economic bottom-up supply and demand model for the assessment of first-order impacts of rational (renewable and new non-renewable) energy technologies on a national, regional or local level against a background of different policy instruments and scenario assumptions	National or Project level	MD	Decision-makers; technical experts	E: Can be used to assess the impact of energy technology and associated policies on a number of economic indicators. Various combinations of energy technologies can be input to see its effect. It Includes an extensive database for 22 renewable energy technologies (RETs) and eight new non-RETs and seven fuelling options for cogeneration plant including fuel cells	L: One of the key economic indicators studied is the 'net employment creation' due to a specific technology, policy combination	ESD Consulting
RETSCREEN4 AND RET SCREEN PLUS	**E-W**	• Energy production KWh or TWh • Financial viability cost/unit of energy (KWh) • Water pumping (m^3) • Tonnes of CO_2 emitted	A decision support tool for project analysis specifically for energy production. Can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of renewable energy and energy-efficient technologies. Helps in identifying and assessing potential energy projects.	Project level	IO	Decision-makers; technical experts	E: Design heating load, heating fuel type, system seasonal efficiency W: Includes hydrology database and hydropower generation project assessment. Input data includes required groundwater flow rate and no. of supply wells required O: Analyses the project level emissions due to energy generation. The NASA climate database from analysis is integrated within the software L: Depending on the type of analysis to be done, the main inputs include available land area andsoil type	Within the cost analysis module the cost database is built into the software. Data are provided and selected for Canadian costs with 2000 as a baseline year. The user also has the ability to create a custom cost database. The main input values are "Quantity Range" and the "Unit Cost Range" corresponding to the energy technology.	Natural Resource Canada

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MODEL OF ENERGY SUPPLY SYSTEMS AND THEIR GENERAL ENVIRONMENTAL IMPACTS (MESSAGE)	E	• Primary and final energy mix (maybe percentage of bioenergy in total energy mix) • Emissions and waste streams (CO_2 emission/ KwH) • Health and environmental impacts (externalities) • Resource use Land use • Import dependence Investment requirements	MESSAGE combines technologies and fuels to construct so-called 'energy chains', making it possible to map energy flows from resource extraction, beneficiation and energy conversion (supply side) to the distribution and provision of energy services (demand side)	Project level	IO	Energy Planners, Policy-makers, Decision-makers	E: MESSAGE provides a techno-economic description of the modelled energy system. It considers both fuels and associated technologies like electricity, gasoline, ethanol, coal, district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology). Additionally, energy system structure (including vintage of plant and equipment), base year energy flow, energy demand projection, type of energy technology and resource availability are entered as inputs O: Environmental aspects can be analysed by keeping track of, or limiting, pollutants emitted by various technologies at each step of the energy chains. The model is extremely flexible and can also be used to analyse energy and electricity markets and climate change issues	C: Depending on the technology and project, economic characteristics include investment costs, fixed and variable operation and maintenance costs, imported and domestic fuel costs and estimates of levelized costs and shadow prices	IAEA/IEJE/ IIASA
RESOURCES AND ENERGY ANALYSIS PROGRAMME (REAP)	F-E	Primary outputs include • Carbon dioxide and greenhouse gas emissions measured in tonnes per capita • The Ecological Footprint required to sustain an area in global hectares per capita • The Material Flows of products and services through an area measured in thousands of tonnes	REAP is a model that helps policy-makers to understand and measure the environmental pressures associated with human consumption. The REAP scenario editor enables the user to look at issues in isolation or together for a single year or over time, for example it has been used to compare the environmental impact of a code for sustainable homes against other energy efficiency policies targeting existing housing	Project level	MD	Policy-makers, technical experts	E: REAP can explore the environmental pressures associated with changes in energy production technology over time. This includes various energy production technologies as well. It uses consumption as well as conversion data on resources used in an economy. This includes data on energy carriers as well as consumption of other raw materials L: It also calculates the Ecological Footprint required to sustain an area in global hectares per capita O: REAP generates ecological, carbon and greenhouse gas (GHG) footprint results for the populations of a specific area or region	–	Stockholm Environment Institute

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BIOMASS INVENTORY MAPPING AND ANALYSIS TOOL (BIMAT)	**E-F**	It provides Internet-based GIS functionality to query and visualize biomass inventory data based on spatially explicit information on biomass quantity and availability in Canada	Presents interactive mapping application that provides Internet-based GIS functionality to query and visualize biomass inventory data. It allows to make well-informed decisions based on spatially explicit information that presents a comprehensive view of biomass quantity and opportunity in Canada.	National (Canada)	IO	Policy-makers, Regulators, Industry	E: Provide access to accurate and reliable biomass and landscape information by creating a Web-based interactive GIS tool to undertake an inventory and analysis of the location, amounts, quality, and impact of exploitation of selected agricultural crops and residues, forest-based biomass sources, and sorted municipal woody wastes. L: Being a GIS tool it gives the land area required as well as availability of feedstock from a particular site. It also accounts for competing uses of Barley, Wheat, Oats. Additionally, it also takes into account the soil conservation. O: The tool also focuses on carbon accounting and as such it calculates average costs (per tonne) for CO_2 emissions and energy expended.	C: Depending on the required quantity and type of biomass, it also calculates the total costs incurred on harvest and transport of the biomass.	Agriculture and Agri-food Canada

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BIOENERGY ATLAS	**E-F**	It provides information on availability of crop residue per hectare on an annual basis.	BioFuels Atlas is an interactive map for comparing biomass feedstocks and biofuels by location. This tool helps users select from and apply biomass data layers to a map as well as query and download biofuels and feedstock data. BioPower is an interactive map for comparing biomass feedstocks and biopower by location.	National (US)	IR	Policy-makers, Industry	L: Provides spatial distribution of bioenergy feedstock. Contains 2 maps, Biofuels Atlas and Bio Power Maps. Biofuels Atlas is an interactive map for comparing biomass feedstock's and biofuels by location. BioPower is an interactive map for comparing biomass feedstocks and bio power by location.	–	National Renewable Energy Laboratory (NREL), USA
AUTOMATED LAND EVALUATION SYSTEMS (ALES)	**E-F**	Land maps and soil maps	Allows land evaluators to build expert systems to evaluate land according to the guidelines presented in the FAO "Framework on Land Evaluation"	–	IR	Decision-makers, Policy-developers	L: The suitability of land and soil could be analysed for cultivation of specific energy crops. It assists governments in reviewing existing land-use policies and to develop modified or new policy options that will facilitate the acceleration of the regional diversification programme. It can also aid in developing agricultural zones	–	Cornell University, USA

MODEL FOR ANALYSIS OF ENERGY DEMAND (MAED-2)

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E	• Final energy demand • Electricity demand • Hourly electric load • Load duration curves (WASP) • Energy usage specifically in agriculture • Energy required for heating or cooling (kWh/m^2/yr)	Helps in the evaluation of alternative paths/ strategies for the development of energy and electricity sector to meet the future demand for energy and electricity in a given country (or a world region), and, in particular, an estimation of the role that nuclear power may play in meeting this demand	Project level	MD	Energy Planners, Policy-makers,	E: MAED model evaluates future energy demand based on medium- to long-term scenarios of socio-economic, technological and demographic developments. Various energy forms are considered including modern biomass, fossil fuels as well as solar power systems. It presents a flexible framework to disaggregate energy demand in each of the six economic sectors viz. Agriculture, Construction, Mining, Manufacturing, Service and Energy. Main inputs include total energy demand and supply by sector and energy balance. Based on these, secondary inputs are made such as energy intensity in agriculture, mining, construction and manufacturing.	O: The inputs include data about economic growth, life style, population etc.	International Energy Agency (IEA)

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BIOENERGY ASSESSMENT MODEL (BEAM)	**E**	BEAM covers particular types of feedstock and conversion technologies and energy products and can be used for cost analysis. The main outputs include unit cost of production, technical performance, energy output, and profit, to identify the optimal system for development.	Biomass Energy Analytical Model (BEAM) to assess biomass energy availability, transport options, and delivery cost. BEAM models resources from field/ forest, through processing, to demand, providing a geographic quantification, storage and densification options and transportation analysis.	Regionana-tional, project level	MD	Energy Planners	E: Enables the user to select a range of biomass production, conversion, and product systems. It contains a list of feedstock and corresponding conversion technology (like pyrolysis, combustion etc.) and the final production (heat, electricity or ethanol)	–	International Energy Agency (IEA)
BIOENERGY AND FOOD SECURITY (BEFS) RAPID APPRAISAL TOOL (RA)	**E-L-W**	The BEFS RA calculates the initial estimate of which sustainable bioenergy supply chains are viable in the country based on economic profitability, financial viability, investment requirement, labour implications and smallholder inclusion	The BEFS Analytical Framework offers the tools to assist policy-makers in making informed decisions on the basis of clear information concerning the many varied consequences of bioenergy developments on food security, poverty reduction, agriculture development and economic growth	National level	–	Policy-makers, Food security specialists	E: Data on main energy and industry are entered including energy prices, utility prices, storage costs and operating hours by industry types W: The natural resource component of the tool analysis takes into consideration the effect of bioenergy development on water and implications for water management L: Data on agriculture is entered. This includes data on yield levels and productivity of the selected crop and prices of fertilizers and seeds. Livestock residues and other crop residues also act as input to the program. Additionally, data on forestry are also entered. These include forest harvesting and wood processing residues as well as wood plantation budget O: An overall assessment of GHG emission could be done along with other economy wide impacts	O: The effect of bioenergy development on household food security and vulnerability could also be analysed	FAO Bioenergy and Food Security (BEFS) project

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BIOENERGY CROP PRODUCTION COST MODEL (BIOCOST)	E	Calculates the bioenergy crop production costs (cost/tonne) including opportunity costs in seven states in USA.	BIOCOST is an Excel-based software program that can be used to estimate the cost of producing bioenergy through specific energy crops.	National (some USA states)	IO	Energy Planners	–	Main inputs include data about costs such as variable cash expenses (e.g., seeds, chemicals, fertilizers, fuel, repairs and hired labour), fixed cash costs (e.g., overheads, taxes, interest payments), and the costs of owned resources (e.g., producer's own labour, equipment depreciation, land rents, the opportunity cost of capital investments)	Oak Ridge National Laboratory
BEE (BIO CHAINS ECONOMIC EVALUATION)	E	Mainly calculates the costs associated with bioenergy production. The main outputs are: • Cost/cultivated ha, • Cost/km (for transportation)	BEE is a packaged computerized model, which performs full economic evaluation of bioenergy chains based on the cultivation and production of biomass from different bioenergy crops. It examines the whole chain from farm to useful energy or fuel delivered at the conversion plant gate and it may analyse more than one crop and more than one conversion technology at the same time. It consists of three modules: (a) The AgrEcon module, for the economic analysis of agricultural production, (b) The TransEcon module, for the economic analysis of transportation and storage costs. (c) The ConvEcon module, for the economic analysis of biomass to energy conversion.	Project level	MD	Decision makers, Policy developers	E: Analysis of the costs associated with production of energy crops, transport and conversion to energy L: The first module called the AgrEcon module performs the economic analysis of agricultural production. The main input variables are: • Agricultural project data, such as total occupied land, cultivated land etc. • Crop details, such as economic life, yields and other data concerning every individual crop. • Production factors databases about agricultural land, equipment, labor and raw materials. • Operation details that conclude operation timing and needs.	C: BEE analysis consists of all the steps necessary for decision-making and capital budgeting, i.e. cost analysis and investment appraisal. For this purpose, it maintains monthly balance sheets, cash flows and income statements of each and all of the project modules. It also estimates and analyses the full cost of biomass production and calculates the most important financial indices and criteria of investment appraisal.	Agricultur al University of Athens and partners (EU funded)

	NEXUS ELEMENTS INFORMED[58]	OUTPUT INDICATOR	DESCRIPTION OF THE TOOL	GEO-GRAPHICAL SCOPE	TYPE OF TOOL[59]	TARGET USERS	NATURAL SYSTEM RESOURCES THAT ARE CONSIDERED[60]	HUMAN SYSTEM RESOURCES THAT ARE CONSIDERED[61]	AUTHOR
SOIL AND WATER ASSESSMENT TOOL (SWAT)	**W-L**	The main output include indicators regarding water usage and soil nutrients (in KgN/ha or KgP/ha)	SWAT is a small watershed to river basin-scale model to simulate the quality and quantity of surface and groundwater and predict the environmental impact of land use, land management practices, and climate change.	Project level	IO	Decision-makers, Policy developers	W: Data about sub-basins, Reach/main channel segments, impoundments on main channel segments and point sources act as input. Within these, soil attributes, as well and soil management techniques are entered. L: The various land management practices can be examined and their effect on water. This includes agricultural practices and pesticides. Data on land cover and plant growth is entered using a compiled database made available by SWAT. The full list of inputs can be found in the user manual. O: An overall effect on environment through soil contamination and nutrition can be analysed.	–	USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research
EUROPEAN DROUGHT OBSERVATORY (EDO)	**W-L**	Maps based visualization regarding drought, soil moisture anomaly and vegetation anomaly are presented	Based upon the innovative concept of 'Dynamic Land Functions', the Land Use Modelling Platform (LUMP) has been developed by the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC) to support the policy needs of different services of the European Commission, such as the exploration of future policies and impact assessments of specific proposals.	Project level	IR	Hydrologists, Policy-makers	W: Helps analyse the impact of land demand and usage on water and hydrology. The EDO pages contain drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modeled soil moisture content). L: LUMP is based on the dynamic simulation of competition between land uses. Its spatial allocation rules stem from a combination of demand for land, overall suitability, neighborhood characteristics and scenario/policy-specific decision rules	–	JRC

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LAND RESOURCE INFORMATION MANAGEMENT SYSTEMS (LRIMS)	**L-W**	Assesses and models the land suitability and responses to potential agricultural process	LRIMS was conceived to support land evaluation and land-use planning in Libya by means of a GIS application, which manages spatial data (land resources, including components of climate, soils and landform) and non-spatial information (mainly crop requirements).	Project level	IO	Policy makers	W: It can calculate soil water content and can use both daily and decadal rainfall data, depending on the release adopted L: Data on soil characteristic and land cover is entered which goes through a land suitability module to produce results.	O: A socio-economic model exists which includes the following characteristics Illiteracy, population, accessibility and poverty and its impact on land evaluation.	–
AQUACROP	**L-W**	It mainly measures yield response to a water usage. It also displays yield changes under various climate change scenarios.	AquaCrop is a crop water productivity model. It was developed to simulate yield response to water of herbaceous crops under any climatic and soil conditions, including climate change cases	Project level	IO	Extension services, governm ental agencies, NGOs and farmers' associations	W: Main inputs include irrigation management practices as well as irrigation schedule and net irrigation requirement as well as data on rainfall L: Main inputs include field management practices, soil fertility levels and practices that affect soil water balance	–	FAO

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GLOBAL AGRO ECOLOGICAL ZONES (GAEZ)	**L-W**	Basically measures yield (Kg/Ha). Agro-ecological potential yield (Agro-climatically attainable yield as reduced by constraints (e.g. water).	On the basis of a global inventory of land resources, including components of climate, soils and landforms, GAEZ estimates, for many combinations of crops and management levels (Land Utilization Types - LUTs), agro-climatic potential attainable yield, agro-ecological suitability and potential yield.	Project level	IR	Decision-makers, Policy developers	W: Water used for irrigation and irrigated land is an input to the model L: Assists in assessing crop potential based on various characteristics like soil characteristics, climatic data, land cover, irrigated areas	–	IIASA-FAO
LISFLOOD	**W-L**	• Maps for the whole catchment area • Time series at user-defined points • Time series, averaged over the contributing area of each gauging station	LISFLOOD is a GIS-based hydrological rainfall-runoff-routing model that is capable of simulating the hydrological processes that occur in a catchment.	Local or project level	MD	Decision-makers	W: Used in large and transnational catchments for a variety of applications, including flood forecasting, and assessing the effects of river regulation measures, land-use change and climate change. L: The effect of land use changes on water	–	JRC
EROSION PRODUCTIVITY IMPACT CALCULATOR (EPIC)	**W-L**	• Yield and N, P and C cycle • Crop stress • Water / wind erosion • Water cycle / hydrology	A tool for assessment environmental impacts of cropland management	Local or project level	MD	–	W: Considers wind and water erosion on land (soil). It also considers water cycle and hydrology L: Studies various causes of soil erosion and depletion of nutrients of soil and expresses them in maps	–	FAO

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INTEGRATED SPATIAL POTENTIAL INITIATIVE FOR RENEWABLES IN EUROPE (INSPIRE)	**E-F**	The model suggests that if the net profit margin for the biomass activity is greater than that of pre-existing farming activities. Based on this the farmer may switch a proportion of that land to energy crop production. By using GIS data in conjunction with regional economic data, the model is able to locate existing and potential biomass sources, the location of potential sites, and the potential regional economic gains	The model aims to link renewable energy resource mapping with economic and life cycle analysis modeling (based on a Geographic Information System – GIS)	Regional (Europe)	MD	Project develop., Decision-makers	L: The tool is based on the concept of a 'trigger mechanism' that uses the base agricultural statistics (current land-use and farm income data) to determine existing incomes from agriculture. At the same time a set of potential incomes from biomass related activities are calculated using one of the inter-related financial models.	–	JRC
CROPWAT	**L-W**	CropWat calculates crop water requirement and irrigation scheduling based on input data about climate, soil, and irrigation	CropWat calculates crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.	Project or local level	MD	Project develop., Decision-makers	W: The tool takes into account the data on water availability and monthly rainfall. L: the tool takes into account the cropping pattern, soil characteristics and user defined scheduling criteria to calculate irrigation scheduling and crop water requirements	–	FAO

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RUSLE2	F	RUSLE2 estimates rates of rill and interrill soil erosion caused by rainfall and its associated overland flow	RUSLE2 bases its calculation on climate, soil, topography, and land use determine rates of rill and interrill erosion. A RUSLE2 user applies RUSLE2 to a specific site by describing field conditions at the site for these four factors. RUSLE2 uses this field description to compute erosion estimates.	Project level	IO	Academic , policy and decisions-makers	L: Land topography and soil characteristics are influencing factors for erosion and are taken into account in the software O: Climate data is also used to make calculation on interrill soil erosion	–	USDA
GREET	E	• Consumption of total energy (energy in non- renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas. • Emissions of CO_2-equivalent greenhouse gases - primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). • Emissions of six criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM10), particulate matter with size smaller than 2.5 micron (PM2.5), and sulfur oxides (SOx).	GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) is a full life- cycle model. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel- cycle/ vehicle- cycle basis.	Project level	IO	Academic, policy and decisions -makers	E: Most calculation is done using energy use data. This includes total energy consumption and other GHG emission of key gasses like CO_2, CH_4, N_2O etc.	–	Argonne National Laboratory (USA)

	NEXUS ELEMENTS INFORMED[58]	OUTPUT INDICATOR	DESCRIPTION OF THE TOOL	GEO-GRAPHICAL SCOPE	TYPE OF TOOL[59]	TARGET USERS	NATURAL SYSTEM RESOURCES THAT ARE CONSIDERED[60]	HUMAN SYSTEM RESOURCES THAT ARE CONSIDERED[61]	AUTHOR
WBCSD WATER, ENERGY, FOOD/FEED/F IBRE/FUEL NEXUS TOOL	**E-W-F**	Various indicators dealing with: • Water for food • Water for energy • Energy for food • Energy for water (agriculture water only)	This tool provides a quick and simple way to better understand and quantify the interconnectedne ss of the water, energy and food/ feed/fibre/f uel nexus. The framework informs regional, national, and global policies and regulations while offering businesses an effective tool to assess risks and opportunities. The tool relies on GIS maps containing information about water, land, and energy. The tool can be used (in future) through a web-based platform.	Global, na-tional, sub-national to regional up to 30x30 arc minutes	IR; in future) the user interface will enable tweaking of variables to generate instant results	Business es, policy-makers, think-tanks	E: Energy demand and future projections (based on Shell study) W: Agriculture water (estimated based on Water Footprint Network methodology, which takes crop data from Land Use and Global Environment); Irrigation efficiency and spread of micro irrigation technologies (estimated based on IWMI's irrigation efficiency of its PODIUM model and ICID's irrigation scenarios); Domestic and Industrial water (adopted from Global Water System Project) L: land-use, crop and fertilizer applications (based on Land Use and Global Environment)	–	World Business Council for Sustainable Development (WBCSD)

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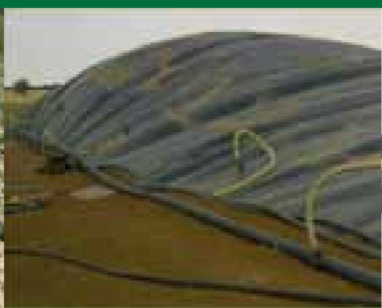
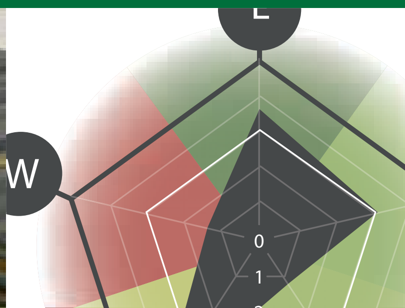
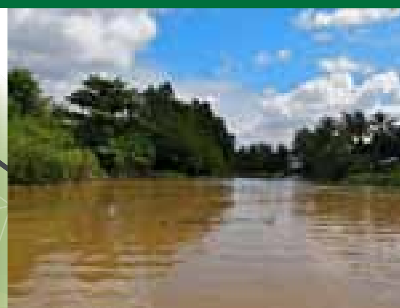
Due to global transformational trends, such as population growth, economic development and climate change, energy, water, land and human resources are increasingly under pressure to support societal development and to maintain necessary services. Decision-makers need improved tools in order to be better informed about trade-offs and synergies between different development and management choices, and to help them identify options on how to sustainably manage resources.

This report proposes a way to carry out a water-energy-food nexus assessment approach in order to: a) understand the interactions between water, energy and food systems in a given context, and b) evaluate the performance of a technical or policy intervention in this given context. The ultimate goal of the nexus assessment is to inform nexus-related responses in terms of strategies, policy measures, planning and institutional set-up or interventions.



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