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Water-Energy-Food nexus: framing the opportunities, challenges and synergies for implementing the SDGs

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Abstract The Water-Energy-Food Nexus has been promoted by a number of prominent and influential global policy actors over the last couple of years. Increasingly, the concept has emerged as a major research, policy and planning instrument to govern and address demand and supply challenges across four main development sectors: water, energy, food and ecosystems. These sectors are often considered within an interdependent relationship and intertwined framework for balancing tradeoffs and identifying synergies and opportunities. This article frames the water-energy-food nexus as a crucial policy and planning instrument for strengthening cross-sector interactions and highlights the opportunities and challenges for doing so. The article is divided into four main sections. The first section describes the major linkages between water and energy and shows that the links between water and energy goes far beyond where water and energy are needed for each other. The second section describes other nexus dimensions beyond water and energy to include dimensions such as food, ecosystems and climate change for example. The key challenges in pursuing the nexus perspective in integrated planning and management of natural resources are presented in the third section and lastly, as a way of concluding, the article outlines some of the measures that are needed to operationalize the nexus perspective. Considering the implications of this analysis for the implementation of SDGs would be an important undertaking going forward for the operations of development agencies and the means of ensuring that the interdependences among sectors are taken into account in policy formulation and implementation.

Keywords Cross-sector interactions · Sustainable development goals · Water-energy-food nexus

Water Energy Food Nexus: Ausarbeitung der Möglichkeiten, Herausforderungen und Synergien bei der Umsetzung der Ziele der nachhaltigen Entwicklung (SDG)

Zusammenfassung Der Water Energy Food Nexus wurde von zahlreichen bekannten und einflussreichen Akteuren globaler Politik in den letzten Jahren gefördert. Das Konzept entwickelte sich zunehmend zu einem großen Forschungs-, Politik- und Planungsinstrument zur Lenkung und Bewältigung der Herausforderungen hinsichtlich Angebot und Nachfrage in den vier wichtigsten Entwicklungsbereichen: Wasser, Energie, Lebensmittel und Ökosysteme. Diesen Bereichen werden oft ein wechselseitiges Verhältnis und miteinander verflochtene Rahmenbedingungen für Austauschbeziehungen und zur Ermittlung von Synergien und Möglichkeiten zugeschrieben. Dieser Artikel setzt den Water Energy Food Nexus fest als ein zentrales Politik- und Planungsinstrument zur Stärkung sektorübergreifender Interaktionen und beleuchtet die Möglichkeiten und Herausforderungen in dieser Hinsicht. Der Artikel ist in vier Hauptabschnitte aufgeteilt. Der erste Abschnitt beschreibt die wesentlichen Verflechtungen zwischen Wasser und Energie und zeigt auf, dass die Verbindungen zwischen Wasser und Energie weitaus über den Bereich, in dem Wasser und Energie aufeinander angewiesen sind, hinausreichen. Der zweite Abschnitt beschreibt andere Verflechtungsausmaße neben Wasser und Energie, das heißt Dimensionen wie zum Beispiel Nahrungsmittel, Ökosysteme und Klimawandel. Die entscheidenden Herausforderungen bei der Verfolgung der Verflechtungsperspektive (Nexus Perspektive) hinsichtlich integrierter Planungs- und Managementprozesse natürlicher Ressourcen werden im dritten Abschnitt vorgestellt. Zuletzt werden zusammenfassend einige der Methoden, die für die Standardisierung der Verflechtungsperspektive erforderlich sind, skizziert. Die Betrachtung der Auswirkungen dieser Analyse zur Umsetzung der Ziele der nachhaltigen Entwicklung (SDG) ist ein bedeutendes Vorhaben hinsichtlich des Fortschritts der Projekte von Entwicklungsorganisationen, ebenso wie die Bedeutung der Gewährleistung, dass die Wirkungszusammenhänge zwischen den Sektoren bei der Formulierung und Umsetzung der Politik berücksichtigt werden.

Schlüsselwörter Sektorübergreifende Interaktionen · Ziele der nachhaltigen Entwicklung · Water Energy Food Nexus

1. Introduction

The year 2015 has been described as an exceptional year for sustainable development. It is the target year for achieving the MDGs (Millennium Development Goals) and the year during which a new set of SDGs (Sustainable Development Goals) were agreed upon in the framework of the post-2015 Development Agenda. In September 2015, 17 SDGs replaced 8 MDGs at the United Nations Summit on the Post-2015 Development Agenda. Many of the 17 SDGs and their associated 169 targets are intertwined and closely related. The SDGs aim to provide a road map to deal-

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ing with the interconnected challenges of poverty, inequality, and environmental change. Hence there are growing calls for the Goals to be reached through an integrated management and implementation framework to use resources more efficiently and optimize desired outcomes. This is particularly relevant as the exploitation of natural resources is rising in many regions as a consequence of rising demand which is fueled by increasing economic and population growth and climate change.

Current official UN projections show that by 2100 global population will have increased to 10 billion people and by 2030, water supply could face a 40 % shortfall, whereas the world's food needs growing by as much as 50 % and energy demand will be three times greater than it was a mere decade ago (FAO 2011; Nellemann et al. 2009). New demands from urbanization, changes in infrastructure and investments opportunities, demand and supply management solutions could all impact water resources, food and energy production (Fig. 1). Besides, limitations on the availability of fresh water in some regions of the world may restrict the type and extent of energy development (IEA 2012). At the same time, high energy costs or limited energy availability will constrain efforts to provide adequate clean water and sanitation services to the thousands of millions of people who currently lack those basic services. Given these linkages, it is becoming increasingly important to pursue solutions that take into account cross-sectoral impacts and trade-offs among the various dimensions. In reality, the need to carefully plan and manage resources in an integrated way has never been as important and urgent as it is at the moment.

The interrelationship between energy and water in the production and transmission of each resource is often referred to as the "Water-Energy Nexus". The "Water-Energy Nexus" is an integrated approach on water and energy resources use and management, coupled with several related dimensions such as land, food production, ecosystems management and climate change. Hence, the more inclusive expression 'water-energy-food nexus' is preferred and used by many authors and international development organizations (Fig. 2). Since the 2011 Bonn Nexus Conference, there has been increasing calls for a more systemic approach on water, energy and food to address human and ecosystem needs in a changing world. The 'Nexus Perspective' is a call for action by those leading transformational changes in policy, infrastructure planning, financing and operation, as well end use applications to minimize risks and trade-offs. There is now a push to take an integrated approach that recognizes the critical links between water, energy, and food and the complex interactions between ecosystems and human activity at different scales (international, local, regional, and transboundary). Coherent water and energy policies increasingly require policy-makers to integrate the connections between water and energy and other dimensions into their decisions. An integrated approach to resources management can highlight the trade-offs and help ensure that benefits in one realm do not come at the expense of another, and if they actually do, the risks involved can be minimized. By pursuing a 'Nexus Perspective' in policy and implementation, it is easier to work across sectors and share experiences, lessons, tools and solutions that are emerging around the world.

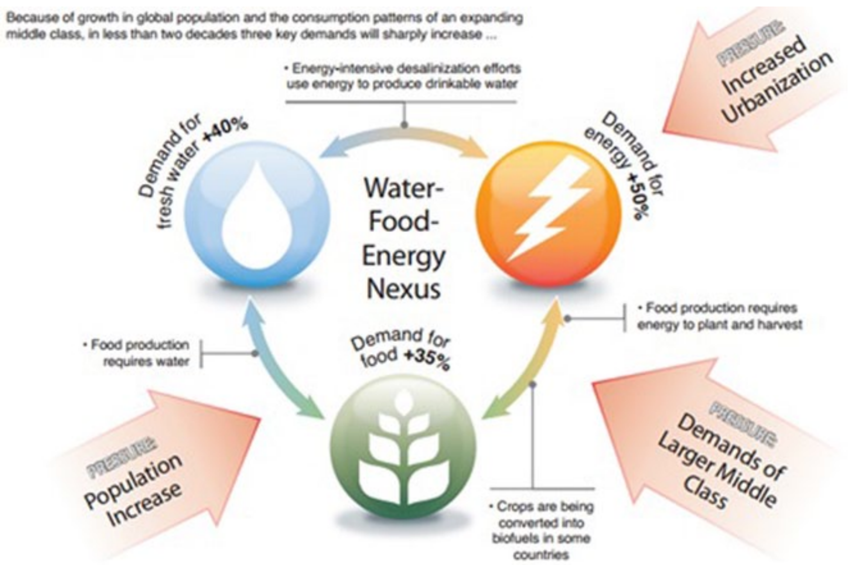


Fig. 1 Drivers of global change are intensifying water-energy-food interactions (Source: http://chinawaterrisk.org/resources/analysis-reviews/water-risk-national-security/)

The interdependencies between nexus resources have often been viewed from what could be called a "static perspective", i.e. by taking into account only one (or two) target resources (e.g., increase or optimization of electricity generation or potable water supply) while ignoring broader interdependencies between them (Hermann et al. 2012). For example, energy and water policies are rarely discussed in the same forum even though water and energy resources are fundamentally intertwined. It is well known that constraints on water availability can challenge the reliability of existing energy operations, as well as the physical, economic and environmental viability of future projects. On the other hand, the use of water for energy production can impact freshwater resources, affecting both their availability and quality. Evaluating these tradeoffs by encouraging cross-sector planning is required for sustainable management and development of natural resources (IEA 2012). This need will become even more crucial with increasing pressure on both water and energy resources in the coming decades. Integrated resource planning will become more imperative for both economic and environmental reasons as competition for natural resources increase. Already water and energy constraints are threatening the reliability of existing operations and increasingly imposing additional costs in some regions. This trend is expected to continue in the future as population and economic growth intensify competition for water, energy and other resources.

The traditional divisions between management institutions for energy, food, water, land and ecosystems are still very much present in many countries as most governments have separate institutional settings to manage water, energy and food in terms of policies, planning and implementation, with relatively little coordination between them. Policy makers and planners continue to routinely make decisions within one sector without adequately taking into consideration the policy complexities and implications of other sectors. Similarly, international development efforts are pursued along the same sectoral divisions. Often, the lack of policy coherence inhibits each sector from fully benefiting from joint opportunities and accounting adequately for the financial, environmental or social effects they have on each other to the detriment of budgets, efficiency, the environment and even public health. Yet the links between various nexus dimensions are opportunities for policy makers, business leaders, investors, non-governmental organizations and the public at large to manage key global resources in an integrated way when addressing major global challenges like eliminating poverty and improving access to water, energy and food supply. Understanding the interdependencies between various Nexus dimensions and being able to address challenges and make use of existing opportunities across dimensions is crucial for decision-makers, the business community and general public at large.

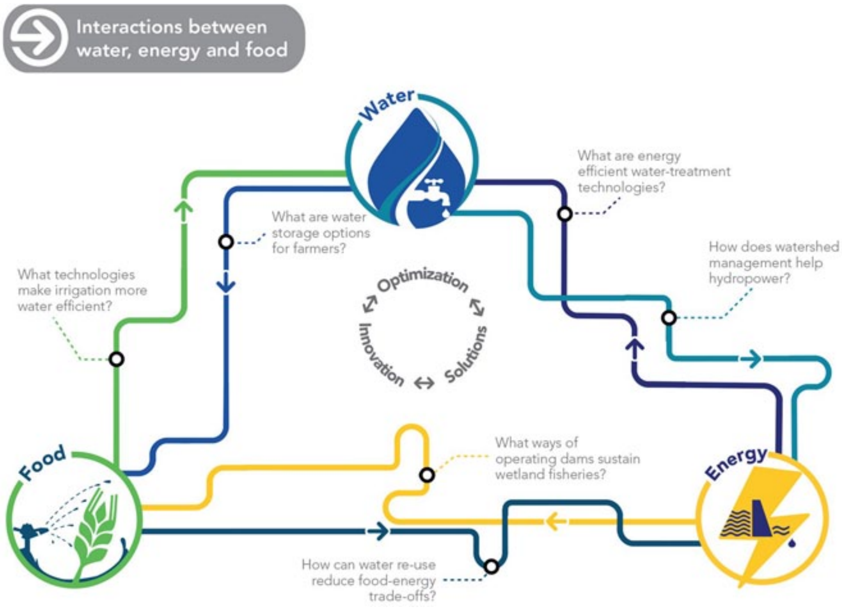


Fig. 2 Interactions between water, energy and food. (Source: https://www.iucn.org/about/work/programmes/water/resources/wp_resources_infographics/)

The nexus perspective is a structured way to address cross-cutting issues related to the water, energy and food, as well as other related dimensions. This requires the close involvement of all relevant stakeholders in the decision-making process to identify synergies and trade-offs. A nexus perspective increases the understanding of the interdependencies across the water, energy and food sectors and influences policies in other areas of concern such as biodiversity and climate change. It helps to move beyond silos and ivory towers that preclude interdisciplinary solutions, thus increasing opportunities for mutually beneficial responses and enhancing the potential for cooperation between and among all sectors. The nexus approach also allows decision-makers to develop appropriate policies, strategies and investments, to explore and exploit synergies, and to identify and mitigate trade-offs among the development goals related to water, energy and food security. Given that a true nexus approach can only be achieved through close collaboration of all actors from all sectors, the concept ideally promotes the active participation of all stakeholders at all scales of governance, including government agencies, the private sector and civil society which is critical for avoiding unintended consequences.

As the nexus perspective typically promotes integrated management and governance across sectors and scales, it can support the underlining principles of sustainable development, which includes, among other things, greater policy coherence and resource use efficiency. Given the increasing interconnectedness across sectors, a reduction of negative economic, social and environmental externalities can increase overall resource use efficiency, provide additional benefits and secure the human rights to water and food. In a nexus-based approach, conventional policy- and decision-making in “silos” therefore would give way to an approach that reduces trade-offs and builds synergies across sectors.

This article frames the water-energy-food nexus as a crucial policy and planning instrument for strengthening cross-sector interactions and highlights the opportunities and challenges for doing so. The article is divided into four main sections. The first section describes the major linkages between water and energy and shows that the links between water and energy goes far beyond where water and energy are needed for each other. The second section describes other nexus dimensions beyond water and energy to include dimensions such as food, ecosystems and climate change for example. The key challenges in pursuing the nexus perspective in integrated planning and management of natural resources are presented in the third section and lastly, as a way of concluding, the article outlines some of the measures that are needed to operationalize the nexus perspective.

2. Water for energy

2.1. Extraction and processing of fossil fuels

Water is essential in the conventional extraction of energy resources to energy production: in power generation; in the extraction, transport and processing of oil, gas and coal; and, increasingly, in irrigation for crops used to produce biofuels (Table 1, 2). Water is also used in energy conversion to useful forms, i.e. converting coal or uranium to electricity or converting petroleum into fuels such as gasoline or diesel (Gleick 1994; U.S. DOE 2006). Many parts of the coal fuel cycle are water intensive, including coal mining, reclamation of mined land, and coal combustion, which requires substantial water for cooling, ash handling, and waste disposal. The extraction of conventional oil and natural gas also require relatively modest amounts of water during the exploration and drilling process and for human sanitation and drinking water in settlements set up for drilling operations (Feeley et al. 2005). Drilling for natural gas has usually required modest amounts of water for preparing drilling fluid. However, water requirement for oil and gas extraction is growing considerably with expansion into unconventional resources such as shale gas and oil sands, which are much more water intensive because of the enhanced recovery techniques that are currently in use. The drilling method

Table 1 Key uses of water for primary energy production

Fuels	Description
Oil & Gas	Drilling, well completion and hydraulic fracturing; injection into the reservoir in secondary and enhanced oil recovery; oil sands mining and in-situ recovery; upgrading and refining into products.
Coal	Cutting and dust suppression in mining and hauling; washing to improve coal quality; re-vegetation of surface mines; long-distance transport via coal slurry.
Biofuels	Irrigation for feedstock crop growth; wet milling, washing and cooling in the fuel conversion process.

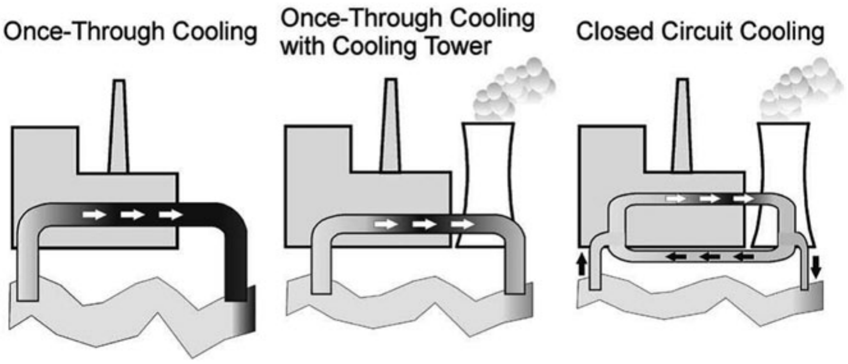


Fig. 3 Main types of cooling systems for thermoelectric power plants; (Source: Koch & Vögele 2009)

known as hydraulic fracturing (hydrofracking) is currently used to blast huge volumes of water, fine sand and chemicals into the ground to crack open valuable shale formations (U.S. DOE 2006). The method has been heavily criticized because of the water quality challenges posed and the huge amounts of water required, especially when drilling operations are located in water scarce areas. The amount of water needed for hydrofracking varies greatly depending on how hard it is to extract oil and gas from each geological formation (Bartis et al. 2005). Accurate water volumes necessary to support a commercial oil shale industry are not known, but they are thought to be substantial for mine and plant operations, reclamation, supporting infrastructure, and associated economic growth (NETL 2006). Water may come from a variety of sources—ground water wells, surface streams and rivers, water produced from oil shale processing, waste waters from other industries.

2.2. Thermoelectric power

The vast majority of water used in the energy sector is for cooling at thermal power plants, as water is the most effective medium for carrying away its huge quantities of waste heat (IEA 2012). Some of that water is used to produce the steam which turns the turbines to generate electricity, while most of it is used for condenser or evaporative cooling of the excess heat that is produced from the conversion process. Thermoelectric power plants require fuel to heat water to produce steam. This could come from a variety of sources, including coal, nuclear, natural gas, oil, biomass (e.g., wood and crop waste), concentrated solar energy, and geothermal energy (U.S. DOE 2006). Compared to fossil fuel power plants, nuclear power plants require the largest water withdrawals per unit of electricity produced. Gas-fired power plants are the least water intensive. Hence, the water requirement of a thermoelectric power plant is largely driven by the characteristics of the fuel used and the type of cooling technology installed. There are three basic types of cooling technology in use: once-through-cooling, recirculation or wet cooling, and dry cooling (Fig. 3). With once-through-cooling, water passes through the cooling systems once and cooling is achieved through thermal conduction in a condenser. After having passed through the condenser, the cooling water is returned to its source at a higher temperature. These plants typically withdraw large amounts of water but consume a very small percentage of that water. Wet cooling systems conversely re-circulate water through the cooling systems many times and achieve cooling through an evaporative process. These systems have lower withdrawal rates but can actually consume more water as more and more water evaporates. Dry cooling is the least water intensive from both withdrawal and a consumption point of view but it is also the least energy efficient (Koch & Vögele 2009). It re-circulates water through a closed loop system and achieves cooling through convection as electrically driven fans blow air over cooling fins. By changing the cooling system of power plants from once-through systems to closed circuit systems, the vulnerability of power plants to water shortages can be reduced (Gleick 1994). However, converting the cooling system from once-through to closed circuit could significantly increase the water consumption (Koch & Vögele 2009).

2.3. Hydropower

Hydroelectric power generation is probably the most obvious link between energy and water. However, quantifying water use for hydropower is less clear-cut compared to other forms of electricity generation or energy production (Averyt et al. 2011). Water flowing through the turbines and into the river is not considered consumptive because it remains in the river and can actually be used multiple times by successive dams whilst still being available for other uses. For instance, a dam may generate power as it releases water for downstream uses and ecosystem needs, and such facilities could be seen as not "withdrawing" any water whatsoever. Nevertheless, dams may alter the timing of stream flows, both seasonally and hourly, as the timing of water releases is generally governed by the demand curve for electricity, within environmental and engineering constraints (Bazilian et al. 2011). Also conflicts can arise with downstream uses, including irrigation, in-stream uses, and supporting ecosystems. Water consumption or loss due to hydropower is limited to the loss by evaporation in the dams/reservoirs. The increased surface area of the reservoir, when compared to the free flowing stream, results in additional water evaporation from the surface (Mekonnen & Hoekstra 2011). But this is much more complicated as most dams provide more than one function and there is no easy way to disaggregate the water used by the various activities in and around dams. Water stored in reservoirs for hydropower generation usually has multiple uses such as flood control, water storage, recreation, navigation, fishing, or water withdrawal for irrigation, drinking municipal water, and thermoelectric power plant

Table 2 Key uses of water for power generation

Fuels	Description
Thermal (fossil fuel, nuclear and bioenergy)	Boiler feed, i.e. the water used to generate steam or hot water; cooling for steam-condensing; pollutant scrubbing using emissions control equipment.
Concentrating solar power and geothermal	System fluids or boiler feed, i.e. the water used to generate steam or hot water; cooling for steam-condensing.
Hydropower	Electricity generation; reservoir storage (for operating hydro-electric dams or energy storage).

cooling (Torcellini et al. 2003). Therefore, evaporation losses from reservoirs used for generating hydroelectric power cannot be attributed to that use alone and the subject of ongoing debate because determining the relative impact of other uses versus hydroelectric projects is a very complex issue. Nexus issues around dams for hydropower revolve around water loss from reservoirs, upstream-downstream problems and potential for conflict, loss of agricultural land, environmental degradation and loss of ecosystem biodiversity. While there are many benefits to using hydropower as a renewable source of electricity, there are also environmental impacts. These impacts generally relate to how a hydroelectric project affects a river's ecosystem and habitats, as well as the livelihoods of people living upstream and downstream. Dams can obstruct the free flow of water, thus fragmenting habitats and hindering the migration of aquatic fauna. Hydroelectric plants can impact water quality and river ecology in several ways. Hydropower plant operations can also change the natural flow characteristics of rivers and operations can change water temperatures and dissolved oxygen and nitrogen levels, which could impact aquatic ecology and other human uses of the water downstream.

2.4. Bioenergy

The international energy community has recently seen an increased interest in biofuels, fueled largely by high oil prices and the initial perception of their role in reducing CO_2 emissions. Biofuels have succeeded in sowing hope for a more large-scale development, particularly to help reduce the dependence on fossil fuels and as a technical option to mitigating climate change. However, this renewable energy source comes with a price. The key drivers for the global biofuels industry include the following: i) they are seen as a technical option to mitigate climate change; ii) they are an alternative source of energy for reducing oil-dependency with rising crude oil prices, iii) they increased/new revenue for farmers through the production of value added products; iv) some farmers see biofuels as the answer to often inaccessible and unpredictable global agricultural markets; v) they are seen as an opportunity to revitalize a deteriorating agricultural sector, both in developing and developed countries. However, besides competing with food crops for scarce arable land, biofuels compete with other water needs when grown in water scare regions. The most water-intensive aspect of biofuel production is growing the feedstock but in general, water consumption for refining biofuel is generally similar to that used in conventional oil refining processes. Even though the amount of water used may appear minor on a global level, this must be viewed in the context of local water resources and potential risks posed to water quality (IEA 2012). For example, based on data from the US Department of Agriculture, the volume of irrigation water consumption in arid or semiarid regions of the US for the same volume of fuel produced can exceed the water consumption for refining by a factor of one thousand when the feedstock is corn (for ethanol) or soy (for biodiesel) and grown on irrigated land (U.S. DOE 2006). The fastest growth in biofuels production is expected in emerging and developing countries particularly in Asia, Africa and Latin America (Urbanchuk 2012). In those countries, biofuels will supply rapidly growing domestic markets and provide an important base for expanding export earnings needed to fuel economic growth. The cases of Brazil, Mexico and Malaysia are good examples. However, in some of those countries, the ecosystems-land-water-food-related consequences of large-scale biofuel production and the potential need for policy guidance in this area are yet to be fully explored (Hughes et al. 2007).

2.5. Renewable energy

A shift towards renewable energy sources has been heavily promoted because they are considered as a sustainable source of energy. Others see them as an alternative to crude oil and as a response to climate change mitigation measures. Renewable energy present a way to meet Kyoto Protocol commitments for GHG emission reductions, decrease air pollution for domestic reasons, and/or generate greater domestic energy security in non-oil producing countries. The utilization of renewable energy sources has numerous advantages, such as reducing greenhouse gas ("GHG") emissions, improving energy security, and providing economic opportunities in the world's impoverished rural areas. Other advantages of renewable energy are an increase in resources diversification and the absence of depletion risks (Gerbens-Leenes 2009). These alternative sources of energy are perceived not only as one of the answers to the present energy crisis on a global level, but also as one of the solutions to the global warming problem attributed to greenhouse gas emissions (Urbanchuk 2012).

Water-intensive renewable energy sources include hydropower, bioenergy, geothermal, concentrated solar power (CSP). Other forms of renewable energy sources, such as solar photovoltaic cells, wind energy, energy from sea waves etc. consume minimal amounts of water. However, an ideal location for a concentrating solar power plant would be a dry desert flatland close to the equator where the sun shines every day of the year out of a clear blue sky. Usually, these places have warm climates and few natural freshwater supplies making CSPs in such locations quite competitive with other water needs. Therefore, care must be taken when promoting certain forms of renewable energy sources in certain locations as some renewable energy technologies can be water intensive.

3. Energy for water

3.1. Conventional drinking-water treatment

Energy is needed for obtaining, transporting, treating, and distributing potable water to end users, use by end users, and transport and treat resulting wastewater. Water Utilities are high energy users, much of which comes from fossil fuels which is imported. Virtually every drinking water supply is treated in some form or fashion, driven by a number of factors primarily associated with the discovery of new contaminants: advanced testing methods; public perception; verifiable health risks; and development

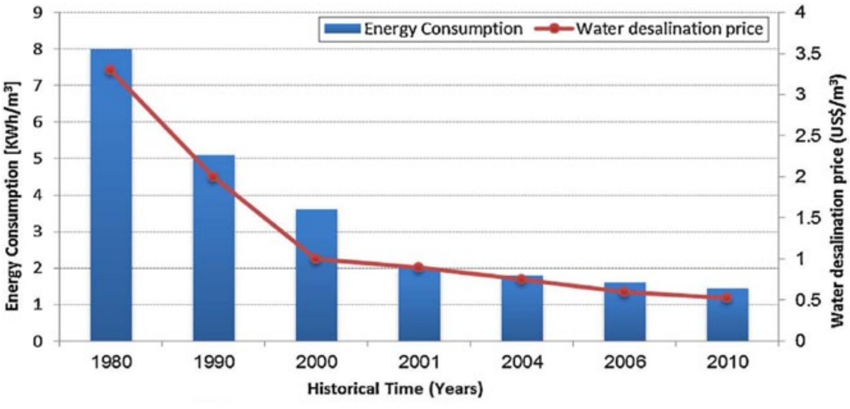


Fig. 4 Developments in energy consumption and related costs for Reverse Osmosis; (Source: Shatat et al., 2013)

of improved/new water quality standards. The extent of water treatment—and the energy needed to meet those requirements—can vary considerably, as expected, because of the accessibility and initial quality of a raw water supply. Nevertheless, energy costs alone can account for about 75 % of the processing and distribution cost of municipal water. In the US for example, between 30 and 50 % of the municipal energy budget for many cities is consumed by water supply processes (AGU 2012). In regions where pumping and distributing water requires significant electricity use, policies that lead to reduced water consumption could address climate change more efficiently than requiring businesses and households to use less energy. The wide range in energy intensity in different parts of the world is driven primarily by difference in water quality and access to sources of water, e.g. water stressed regions may rely on lower quality water sources and consequently may require more energy intensive water treatment. But the actual percentage of energy contribution to the total can vary with the type and magnitude of the water project. Generally, the energy costs are linked to issues such as: i) the source/quality of raw water and the treatment method(s) used; ii) the number of inhabitants and/or size/type of industry supplied, and iii) the type of water distribution network, including the piping distance, elevation changes and pressure requirements. In future, the energy requirements of conventional drinking-water treatment processes is expected to increase as more and more surface waters become polluted. Furthermore, given that as all treatment methods must comply with certain water quality objectives and contaminant removal criterion, future implementation of new drinking water regulations will increase the use of treatment techniques that require higher energy consumption, such as ozonation and membrane filtration. Conventional treatment processes for most surface water sources usually rely on chemical addition, coagulation and settling, which is then followed by filtration and disinfection techniques that are less energy intensive compared to ozonation and membrane filtration.

3.2. Desalination

Desalination is a water treatment process that removes dissolved minerals from seawater, brackish water, or treated wastewater as alternative sources to address increasing demands on limited fresh water resources. The installed capacity of desalination plants has increased in an exponential scale over the last 30 years. Worldwide, desalination plants produce over 3.5 billion gallons of potable water a day. In energy-rich arid and water-scarce regions of the world, desalination is already a vitally important option. Many areas of the Caribbean, North Africa, Pacific Island nations, and the Persian Gulf rely on desalinated water as a source of municipal supply. In some regions of the world, nearly 100 % of all drinking water now comes from desalination—providing an essential and irreplaceable source of water (DLR 2007). For example, UAE produces over 90 % of its potable water through desalination. In spite of all the progress over the past several decades, and despite recent improvement in economics and technology, desalination still makes only modest contributions to overall water supply globally. This is mainly because of the associated costs resulting from its huge energy requirements of the technologies in use, namely, Reverse Osmosis (RO), Distillation, Electrodialysis (ED), and Vacuum Freezing (IEA 2012). RO technology is the most economical and environmentally friendly form of desalination given that plants using RO technology require less energy than other desalination technologies (Shatat et al. 2013). Also generated energy during RO can be redirected to the water pumping system, which will reduce the total energy requirements of the process (IEA 2012). These technologies are more costly than conventional methods for the treatment of freshwater supplies. even if energy consumption and related costs for RO technologies declined sharply between 1980 and 2010 (Fig. 4). The desalination cost for seawater is estimated at around US$ 1/m^3, for brackish water it is US$ 0.60/m^3 (Zhou & Tol 2005) compared to freshwater chlorination, which costs US$ 0.02/m^3. The cost of desalination has fallen in recent years. Nevertheless, desalination remains an expensive water-treatment option given that even the most energy efficient technologies currently in use still have huge energy demands. As energy is the largest single expense for desalination plants, it accounts for as much as half of the total project costs. The most energy-efficient desalination plants in the world consume about 3.2 kilowatt hours (kWh) of energy to produce a cubic meter of water. Plans for new energy efficient desalination plants in the United Arab Emirates (UAE), for instance, are targeting roughly 3.7 kWh per cubic meter of water. Currently, desalination plants in the region require 4–6 kWh of electricity to produce one cubic meter of water. The choice to invest in energy-intensive desalination technologies implicitly is a choice to tradeoff higher energy intensity in order to extend the water supply. This certainly raises the concern that the water supply could become more energy intensive.

3.3. Water-related end-use applications

Energy for the end use of water is difficult to calculate due to the varied users and uses of water, and therefore, has significant limitations for computing the nexus energy for water end-use applications (Perrone et al. 2011). However, both domestic and industrial water-related end-use applications of water equipment need considerable amounts of energy. In

Fig. 5 Water and energy interactions go far beyond the links where water and energy are needed for each other (Source: http://www.water.ca.gov/climatechange/WaterEnergyStatewide.cfm)

California, for example, 14 % of the state's electricity consumption and 31 % of its natural gas consumption is used for activities such as water heating, clothes washing, and clothes drying (Klein et al. 2005). Most of that use is estimated to come from the residential sector. These data illustrate that both water and energy can be conserved through the use of appliances and fixtures that reduce hot water use (U.S. DOE 2006). Reducing domestic and other end-user water intensity could conserve both water and energy. Actually, some of the cheapest greenhouse gas emission reductions measures that are currently available seem to be not energy-efficiency programmes, but water-efficiency programmes. For example, it may be cheaper for consumers to reduce the overall hot water usage in their homes than to replace their incandescent light bulbs with more energy-efficient alternatives (Klein et al. 2005). Energy efficiency water programmes have traditionally focused on saving energy in end-use applications, including water heating, clothes washing and drying or process heating, in addition to saving energy in water and wastewater treatment facilities (Klein et al. 2005). Reducing urban and other end-user water intensity conserves both water and energy. Some of the cheapest greenhouse gas emission reductions available seem to be not energy-efficiency programs, but water-efficiency programs. Therefore, it seems appropriate, for example, for consumers to reduce the overall hot water usage in their homes than to replace their incandescent light bulbs with more energy-efficient alternatives. There is tremendous additional potential for improving efficiency and productivity of water use. Water shortages have become emergencies and droughts may worsen with climate change. Conditions may become more severe in the future as consumers turn to water solutions that often require even greater energy supplies. With efficiency, much more can be done with much less water in every sector from agriculture to industry to our homes. The notion that demand for water will continue to rise with population growth and economic development is not entirely correct. As a result of a combination of improvements in water use efficiency and changes in technology, many developed countries use less water today than three to four decades ago and even far less per person.

3.4. Wastewater treatment

Wastewater treatment has been described as the quintessential nexus challenge, yet little attention is paid to wastewater, both as a key energy resource and as a major user of energy for its treatment. This is largely because in the past, energy costs were typically not a major priority for municipalities and plant operators who have been more concerned with safety and effective operations to ensure properly processed wastewater (API 2000). However, the connections between energy and wastewater are now being considered more closely and taken more seriously to improve energy efficiency during treatment and to reduce costs for wastewater treatment operations. The energy costs for the treatment process is now a major priority for many plant operators and engineers who design the plants. In future, this will become increasingly important with respect to reducing operating costs of both the plant function and its energy management as energy use and associated cost for wastewater treatment is expected to continue to rise as environmental regulations become more stringent and the volumes of wastewater requiring treatment increase globally. Typically, wastewater treatment plants are regulated to limit their impact on the environment, with particular focus on removing or reducing chemical concentrations in liquid effluents and solid wastes (U.S. EPA 2006). However, such regulations rarely consider the broader effects associated with the life cycle of the wastewater system as a whole, including the impacts on energy

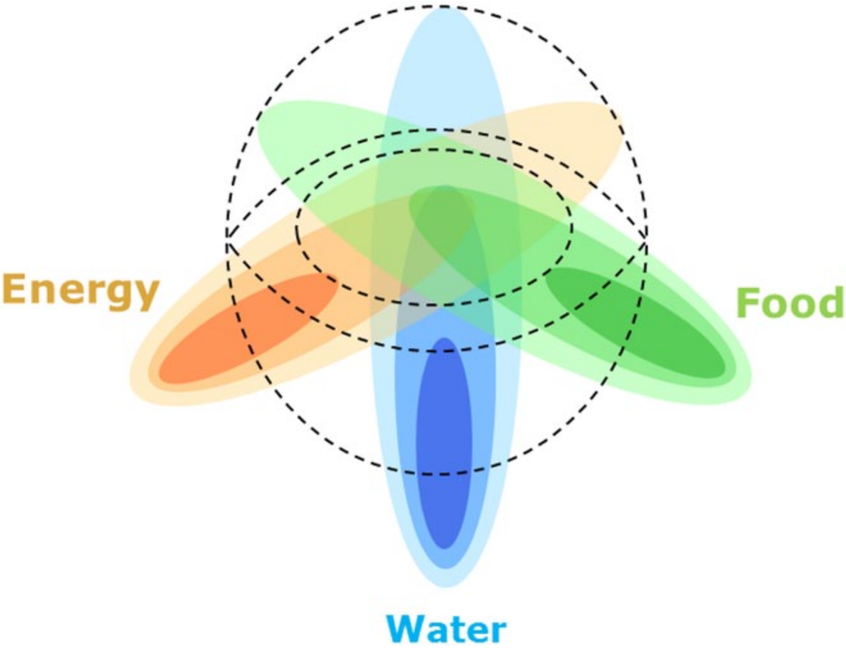
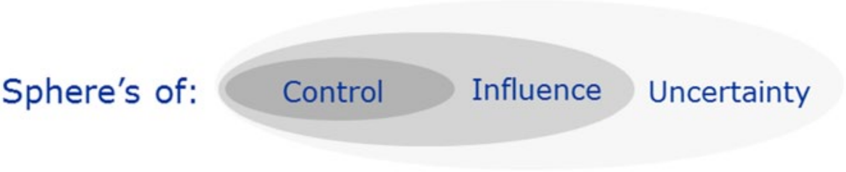


Fig. 6 Knowledge of how the spheres of control, influence and uncertainty operate for each sector is critical for managing nexus interactions



use, material production and use, or the infrastructure construction and maintenance. Like drinking-water treatment plants, wastewater treatment plants and their operations increasingly warrant specific attention to capture energy savings opportunities, which will help reduce financial pressures on these industries (U.S. EPA 2006).

4. Critical nexus dimensions

4.1. Water-Energy-Food

The interactions between water and energy go far beyond where water and energy are needed for each other (Fig. 5). Agriculture, for instance, is probably the most prominent human activity through which the complex web of inter-linkages between various nexus dimensions are most visible. Current crop production practices are heavily dependent on natural variables such as climate, land/soil and fresh water resources. For intensive/mechanized forms of agriculture, energy is required for ploughing, irrigation, harvesting, transport and packaging. For this reason, food is usually referred to as the third dimension of the nexus. Its inclusion in the nexus discourse is important as the water-energy-food (WEF) nexus ties together three mutually-dependent global security concerns, i.e. access to water, sustainable energy and food security. Water and energy are closely intertwined throughout the food production chain, from crop cultivation and livestock rearing to transport and food processing. Agriculture accounts for about 70 % of global fresh water use and energy is needed not only for pumping large volumes of water for irrigation, but also for other farm applications. A change in cultivated crops and/or production methods can have considerable impacts on local energy demands, which can account for a large proportion of the electricity requirements of a given country. In addition, mechanized agriculture relies heavily upon machinery that runs on gasoline and diesel fuel (e.g. tractors and combine harvesters), and equipment that uses electricity (e.g., lights, pumps, fans, etc.). Energy is also used to manufacture fertilizers and pesticides. In addition, most of the food produced today is processed and packaged, and transported over long distances, thereby increasing its energy and water footprints.

Alternatively, energy has become a major agricultural output in some parts of the world. Increasing energy prices and global initiatives on limiting CO_2 emissions from fossil fuels has triggered the substitution of food crops with fuel crops. However, many of the crops used for bioenergy can also alternatively be used as food or feed, which is of course a growing concern for food security in both developed and developing countries. Current biofuels technologies rely on converting crops that farmers have traditionally grown for food/feed purposes (e.g. corn, rapeseed, soybeans, canola, wheat, beets, sugar cane, jatropha and palm oil) into ethanol or biodiesel that could displace fossil fuels in motor vehicles, a significant source of carbon dioxide emissions. Biofuel crops compete with food or feed crops for land, water and other resources needed for crop production. Depending on where they are grown, many biofuels have potentially high water requirements. Thus increased cultivation of large scale fuel crops can compete with food crops for irrigation water needs. Moreover, a change in cultivated crops and agricultural production methods (e.g. by increasingly forcing traditional subsistence farming to formerly marginal land areas) may induce land use changes, with considerable consequences on the local ecosystems (Hermann et al. 2012). Furthermore, agriculture can pollute freshwater supplies, including both surface water and groundwater, thereby impacting negatively on the quality of available water for other societal needs.

In addition, there are additional dimensions that are emerging in more recent years. Energy companies around the world are exploiting new energy reserves, in particular, shale deposits. This is claiming farmlands and/or competing seriously with crop production systems for scare water resources, especially in drought prone regions. Hydro-fracking—the method used for extracting shale oil and gas deposits—typically consumes less water than farming or residential uses. However, drilling operations in drought-stricken areas can increase competition for scare water resources, driving up local water prices and burdening already depleted aquifers and rivers in certain stretches. In the US, for example, overtures by oil and gas companies that want to drill new wells amid plantations have prompted controversial discussions on managing farmlands west of the Mississippi. In Arkansas, Colorado, New Mexico, Oklahoma, Texas, Utah and Wyoming, the vast majority of the counties where fracking is occurring are also suffering from drought according to the U.S. Department of Agriculture (U.S. DA 2004).

Given all the interactions and the competing demands and trade-offs involved, addressing the triple challenge (water stress, food security and access to energy) in a successful way means taking a holistic view to balance trade-offs and explore new opportunities. A comprehensive approach to the water-energy-food nexus can secure water, energy and food, and improve the well-being of the poorest and most vulnerable populations around the world. Using the nexus perspective around the linkages can lead to better decisions and a wiser management and use of three very important resources that are essential in addressing important global development challenges.

4.2. Water-Energy-Ecosystems

Ecosystems have been described as the unseen dimension of the nexus. Ecosystem services are provided in several ways through well-functioning watersheds, forested hill slopes, rivers, wetlands and floodplains. Actually, ecosystems underpin each of the three often talked about dimensions of the nexus (water, energy and food) and the extent to which livelihoods are dependent on the sustainability of ecosystems through the variety of services that they provide. The provision of water, for instance, is optimal if it is connected to and balanced with the supporting and regulating ecosystem. Similarly food and energy production systems are more efficient and reliable when they are complementarily developed and managed with ecosystem services. On the other hand, ecosystem degradation can seriously undermine food production, energy access and the availability of water, thereby threatening human health, livelihoods and ultimately societal stability. Without well-functioning ecosystem services, the construction of man-made infrastructure to address challenges such as energy access (hydropower), flood mitigation, irrigation or municipal water supply can hardly function effectively and sustainably.

Therefore, it is important to include the value of ecosystem services into resource utilization and management. Currently there is much talk and emphasis on the pursuit of opportunities for investments which rely heavily upon natural resources and ecosystem services. The benefits of such investments can be seen in terms of economic returns, social equity and the resilience of vital ecosystems. By including the nature dimension, investment decisions can then be based on the full picture of the options available. In particular, considering solutions that put natural and man-made infrastructure in synch will help both ecosystems and sustainable development. Actually, recognizing the valuable but non-monetized benefits of conserving ecosystems is an opportunity for achieving sustainable growth. It has been argued that this understanding opens the way for nature conservation and restoration of ecosystems when formulating policy and undertaking investments in man-made infrastructure. Furthermore, experience has showed that formulating isolated policies and investments without considering their impacts on ecosystems may not be sufficient in many cases (Krchnak et al. 2011). Instead options that combine man-made and natural infrastructure are more cost-effective in terms of risk reduction and the benefits received. For example, building a reservoir to store water upstream may provide for water supply throughout the year but the reservoir can affect the flooding regime downstream that replenishes soil water for agricultural production. However, human activities upstream of the reservoir may increase soil erosion and siltation of the reservoir. Alternatively, a nexus approach with considerations for ecosystem services could combine the engineering of man-made infrastructure with management of natural infrastructure, for example, by releasing water downstream to mimic the natural flow regime or by investing in water catchment protection and conservation of forested hill slopes to control soil erosion to reduce sedimentation of downstream man-made reservoirs.

4.3. Water-Energy-Climate change

All nexus dimensions, including water, energy, food and ecosystems are linked to climate and they have been included in several ways in the ongoing discussion on climate change mitigation and adaptation. Climate change threatens a more water constrained future in many regions as its impact is first felt through global hydrological systems, and in consequence the availability of water both in quantity and quality. On the other hand, rising global temperatures, which are largely driven by current energy use patterns, will accelerate the movement of water by increasing both evaporation and precipitation (IEA 2012). These effects will most certainly affect different regions of the world, with particularly acute threats to the high mountain ecosystems such as the Himalayas and the Andes, as well as low-lying islands in the Pacific and the Caribbean. Expected impacts include falling average surface water flows (glacier melt being an exception); higher surface water temperatures; a reduction of snowpack and change in the timing of the snowmelt season; sea level rise, which will contaminate freshwater supplies; and droughts, heat waves and changes in precipitation patterns and runoff with the potential for droughts and floods, which will be more frequent and severe (IPCC 2008). These events will in turn impact ecosystems, the availability of farmland and its productivity, the accessibility of water for drinking and industrial use and access to certain forms of energy, in addition to changes in energy consumption patterns (Bazilian et al. 2011; Hermann et al. 2012). Consequently, the present challenges of balancing the various dimensions of the nexus will be exaggerated in future by climate change and together with other global development challenges (such as water scarcity, access to energy, food security, pollution, land degradation and biodiversity loss), climate change is certain to continue to attract the attention of policymakers as population grows and pressure mounts on the use of natural resources. In the coming years, this is very likely going to strengthen and increase the visibility of the inter-linkages between the various nexus dimensions. Therefore, if manages and used properly, the climate dimension of the nexus could emerge as one of the most potentially rewarding aspects for sustainable development in the post-2015 period.

5. Key nexus challenges

5.1. Complexity of the nexus dimensions

The complexity between various nexus dimensions is still poorly understood. For instance, those concerned with climate change and sustainable development appreciate the importance of water and energy in the debate and the complex links between them. However, it is easier to appreciate the links but it far more difficult to understand how the links work and how any hindrances can be removed and frameworks created to use the links meaningfully and help secure water, energy and food security in a sustainable way. For example, it is generally accepted that renewables such as wind and solar power may indeed reduce greenhouse gas emissions. However, the emissions created upstream, during the manufacturing, installation, operation, and also during decommissioning are not fully understood and considered in the matrix (Horvath & Stokes 2011). A better understanding of the inter-linkages between various nexus dimensions can lead to improved management and better investment opportunities across sectors. Clearly, the value lies in simplification, i.e. reduction of the complex nexus problem into manageable dimensions to explore synergies and address shared uncertainties. In particular, knowledge of how decision making processes within the sphere of control, the sphere of influence and the sphere of uncertainty operate within each sector and how actions taken within these shperes affect decisions and the corresponding actions in related sectors is important for managing cross-sector interactions in any meaningful way (Fig. 6). The knowledge for doing so seems to be largely present but silo-based approaches have continued to hider progress as various government ministries prefer to work within their own sphere of control (own silos) rather than working together. In many countries, there are well established sets of policy for managing natural resources. However, policy and implementation is still sector-driven for various dimensions of the nexus. As a result, planning and management for the dimensions is not undertaken in an integrated manner and resources are not utilized in an integrated way. This constraint is limiting the possibilities for collaboration and synergy across sectors that are otherwise essentially related. Resolving the growing issues and priorities within the various dimensions of the nexus require better and integrated policy frameworks and political engagement to address all of them adequately. Nexus issues can be addressed in a more coordinated way to help overcome communication barriers between them and ensure that each resource is more adequately protected. For instance, exploring policy objectives that explore the linkages between various nexus dimensions and clearly define coordination mechanisms between related sectors that manage the dimensions can be developed and strengthened.

5.2. Unequal visibility of nexus dimensions

The boundaries of different nexus dimensions are not clearly defined, and to complicate matters, it is rare that they align with established management/administrative boundaries, e.g. river basin, urban center, or even geopolitical divisions. For example, large cities can have more than one energy provider, especially because there are multiple energy sources available (Perrone et al. 2011). Normally national energy grids operate as a network composed of thermoelectric, nuclear, hydroelectric, and alternative source facilities, and services can extend well beyond the power producing plants. Water, food and other natural resources have similar open-ended boundary conditions, and it is also rare for them to align with each other. With drivers such as population, land-use changes and climate change having significant impacts on and policy for water, energy and food systems, the management and governance of natural resources needs to be approached in a coherent way across all sectors and scales. Yet there is unequal visibility and interest in various dimensions of the nexus. Energy and climate change, for instance, is more in the spotlight than any other nexus dimension due to their perceived importance for economic growth and sustainable development compared to other important dimensions like water or food or even ecosystems. For example, more global attention has continued to be paid on reducing carbon emissions rather than on water management for energy production even though it is now increasingly clear that water is consumed in energy production and water can be a constraint in do so. A more balanced approach is required to manage natural resources in a more sustainable way. For instance, sustainable energy production would require that water is considered at the same level of importance as energy in energy planning and development. This is very important because there is a wide range of water intensities in energy production and water intensity can be optimized in design and operation of energy infrastructure.

5.3. Quantification of nexus elements

Optimizing and balancing the complex tradeoffs in the water-energy-food nexus requires the quantification of various nexus elements (energy use, and water use/consumed, food production, ecosystem services etc.) and fully understanding how they interact. For example, by benchmarking water consumption for energy generation to standard measures, plant operators can better understand and track the status of this coupled system. They are then able to set targets to minimize water consumption or at least understand some of the water implications of particular energy initiatives. However, it is still difficult to access and synthesize information concerning the intersection among the various nexus dimensions even though it is now largely possible to find data in varying degrees of quality and coverage on various elements. Currently, most efforts to quantify nexus elements implicitly focus on technical efficiencies and metrics of the systems, for example, irrigation water use in agriculture, power plants water requirements, energy needs for seawater desalination, etc. (White & Zafar 2013). In addition, accounting procedures and challenges differ for the various nexus dimensions. For example, accounting for water use in the electricity sector is in principle more straightforward than accounting for energy use in the water sector. It is even more difficult to calculate energy end use of water due to the varied users and uses of water and therefore, has significant limitations for computing the nexus energy for water end-use applications (Perrone et al. 2011). Instead, most of the literature has focused on estimating the water consumption of specific energy technologies, country-level or regional analyses of water consumption across a complete energy portfolio or, a global analysis of water consumption by a single energy type. Furthermore, certain Nexus elements, e.g. ecosystem services are difficult to measure. Regulating services such as flood and disease control or social services such as spiritual, recreational and cultural benefits, and supporting services, such as nutrient cycling that maintain the conditions for life, are all difficult to quantity and put a price on. Natural resources managers, stakeholders, and consumers can benefit greatly from enhanced data coverage, improved coordination between stakeholders and government agencies, investments in technology, anticipated supply changes from climate change, and policies to encourage suitable utility and consumer practices.

6. Operationalizing the nexus perspective

6.1. Understanding the drivers of global change

The nexus perspective is an opportunity for policy makers, business leaders, investors, non-governmental organizations and the public at large to manage key resources such as water, energy and food, as well as related dimensions when addressing major development challenges. Understanding the drivers of global change in search of solutions will be important to fully appreciate the value of nexus thinking. Growth in demand for water and energy is primarily driven by population and economic growth, with particular aspects such globalization, urbanization, improvements in living standards and changes in diets and consumption patterns exerting pressure and driving global change in a number of areas. It is important to understand the growth of these drivers and the connections between them. Such an understanding will go a long way in addressing the collective impact of drivers on the Earth System and in finding possible solutions. However, the search for solutions is complicated because each nexus dimension is quite complex and the interdependencies between dimensions are quite difficult to comprehend. Moreover, they are also linked to all aspects of society, and are therefore interconnected with issues such as people's values, habits and livelihoods, all of which further complicate the discussion. This would necessitate strong policy coherence and instituting concrete governance structures to overcome potential tensions and maximize co-benefits.

6.2. Policy coherence and governance

Nexus issues are often closely interrelated and interdepend but the impacts of resources use manifest in very different ways in each dimension of the nexus. Therefore, coherent policies which take into account the need for an integrated cross-departmental decision-making and planning process are required across various nexus dimensions. A nexus perspective would mean that decision makers explore trade-offs before making major investment decisions and in the process achieve greater policy coherence and governance. Decisions on the nexus can be made to revolve around local needs and available alternatives. Such decisions should aim at reaching consensus. They have to be transparent, honest and systematic, involving all actors with complimenting roles and responsibilities. In that way, all levels of governance can be used to achieve promising directions to address development challenges in an integrated way and ensure a sustainable future in which roles and responsibilities are clearly defined and understood.

6.3. Roles and responsibilities

Government and other spheres of influence could make and use policy in a much more integrated way, while the business community may choose to adjust their production systems for much more efficient resource use and work with all actors to benefit fully from the opportunities offered. NGOs (both local and international) could learn to challenge and collaborate with the business sector and local authorities to help deliver real solutions on the ground. NGOs could also support technical assistance, training, and public outreach. Financing institutions could use their experience on working with governments, civil works and procurement of demonstration models that promote further replications of nexus driven initiatives. As direct beneficiaries, governments could play a direct role in project implementation and management of carefully selected projects. Finally, individuals and civil society as a whole could try to understand and manage their consumption patterns and the choices they make in an increasingly water-constrained world, where the vulnerability of the energy sector to constraints in water availability is expected to increase. A nexus perspective can enhance global water, energy and food security by exploring joint opportunities, building synergies and increasing efficiency across related sectors because actions taken in one realm can fundamentally affect other realms.

6.4. Value of economic instruments

Private sector investments can play important roles in improving water and energy security. When properly designed and implemented, economic instruments can serve as a means to adapt individual decisions to desired policy goals. Investments in both sectors are crucially dependent on the functioning of other sectors, e.g. agriculture, ecosystems etc. A better understanding of the inter-linkages between the dimensions will lead to increased and better private investment into water, energy and those dimensions. Often, investments opportunities can only be realized by using synergies between the sectors (e.g. investments in sanitation coupled with fertilizer production). Investments in one sector could lead to negative impacts on other sectors if the right framework is not in place (e.g. agriculture intensification can lead to over-exploitation of water resources). Also, investing in natural capital is critical for restoring and sustaining the services provided by ecosystems. Policies that create the required environment can encourage and increase investor confidence to make better use of the limited financial resources available.

6.5. Infrastructure and technology

Better and appropriate technologies would have to be deployed to fully integrate water and energy policies efficiently. Managing, for instance, the energy sector's water requirements or the agricultural sector's energy and water needs would require the deployment of efficient technologies. There are already a number of technically and economically efficient technologies in place that can be explored jointly with natural infrastructure to improve water and energy efficiency. It is also important that leaders in industry and manufacturers of technologies include these aspects in discussions on infrastructure and technology with policymakers, research institutions and the general public to promote their development and use. With Research, Development and Demonstration (RD&D) efforts on water and energy infrastructure increasing globally, legislators, policy-makers, civil society and academics need to collaborate more closely for such efforts to succeed. Already, many leading companies around the world are finding solutions using the nexus with innovative business models and new technologies. Such models can be replicated and scaled up across the world by building capacity and transferring technical knowhow.

6.6. Capacity building and knowledge transfer

To apply the nexus perspective effectively, several important knowledge gaps need to be filled and appropriate and affordable technology transferred through training and demonstration. Furthermore, a complete comprehension of all nexus dimensions is required to mobilize support and commitment. Knowledge and information is required on land use, terrestrial ecosystems, and water balances at the basin level and also on the close interactions between various nexus dimensions and the new demands created by transformations in policy, planning, financing and operation. Several more studies are required to estimate the strength of the interdependency between various Nexus dimensions and other related themes such as poverty, biodiversity, sustainable development and global security. Further research could examine water, energy and food production in complex social, environmental, and political contexts. This type of studies would require an integrated approach. This is quite complex, but integrated systems models can elucidate the critical interactions that are the basis of the complexity surrounding the nexus. This will enable decision makers to come to terms with the complexity of the nexus and to better understand the interactions between biophysical systems, and political, sociocultural and economic elements for dramatic concern-driven actions on various nexus dimensions in an integrated way.

7. Conclusions and recommendations

Global awareness of the linkage between water, energy, food and other nexus dimensions such as ecosystems and climate change has the potential to stimulate and guide international actions on integrated planning and implementation of several sustainable development goals. The nexus perspective can be important in producing decision making processes that are cross-cutting. In this way, synergies, co-benefits, and trade-offs can be explored in order to identify the smartest paths to achieving multiple sustainable development goals at the same time. Different countries have different priorities, and depending on their national circumstances, each country will put different emphasis on the various goals and targets. In particular, examining how sectors and links across sectors that have a critical importance in a given country are reflected in the SDGs at the global level could inform the development community on additional missing links that are not apparent from a global analysis. The international community must now move towards more concrete measures on the concept to galvanize the global interest it has generated. This can be pursued through a common international framework for action at various levels of policy and governance, which will in turn would require an international framework on the water-energy-food nexus perspective among international organizations, regional and global funding mechanisms, as well as the public and private sectors, research institutions and local stakeholders to encourage and enhance cross-sector planning and decision making.

The action framework can be made to pursue a global agenda that advocate increased consideration of the interdependency between various nexus dimensions. In this way, strategic partnership for the nexus can be enhanced and sustainable solutions to address major global problems can be guaranteed in an integrated way. The framework will create the necessary environment that will enable the global community to tap more directly and effectively into nexus related initiatives and pool of integrated options and solutions that exist around the world. Such a framework will address elements that are directly related or dependent on various nexus dimensions and collect solutions that will help secure water, energy and food for future generations. The programme will attract and/or increase investments in high-impact nexus programmes that promote efficient use and integrated management of natural resources; support reforms and infrastructure innovation that will increase efficient use of natural resources; improve knowledge and strengthen capacity development on innovation and technology; and provide invaluable new insights to address complex challenges in an integrated way. It will facilitate knowledge exchange across various nexus dimensions and provide policy guidance and technical tools and innovative solutions for integrated planning and implementation.

Additional attention can be focused on building strategic partnerships and alliances.

The window of opportunity for action is now as a new global landscape on sustainable development emerges with the adoption of the SDGs and the post-2015 development agenda. Already there are many programmes and initiatives that integrate several nexus themes in optimal ways to address many of the world's development challenges. Those approaches can be consolidated and scaled-up and the experiences can be replicated where they are needed. The international community can take a leading role in coordination and communication, encouraging policy coherence among sectors, motivating innovation and investments in new technology, and offering financial support to improve current infrastructure and develop alternatives. But there are roles as well for governments and other scales of governance and/or influence, from municipalities to river basin organizations, the public and private sectors, industries and manufacturers, academia and civil society to find integrated solutions that are multipurpose, efficient and cost effective across sectors. There is no doubt that the opportunities and the consequent social, environmental and economic implications provided by the nexus perspective are tangible. However, full scale implementation of the concept requires frameworks that facilitate stakeholder engagements and cross-cutting interactions across sectors and the right set of policies and incentives that encourage integrated research, innovation and implementation of cross-cutting solutions.

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