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Review Paper

Food security challenges: Impact of energy- water-climate change Nexus for sustainable development

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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 under the pressure of population growth and mobility, economic development, international trade, urbanisation, diversifying diets, cultural and technological changes, and climate change (Hoff , 2011). Agriculture accounts for 70 percent of total global freshwater withdrawals, making it the largest user of water. Water is used for agricultural production, forestry and fishery, along the entire agri-food supply chain, and it is used to produce or transport energy in different forms (FAO, 2011a). At the same time, the food production and supply chain consumes about 30 percent of total energy consumed globally (FAO, 2011b). Energy is required to produce, transport and distribute food as well as to extract, pump, lift, collect, transport and treat water. Cities, industry and other users, too, claim increasingly more water, energy and land resources, and at the same time, face problems of environmental degradation and in some cases, resources scarcity. This situation is expected to be exacerbated in the near future as 60 percent more food will need to be produced in order to feed the world population in 2050. Global energy consumption is projected to grow by up to 50 percent by 2035 (IEA, 2010). Total global water withdrawals for irrigation are projected to increase by 10 percent by 2050 (FAO, 2011a).

As water becomes scarce, and competition is growing between the energy and agricultural sectors, there is still a lack of reliable and policy-relevant data and information to guide water allocation choices. Effective crosssectoral consultation mechanisms are needed to ensure the development of concerted efforts to address this problem, and to make sure that decisions on water release and allocation are taken as part of an integrated, long-term and multi-sectoral strategy. As demand grows, there is increasing competition for resources between water, energy, agriculture, fisheries, livestock, forestry, mining, transport and other sectors with unpredictable impacts for livelihoods and the environment (FAO, 2011c). Large-scale water infrastructure projects, for instance, may have synergetic impacts, producing hydropower and providing water storage for irrigation and urban uses. However, this might happen at the expense of downstream agro-ecological systems and with social implications, such as resettlements. Similarly, growing bioenergy crops in an irrigated agriculture scheme may help improve energy supply and generate employment opportunities, but it may also result in increased competition for land and water resources with impacts on local food security. In this paper, we will discuss the emerging Food-Security challenges at the Global as well as local levels, giving due recognition to the various impacts posed by Energy-Water- Climate Change nexus. By describing the complex and interrelated nature of our global resource systems, the Nexus approach helps us to better understand and systematically analyze how we can use and manage our resources in light of different, often competing interests and goals.

Keyword: Food security, energy-water-climate, Nexus approach, bioenergy crops, environmental degradation.

INTRODUCTION

The Water, Energy and Food Nexus

Rapid economic growth, expanding populations and increasing prosperity are driving up demand for energy, water and food. By 2050, the demand for energy will nearly double, and water and food demand is estimated to increase by over 50%. Developing countries will account for the majority of growth in consumption over the coming decades, concentrated mostly in urban areas.

In sub-Saharan Africa, for example, the share of urban dwellers is projected to increase from 37% of the total population in 2010 to nearly 60% in 2050 (OECD-FAO, 2012). Moreover, the drivers of global economic growth are increasingly the developing and emerging economies. This is driving up per capita incomes (still marginal relative to OECD countries), contributing to increasingly resourceintensive lifestyles of significant shares of the population and placing acute strains on resources in specific areas.

Access to resources has not been equitable, and a significant portion of the global population still lacks access to electricity (1.2 billion people), clean water (783 million people) and nutrition (842 million people suffer chronic hunger, according to FAO (2013a). In addition to meeting growing demands from those who already have access, the water, energy and food systems will need to overcome this access deficit. Meeting growing demand is becoming more challenging for the energy, water and food sectors. Traditional growth in energy, water and food demand has been met predominantly by tapping further into fossil fuel, freshwater and land resources. These resources are limited in nature, and their extraction and use often have significant social and environmental impacts. Growing reliance on fossil fuel-based energy, for example, is raising environmental costs and further increases vulnerability to price volatility. Moreover, the intertwined nature of the water, energy and food systems means that competition for limited resources intensifies.

Water is required for extracting, processing and refining fossil fuels, as well as for generating electricity. At the same time, energy plays an important role in pumping, moving, distributing and treating water. In addition, energy and water are crucial inputs for food production, processing, transport and preparation. The agri-food chain accounts for around 30% of the world's energy consumption, and agriculture is the planet's largest consumer of water resources, accounting for 80-90% of all freshwater use (Hoff, 2011). Certain technology choices represent the nexus in particularly stark forms, such as reliance on energy-intensive water desalination, or production of biofuels triggering possible conflicts with food commodity prices. Figure 1 illustrates these interlinkages schematically.

The challenge of meeting growing demand for water, energy and food is further compounded by climate change impacts. Extreme weather events, such as intensified droughts and floods, could cause damage to food crops, electrical systems and water infrastructure. All aspects of food security are potentially affected by climate change, including food production, access, use and price stability (IPCC, 2014). Temperature increase in this century is expected to affect crop productivity negatively and significantly, with implications for food security (IPCC, 2007, 2008). Regarding water, climate change is projected to reduce renewable surface and groundwater resources in most dry subtropical regions, intensifying competition for water among sectors (IPCC, 2014). Already there is growing evidence of shifting precipitation world-wide.

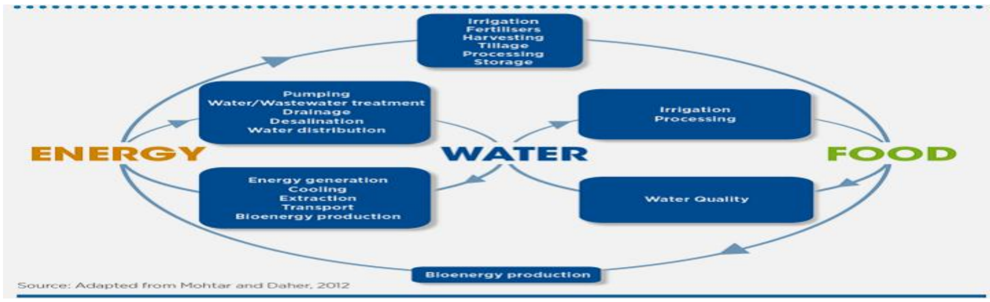
Estimated Increase in Water, Energy and Food Demand by 2050

Water security elements – access, safety and affordability – are affected by the Energy and Food sectors (IISD, 2013). Access to water can be jeopardised if there is a limited or intermittent supply of electricity or liquid fuel for critical needs such as pumping, conveying and distributing water. It can also be limited due to competing uses of water for producing, distributing and processing food. The quality of water for consumption can be affected by other sectors as well. Extraction and processing of fossil fuels, such as oil sand extraction and hydraulic fracturing for natural gas and oil, are known to cause pollution of groundwater with hydrocarbons and heavy metals (Water in the West, 2013). The expansion of intensive agriculture practices, such as the use of chemical fertilizers and concentrated animal farming, has led to the pollution of groundwater and surface waters with nutrients and pesticides (FAO, 2008b). Lastly, volatile energy prices can alter the affordability of water supplies that are dependent on energy intensive infrastructure.

Energy security components (in the narrow sense) – the continuity of energy supply relative to demand, the physical availability of supply, and affordability – all are affected by the water and food sectors. Achieving the key objective of any electricity system operator – meeting energy demand with reliable supply – is imperiled when decreased water flows or increased water temperatures limit production at thermal, nuclear or hydro power plants. Regardless of demand, physical energy supply can be limited when competing needs for water, such as agriculture and domestic use, place a limit on the amount of water that can be dedicated to fuel extraction and energy production. Further, these constraints and trade-offs with water availability can limit energy production and put price pressures on energy supply.

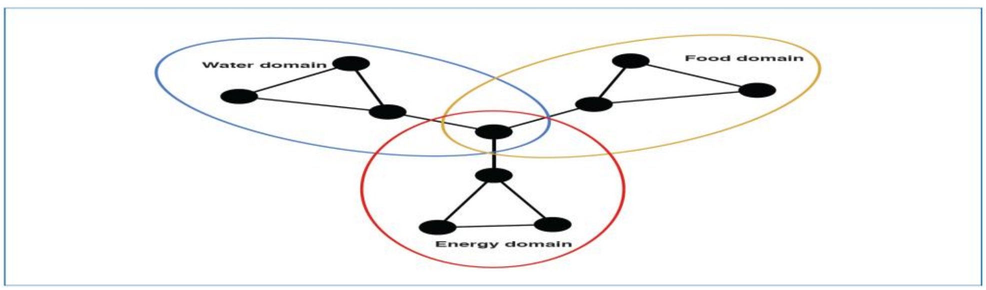
Energy and water supply and demand have an impact on food security elements: the physical availability of food, access (including affordability), utilisation (nutrient content and food safety) and the stability of these elements over time. The physical availability of food can be threatened when water is allocated for other competing needs, when irrigation infrastructure is inefficient, or when the energy supply is unreliable and unavailable to power mechanised farming and food processing practices. These same water and

Figure 1: Schematic illustration of various elements of the Water–Energy–Food Nexus



Source: Mohtar and Daher, 2012.

Figure 2 : Interaction of Different Nexus Domains and Actors wihin them



Source: FAO, 2014.

energy resource strains can affect economic affordability and access to food. Utilisation of food can be hampered by the use of contaminated water sources by households, or by shortages in cooking fuel, such as liquefied petroleum gas (LPG) or fuelwood. Lastly, factors such as the impact of climate change on water resources, and the effects of geo-politics and policies on energy sources and pricing, can hamper development goals that aim to achieve food security in the long run.

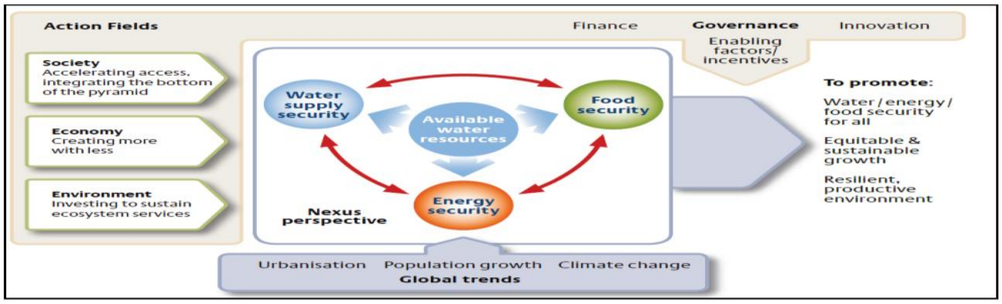
How to manage the complex links between water, food, energy and the associated social, economic and environmental implications is a major policy concern. Within Ethiopia, as in many other countries, water, food and energy are predominantly managed as independent sectors, with little consideration of their interdependence or their cumulative impact on ecosystems. Increasingly, it is recognized that unless their interdependences are taken into account these different sectors cannot be developed and managed in a sustainable and effective way. The water-energy-food nexus perspective highlights the interdependence of water, food and energy systems and the natural resources that underpin those systems. The approach aims at reducing trade-offs and generating cobenefits for sustainable development (Hoff, 2011). While previous research has identified critical linkages between the different sectors (Bazilian et al. 2011; Hoff 2011; Lawford et al. 2013), relatively little attention has been paid to the relevant actors shaping the water-energyfood nexus and the sociopolitical context in which further integration should be achieved. Considering both the diversity of actors influencing the nexus and the complex relationships between these actors, there is a need for analytical tools that allow for mapping of these actor networks and the facilitating processes of stakeholder coordination.

Addressing challenges in one nexus domain without considering the connections to other actors or nexus dimensions can have the result that problems are not solved but shifted to other actors, sectors, geographic locations or scales. For example, expanding irrigation systems upstream may reduce downstream water availability for hydropower and ecosystems. Since no single actor has the knowledge or the resources to address interconnected nexus challenges unitarily, a plurality of actors need to coordinate their activities in order to find comprehensive solutions to their interconnected problems. Pathways toward more sustainable management of water, land, energy and ecosystems will need to work with and through these actors and their relationships. Figure 2 illustrates, in a stylized form, how the different water-energy-food nexus domains and associated actor networks are interconnected.

Water Domain, Energy Domain and Food Domain

Despite their strategic importance, most social networks remain hidden from the view of decision makers and the

Figure 3: The Water, Energy and Food Security Nexus with water as Critical Input



Source: Bonn, 2011.

organizations that shape them (Cross et al. 2002). More recently, social network analysis has been applied to study natural resource management and governance arrangements (Bodin and Crona 2009; Bodin and Prell 2011; Schneider et al. 2003; Stein et al. 2011), providing new and important insights into how social networks affect rural economic development (Murdoch 2000; Newman and Dale 2005) and sustainable agricultural production (Lockie, 2006; Lubell and Fulton, 2007). Social network analysis provides analytical tools to make patterns of interaction visible and to assess certain aspects of social complexity. This scoping study explored actor networks relevant for the water-energy-food nexus in the Upper Blue Nile using a range of social network methods.

Water-Energy-Food Security Nexus

There are many synergies and tradeoffs between water, energy use and food production using water to irrigate crops might promote food production but it can also reduce rivers flows and hydropower potential. Growing bio-energy crops under irrigated agriculture can increase overall water with drawls and jeopardize food security. Converting surface irrigation into high efficiency pressurized irrigation may save water but may also result in higher energy use. Recognizing these synergies and balancing these tradeoffs is central to jointly ensuring water, energy and food. The nexus has emerged as a key concept to describe the complex and interrelated of our global resource systems, on which we depend to achieve different, often competing development goals. In practical terms, it presents a conceptual approach to better understand the interactions between the natural environment and human activities and to work towards a more coherent approach to natural resources management vis-à-vis our social, economic and environmental goals. This can help us to identify and manage trade-offs and to build synergies through our response options, allowing for more integrated and cost-effective planning, decision-making, implementing, monitoring and evaluating (McCornick *et al.*, 2008; OECD, 2011). It is important to note that there are different conceptualizations of the nexus that vary in their scope, objectives and understanding of divers. Several concepts, frameworks and methodologies have looked at the inter-linkages between water, energy and food (Mohtar and Daher, 2012; ADB, 2013; Bizikova *et al.*, 2013; UN-ESCAP, 2013).

Nexus Approach

It is a holistic vision of sustainability that tries to balance different development goals by managing trade-offs and exploring opportunities for synergies in light of growing demand for resources and other key drivers. It recognizes the incremental value of natural environment to humans. Improved water, energy and food security on a global level can be achieved through a nexus approach- an approach that integrates management and governance across sectors and scales. It highlights the interdependence of water, energy and food security and the natural resources that underpin that security-water, soil and land (Figure 3).

A nexus approach can support the transition to a green economy which aims among other things, at resource use efficiency and greater policy coherence. Indeed, the green economy itself is the nexus approach par excellence.

To succeed a green economy must go beyond sectorial solutions and actively address the water, energy and food security in line with human rights-based approaches. Given the increasing interconnectedness across sectors and in space and time, a reduction of negative economic, social and environmental externalities can increase overall resource use efficiency, provide additional benefits and secure the human rights to water and food. Conventional policy and decision making therefore needs to give way to an approach that reduces trade-offs and builds synergies across sectors- a nexus approach. Business as usual is no longer an option. Based on better understanding of independence of water, energy and climate policy, this new approach identities naturally beneficial responses and provides an informed and transparent framework for determining trade-offs and synergies that meet demand without compromising

Figure 4: The Major Components and Conditionalities of Food Security

Source: Clark et al, 2013.

sustainability. The following guiding principles are central to the nexus approach:

Investing to sustain ecosystem services

Creating more with less

Accelerating access, integrating the poorest

The nexus approach will also allow 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. Furthermore, through a nexus approach as it integrates management and governance across sectors and scales improved water, energy and food security can be achieved. A nexus approach can also support the transition to green economy which aims among other things, at resource use efficiency and greater policy coherence. In addition it can also help to avoid "sunk costs" i.e investments that lock development into non sustainable pathways. Active participation and among government agencies, the private sector and civil society is critical for avoiding unintended adverse consequences. A true nexus approach can only be achieved through close collaboration of all actors from all sectors (Hellegers *et al.*, 2008; Karlberg and Hoff, 2013; Stein, 2013).

Climate change

Climate change is mostly driven by energy use and changes in land use. Climatic variability adds further pressures such as accelerating drying of dry lands, reducing glacier water storage, as well as having more frequent and intense extreme events such as droughts or floods and less reliable water supplies and agricultural productivity.

At the same time change mitigation places new demands and water and land resources and biodiversity. Climate adaptation measures such as intensified irrigation or additional water desalination are often energy intensive. Thus climate policies can impact on water, energy and food security and adaptation action can in fact be maladapted if not well aligned in a nexus approach and implemented by appropriately interlinked institutions (IPCC, 2007; Smith and Barchiesi, 2009; FAO, 2011; IPCC, 2011).

Degradation of the Resource base

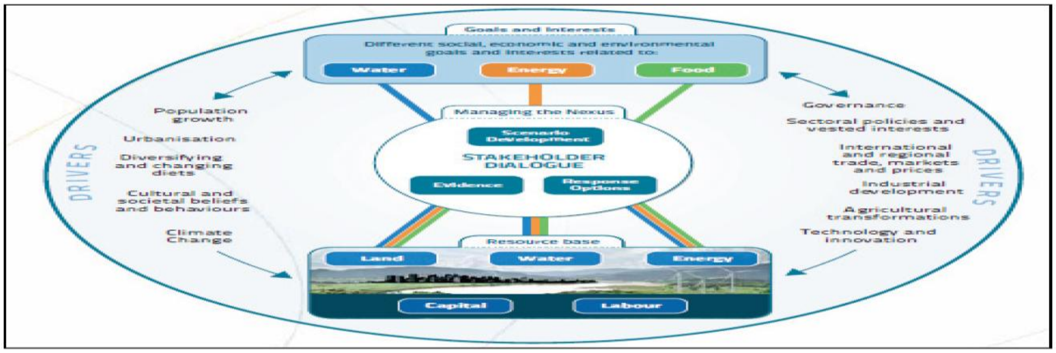
Growing demand and non-sustainable management have increased human's ecological footprint and caused degradation of the natural resource base in many regions including severe modification of ecosystems. This has resulted in a notable reduction in the land primary productivity primarily for food production (MA, 2005; Haberl *et al.*, 2007; Ellis, 2011). Desertification and soil degradation have reduced water and land productivity, water and carbon storage biodiversity and a wide range of ecosystem services. Regarding the water while it is a renewable resource, pollution and over use can still have long lasting impacts such as degraded and depleted aquifers and loss of aquatic ecosystems and wet lands.

Water, Energy and Food Security Nexus

Food water and energy are finally being recognized as most important national and international security issues. However, we are long away from achieving water energy and food security for the entire world's people. Water energy and food security have so far been mainly constrained by unequal access, but mainly is now also approaching limits of global resource availability. Food security refers to both physical and economical access to food and food supplies.

The current food crisis in most developing arid and semi arid countries cannot be understood unless located in the broader nexus that encompasses food, water and energy. According to FAO (1996), as illustrated in Figure 4, the concept of food security has four components, namely food availability, access, stability of supply and utilization. They reflect different social, cultural, political aspects as well as biophysical and socio economic conditions (Clark et al, 2013). Food security is determined by FAO as "availability and access to sufficient, safe and nutritious food to meet the dietary and food preferences for an active and healthy life. Adequate

Figure 5: The FAO Approach to the Water-Energy-Food Nexus



Source: FAO, 2014.

food has also been defined as a human right.

Food security alone does not ensure economic social and environmental sustainability. There is need to a nexus approach as it is a holistic vision of sustainability that tries to balance different development goals by managing trade-offs and exploring opportunities for synergies in light of growing demand for resource and other key drivers. Water security, energy security and food security are inextricably linked and these linkages have always been present. Interactions take place within the context of globally relevant 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 drivers, like governance structures and processes, vested interests, cultural and social beliefs and behaviors (Figure 5) (FAO, 2014)

Indeed water, energy and food sectors are connected in important ways and each sector has its potential to either help or harm the other two. Interrelationships between water food energy and environment are both facing challenges and opportunities (McCornick *et al.*, 2008). Water security, food security and energy security are chronic impediments to economic growth and social stability. Food security in particular can be threatened by water and energy shortages. The availability of water for agriculture directly determines the availability of food. Higher energy prices increase the price of agricultural inputs and reduce the availability of land and water for food production due to competition from expanded biofuel production. This dampens food demand as a result of higher food prices.

Water-Energy-Food Nexus

Water and energy are interdependent as they are major consumers of one another. The water system is an energy user mainly through electricity consumption for pumping fresh water, drainage and water table management, desalination, water treatment, and water distribution in farms and cities. In desalination, for example, reverse osmosis plants consume 4–6 kWh/m3 of treated water versus 21–58 kWh/m3 for multistage flash (Semiat, 2008**)**. These values include the following features as shown in Figure 6.

Energy needed for groundwater pumping is highly dependent on its source. “Groundwater supply from public sources requires 1,824 kilowatt-hours per million gallons – about 30% more electricity on a unit basis than supply from surface water, primarily due to a higher requirement of raw water pumping from groundwater systems (Center for Sustainable Systems, University of Michigan. “U.S. Water Supply and Distribution Fact Sheet.” Pub No. CSS05-17,
http://css.snre.umich.edu/css_doc/CSS05-17.pdf
(accessed 2010).” Water transport is also an energy consumer, a fact that is often overlooked. Water is needed for energy generation, cooling, resource extraction and refining, transportation, and bioenergy production. “Energy end use and waste disposal also use and contaminate water resources. For example, the largest withdrawal of water in the United States and most other industrialized countries is for power plant cooling (World Economic Forum, 2011).” The dependency of one system on the other is largely defined by the choice of technology used in energy–waterdemanding activities. Current policies are in search of alternative energy sources to decrease their reliance on expensive and increasingly scarce fossil fuels. Controversy arises when the sustainability of these alternatives is investigated.

Water-Food Nexus

The world is facing a water scarcity challenge, where agriculture is its predominant consumer. It accounts for approximately 3100 billion m^3, or 71% of global water withdrawals today, and is expected to increase to 4500 billion m3 by 2030 (McKinsey, 2009). In addition to the increase in water scarcity, the agricultural sector faces an enormous challenge of producing almost 50% more food

Figure 6: Schematic showing the Water–Energy–Food nexus with effecting parameters thermal and electric energy consumed to produce desalinated water

Source: Department of Energy, USA, 2014 ; Water-Enery Nexus: Challenges and Opportiunities, USA, 2014.

by 2030 and doubling production by 2050 (OECD, 2010). With regard to improving irrigation efficiency, Kendy et al. argue that water is not saved through reducing seepage, as drainage is needed to recharge the underlying aquifer (Kendy, 2004). It is significant to realize that different countries and areas in the world differ with respect to technological advancement and ability to afford and shift to newer, more efficient practices. There is a need to understand the potential of reallocation of globally grown food products in a manner that maximizes the utility of green water (rain fed). This leads to saving scarce blue water (surface and groundwater) for producing the same amount of food. Water productivity, defined as the output per unit of water volume consumed, varies from one place to another. This process is not just a matter of available technology or available human, social, and institutional capital. The fact that different countries have different water productivities creates a comparative advantage for those countries that have relatively high water productivity in producing water-intensive crops (Hoekstra,, 2010).

According to the Food and Agriculture Organization, 925 million people do not have sufficient food, 98% being in developing countries (FAO News release, http://www.wfp.org/hunger/stats (accessed September 2010). Land that was once used for growing food is now transformed into biofuel production.

Arable land is a limited resource that is struggling to cope with the growing demands, especially since yields have already reached their maximum limits.

On another note, there is serious concern regarding the sustainability of biofuels while considering water consumption, water and soil degradation, and other ecological impacts that could prevail due to excessive use of fertilizers.

Governments should be aware of the sensitivity that exists between both systems and the unfavorable consequences that could surface as a result of any unplanned shift or tradeoff.

Water, energy, and food are three highly connected systems. The ability to face the current and anticipated global challenges will be governed by the ability of better understanding the interconnectedness and tradeoffs between these systems. Higher levels of collaboration between governmental entities concerned in setting future resource management strategies and policies are thus a must.

Opportunities to Improve Water, Eenergy and Food Security

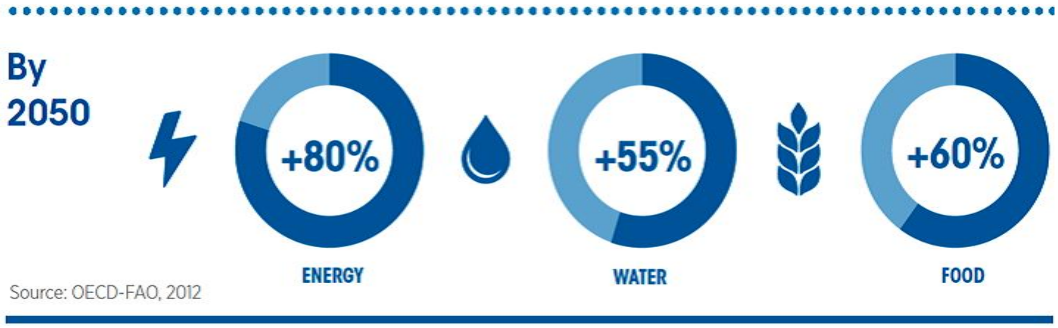
A nexus approach can support a transition to sustainability, by reducing trade-offs and generating additional benefits that outweigh the transition costs associated with stronger integration across sectors. A number of opportunities can be outlined in the followings:

Increased productivity resources. Sustainable and inclusive intensification and decoupling of economic development from resource use both fundamental to a green economy can be achieved through technological innovation, recycling wastage. The nexus focus is on system efficiency rather than on the productivity of isolated sectors.

Simulating development through economic incentives. Innovation to improve resource use efficiency requires investments and reduction in economic distortions. Economic instruments for stimulating investments included for example pricing of resource and ecosystem services, water markets and tradable rights and payments for ecosystem services. A nexus approach can also help to avoid sunk costs, i.e. investments that lock development into non-sustainable pathways.

Governance, institutions and policy coherence. Regulation and collective action can help to guide investments and innovation to minimize negative externalities and share benefits equitably enabling conditions for horizontal and vertical policy coherence include institutional capacity building political will, change

Figure 7: Estimated increase in Water, Energy and Food Demand by 2050



agents and awareness raising. Additional opportunities can be realized if the nexus is addressed coherently across all scales through multi-level governance.

Water and energy are critical resource inputs for economic growth. The correlation between economic growth and energy demand has been widely established (IEA, 2010). The estimated increase in water, energy and food demand by 2050 is given in Figure 7. Meeting that energy demand, however, requires water. In most energy production processes, water is a key input: fossil fuel production requires water for extraction, transport and processing; thermoelectric generation based on nuclear, fossil fuels or CSP requires water for cooling; hydropower can be generated only if water is readily available in rivers or reservoirs; feedstock production for biofuels, such as ethanol, may depend on water for irrigation; and renewable energy resources such as solar require water for cooling and cleaning panels or collectors for improved efficiency (World Bank, 2013). The technology choice, source of water and fuel type determine the impacts of energy on the withdrawal, consumption and quality of water resources.

Conversely, energy inputs are spread across the supply chain of water. The supply chain for water starts with a source, then water is extracted (*e.g.*, pumping of groundwater), sometimes treated, and conveyed – moving directly to an end-use (*e.g.*, household, irrigation, commercial). Once used, the water is returned back to the environment through discharge – with or without treatment – or through evaporation. In some cases, treated water may be reused (Water in the West, 2013). Along each of these stages, energy inputs are necessary depending on the local conditions. This interaction between energy and water resources is the water–energy nexus (see Figure 8).

The water–energy nexus represents a critical security, business and environmental issue, which has been recognised increasingly in recent years. In a survey conducted by the Carbon Disclosure Project of 318 companies listed on the FTSE Global Equity Index Series (Global 500), 82% of energy companies and 73% of utilities said that water is a substantial risk to business operations, and 59% of energy companies and 67% of utilities had experienced water-related business impacts in the past five years (Carbon Disclosure Project (CDP, 2013). There is general recognition that the starting point of any effort to address the nexus is quantifying the interlinkages and understanding the trade-offs. The International Energy Agency (IEA) included a special section on water and energy in its 2012 World Energy Outlook for the first time in the organisation's history (IEA, 2012). Addressing the nexus, the World Bank established the "Thirsty Energy" initiative to help governments in developing countries tackle issues related to water resources and power services. Additionaly, in response to the growing importance of this nexus, water and energy was the theme of the World Water Day 2014 (UN Water, 2014a).

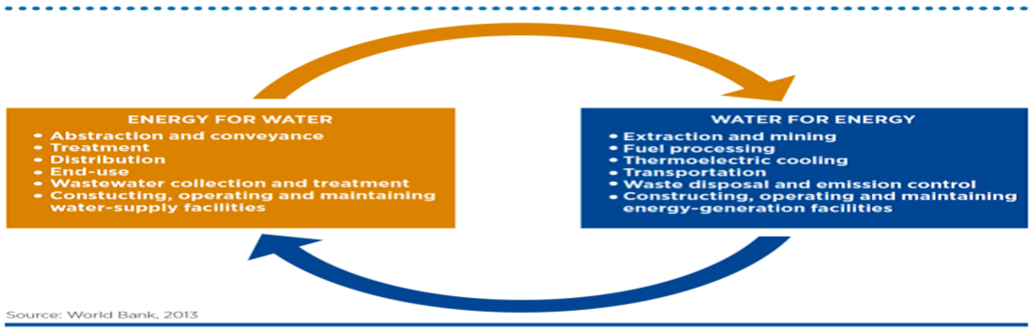
Quantifying the Water–Energy Nexus

At present, energy production accounts for nearly 15% of global freshwater withdrawals – or 580
billion cubic metres (m3) of water – every year (IEA, 2012).

This includes water use during primary energy production and electricity generation. Of this water withdrawn, nearly 66 billion m3, or 11%, is not returned to the source and therefore is deemed to be consumed (Lavelle and Grose, 2013). The share of water withdrawn and consumed for energy significantly varies at the national level. In the United States, for instance, thermoelectric power generation accounts for nearly half of all freshwater withdrawn.

In China, where coal continues to be the dominant fuel powering**c**economic growth, fresh water needed for mining, processing and consuming coal accounts for roughly 120 billion m3 a year - the largest share of industrial water use, or a fifth of all water used nationally (Schneider, 2011). The most direct representation of water dependence for electricity production is hydropower generation. Nearly 16% of global electricity production is hydro-based, and hydropower is a major source of electricity in many countries, accounting for nearly 75% of total electricity generation in Brazil in 2012 for instance (REN21, 2013, 2014; IEA, 2014a& b).

Figure 8: Illustration of the Water-Energy Nexus in a Cyclic Pattern



Global energy demand is projected to increase 35% by 2035. Meeting this rising demand could increase water withdrawals in the energy sector by 20%, and water consumption in the sector by 85% (World Bank, 2013). China, India and the Middle-East will account for most of the growth in energy needs to 2035; however, these are also among the countries with the lowest renewable water resources per capita, meaning that as the demand for energy grows, the strains on limited water resources could intensify. Energy demand for water services is set to increase. Global data on energy use in extracting, producing, treating and delivering water remain limited. This is primarily because of large variations in the energy intensity of delivering water due to differences in water source (such as groundwater or surface freshwater), water quality (high-salinity seawater is the most energy intensive to treat and use) and the efficiency of water delivery systems. However, some national and regional estimates exist: in the United States, for example, waterrelated energy use accounts for 13% of total annual energy consumption (River Network, 2009; Sanders and Webber, 2013).

As easily accessible freshwater resources are depleted, the use of energy-intensive technologies, such as desalination or more powerful groundwater pumps, is expected to expand rapidly (World Bank, 2013; WEF, 2011; Hoff, 2011). The Middle-East and North Africa (MENA) region, among the regions with the lowest renewable water resources in the world, is home to most of the world's desalination capacity, and the region's capacity is projected to increase more than five times by 2030. This will raise total electricity demand for desalination in the region by three times, to 122 Terawatt-hours (TWh) by 2030 (IRENA and IEA-ETSAP, 2012; 2013). Significant energy is used to heat water for domestic and industry applications. This energy is derived either directly from the combustion of fuels, such as natural gas and fuel oil, or indirectly through electricity. In the latter case, the risks posed by the nexus become more pronounced because of the destabilising impact that increased heating demand can have on the electricity system. In South Africa, nearly 5% of domestic electricity demand comes from electric water heating systems. Even at that level of demand, measures were required to reduce demand from electric water heaters during peak times.

The intensity of the water–energy nexus is a regional, national or sub-national characteristic, which depends on the energy mix, demand characteristics, resource availability and accessibility. For power production, for example, the choice of fuel and technologies holds significant impacts for the quantity of water required (World Bank, 2013; IEA, 2012). Where water resources are limited, technologies that impose less strain on water resources may be preferable. Renewable energy technologies such as solar photovoltaics (PV) and wind consume little-to-no water during operation compared to fossil fuel-based plants that require large amounts of water during the different stages of energy production. The risks posed by the water–energy nexus affect all essential elements of water and energy security.

These risks confront not just governments, but any stakeholder engaging in activities that are affected directly or indirectly by the availability, accessibility and affordability of water or energy. Consequently, these risks and associated impacts manifest at different levels – regional, national and local – causing governments, communities and businesses to increasingly consider the nexus as a key variable affecting the socio-economic sustainability of their operations and long-term objectives. The first step of the process of managing the water–energy nexus is to understand the entire spectrum of risks that are relevant for a specific country, business or community. The intensity of each risk will vary depending on the local context, but system-level assessments covered in the literature highlight the following principal risks for water and energy security.

Water-related Risks to Energy Security

Water is a critical input for fuel extraction and processing as well as for power generation. The risks that the water sector presents to energy security have been studied widely (UN Water, 2014b; World Bank, 2013; WEF, 2011;

Table 1: Summary of Risks and Impacts within the Water–Energy Nexus

	RISKS	IMPACTS
Water-related risks to energy security	Shifts in water availability and quality due to natural or human-made reasons (including regulatory restrictions on water use for energy production/ fuel extraction)	• Reduced reliability of supply and reliance on more expensive forms of generation • Possibility of economic pricing of water and therefore higher costs of energy production • Reduced availability of water for fuel extraction and processing stages, leading to reduced outputs
	Increase in energy demand for water production, treatment and distribution	Strains on the energy system and reduced efficiencies given the different demand profiles for water and energy
Energy-related risks to water security	• Limited or unreliable access to affordable energy necessary to extract water • Re-allocation of water resources from other end-uses to energy	• Disruption in water supply to end-users or diversion of resources away from other core activities such as agriculture • Changes in delivery cost of water due to fluctuating costs of energy inputs
	Contamination of water resources due to energy extraction and transformation processes	Water resources, including for drinking purposes, rendered unsuitable due to contamination, often requiring additional treatment

Source: IISD, 2013.

IISD, 2013; Hoff, 2011) and can be summarised as follows:

Different s tages o f t he e nergy s upply c hain a re extremely sensitive to the availability and quality of the water they require. The ability of thermoelectric or hydropower plants to operate optimally relies in part on the characteristics of the input water, such as temperature, volume flow rates and density. Any deviations can translate into lower output or shutdown of plants. These deviations could be a result of unanticipated weather activity (*e.g.*, changes in precipitation patterns, extreme weather conditions, prolonged heat waves, etc.), reallocationof water resources (*e.g.*, rising competing water demands for other uses such as agriculture).

Shifts in water availability and quality due to natural or human-made reasons (including regulatory restrictions on water use for energy production/ fuel extraction): Reduced reliability of supply and reliance on more expensive forms of generation.
Possibility of economic pricing of water and therefore higher costs of energy production
Reduced availability of water for fuel extraction and processing stages, leading to reduced outputs Increase in energy demand for water production, treatment and distribution Strains on the energy system and reduced efficiencies given the different demand profiles for water and energy.
Limited or unreliable access to affordable energy necessary to extract water
Re-allocation of water resources from other end-uses to energy
Disruption in water supply to end-users or diversion of resources away from other core activities such as agriculture
Changes in delivery cost of water due to fluctuating costs of energy inputs
Contamination of water resources due to energy extraction and transformation processes
Water resources, including for drinking purposes, rendered unsuitable due to contamination, often requiring additional treatment. Recent cases illustrating these risks include:
Because of prolonged drought conditions, hydropower plants in the U.S. state of California
generated less power in 2013 than in the previous 21 years. In a state with more than 300 hydropower plants, the share of hydro in the electricity mix dropped to 9% in 2013, compared
to a 30-year average of 14% (Garthwaite, 2014). The reliability of the energy system was maintained in part through increased use of natural gas plants.

In 2010-11, thermal power generation in India declined by nearly 4.4 TWh – enough electricity to power nearly 1.3 million Indian households for a year – due to acute water shortage (Central Electricity Authority (CEA), 2011).

Half of China's proposed coal-fired power plants, which require significant water for cooling, are located in areas already affected by water stress, creating potential conflicts between power plant operators and other water users.

The expansion of shale gas production is transforming several energy markets. As interest in exploring and exploiting shale resources rises, there is growing concern about the environmental impacts of hydraulic fracturing (or fracking), the process used to extract natural gas from shale deposits. These impacts range from the possibility of ground and surface water contamination to competition for water (a key input to the fracking process) with local uses.

NEW PERSPECTIVES ON THE WATER-ENERGY-FOOD NEXUS

Water, food and energy security are crucial for sustainable long-term economic growth and human wellbeing and there are strong linkages between all three. Activities in one sector may influence or even constrain economic growth in the others. Additionally, competition for scarce resources can lead to price pressures with short-term consequences and to irreversible ecosystem changes that impact on resource security over a longer timescale.

The water sector often assumes that it will have all the energy it needs to pump, clean and transfer water, while the energy sector generally takes for granted that it will have access to the water it needs for cooling and power generation.

The food sector has crucial linkages to both water and energy, both as a consumer and source of these resources. The food price spike in 2007-2008 and subsequent widespread social unrest highlighted the economic and political fragility of our societies in the face of interlinked shocks to water, energy and food acting across global value chains. This underscored the danger that policies that neglected these critical linkages would create more problems than they solved.

The Bonn 2011 Nexus Conference was a watershed moment as governments and the international community acknowledged that policies regarding water, energy and food cannot be managed in isolation.

This conference heralded an period of increased attention and activity on the nexus in academic, policy and business circles. For example, the World Business Council on Sustainable Development engaged in nexus discussions and published papers on the topic. In 2011, United Nations Secretary-General Ban Ki-moon underlined the importance of the "nexus approach" noting: "As the world charts a more sustainable future, the crucial interplay among water, food and energy is one of the most formidable challenges we face (UN, 2011)."

Much of the national and international focus since the Bonn Conference has been on attempting to better understand the complex relationships between water, energy and food policies and how these can be addressed in policy development and implementation. Trying to move beyond the nexus as a "slogan" and making it an operational reality has proved to be challenging given the multi-dimensional inter-linkages. Physical scarcity may be less of an issue at the global level: the global economy is not running out of 2 resources any time soon. But bottlenecks resulting from the relative scarcity of land, water and energy are time and place specific. For instance, water may be a plentiful resource, but it is not always available for human use in the quantities or at the quality, time and place required. The sheer complexity of these nexus relationships makes it difficult to develop truly holistic policy frameworks. Analysts and policy makers have focused on addressing how to manage these complex relationships in a time of rapid population growth, changing economic conditions and constraints, and in the face of a changing climate.

This OECD Global Forum on the Environment aims to contribute to this intellectual effort by bringing together experts and policy makers from both OECD and partner countries for wide-ranging and inclusive discussions on a number of nexus topics that have not been a major focus of policy attention to date. With the theme of "New Perspectives on the Water-Energy-Food Nexus", the Global Forum will address important questions around:

The linkages between the nexus and sustainable economic growth;
How the nexus is integrated into national planning;
Regional and local perspectives on the nexus;
Incorporating the nexus into economic modelling;
Addressing the nexus in economic, finance and development policies;
How nexus risks are considered by investors; and
The role of the nexus in the Post-2015 development agenda.

The rest of this background note for the Global Forum provides relevant information to help to guide debate in each of the sessions over the two days. The question highlighted for each session are intended to provide an initial stimulus to launch discussions and provoke debate. A summary of the Global Forum, with non-attributed comments, will be prepared and made available following the event.

Water, Energy and Food: Risks and Trade-offs for Sustainable Growth

As the world population rises to an expected 9 billion by 2050, pressures on water, energy and food resources will rise, potentially posing a significant global challenge. By 2050, the FAO predicts a 70% increase in food production, the World Energy Council expects a 100% increase in energy supply, and the OECD projects that more than 40% of the world population will live in river basins under severe stress. There is increasing evidence that the quality and availability of natural resources can affect the economy. The *OECD Environmental Outlook to 2050*: *Consequences of Inaction* projected that, without more ambitious policies, by 2050 the costs and consequences of inaction on climate change, biodiversity loss, water scarcity and health impacts of pollution could be significant. It is clear that more ambitious policies are needed to reconcile economic growth with the conservation and sustainable use of the environment and natural resources (OECD., 2012). The challenge will grow over the next decades as the effects of climate change become more significant, affecting the availability and demand for water, energy and food. For example, climate change will affect the future availability of water for energy production and changes in precipitation, crop yields and temperatures will strongly influence both food and bioenergy production.

We still know little about how policies addressing the nexus can contribute to sustainable growth. Over the medium- to long-term, it is clear that water, energy and food policies need to be well-aligned and mutually supportive for prosperity. However, in the short-term, there are real and potential trade-offs between these resources that could significantly alter development pathways and reduce growth prospects. Identifying the nexus risks and trade-offs will help to ensure a greater potential for economic growth. In this regard the Global Water Partnership and the OECD (2012) has launched the Global Dialogue on Water Security and Sustainable Growth in order to illustrate pathways that countries have taken or could take to achieve a greater degree of water security, and how they can manage the risks and trade-offs. The Global Dialogue engages high-level policy makers and a Task Force undertaking substantive research to build an evidence base on the impacts of water security. It also includes a country consultation process to investigate perceptions and priorities regarding water security. The Global Dialogue will result in a milestone report on *Water Security and Sustainable Growth* to be presented at the World Water Forum in South Korea in 2015. In this session, the early messages from the Global Dialogue on Water Security and Sustainable Growth will be discussed in the context of the water-energy-food nexus.

Integrating the Water, Energy and Food Nexus into National Planning

Planning for nexus interactions will require an integrated approach and can be an effective instrument to make the nexus work on the ground. However, this is not yet the case in many countries. Often, plans develop without consideration of similar initiatives in other sectors. For instance, how much do irrigation planners factor in demand for water from other sectors, e.g. energy suppliers? And vice versa. The capacity to develop plans and to implement them is uneven across sectors, leading to asymmetries and tensions. This situation creates uneven access to scarce resources (e.g. water). It also generates additional financial costs, for instance when infrastructures fail to address multiple purposes. Short-term thinking and fragmented knowledge and institutions contribute to unsustainable policymaking.

Although water, energy and food scarcity issues play out at different scales, sometimes local, there is still a key role for national governments to set regulatory frameworks and standards, remove policy barriers, provide funding and technical assistance and facilitate co-ordination among sectors and different levels of government. National governments will also be essential to integrate the nexus into national strategies, development plans and policy frameworks. Yet in most governments, responsibilities for water, food and energy are placed in separate ministries such institutional choices may appear to make the policy design task tractable in the short-term, and may produce policies that may work initially. But as the effects of such siloed policies unfold, their consequences across the sectors and the economy as a whole may be less benign; the policies may even fail in the medium- to long-term. This reinforces the importance of flexible forms of inter-ministerial co-ordination, such as high-level councils and inter-ministerial task forces, rather than a single ministry for these issues. The need to integrate policies is not new and there is a wide range of literature supporting environment-specific horizontal policy integration. There are also specific resource-management approaches that consider the interactions of water, energy and food such as integrated water resource management (IWRM) or the “landscapes approach.”

Effective governance and a proper enabling environment and capacity will be essential prerequisites. A clear regime that lays out the legal rights and responsibilities for natural resources will be crucial to enable nexus development. Well-defined resource property rights are important enabling prerequisites yet no single property regime will be universally efficient, fair and sustainable. Creating coherent time horizons for national planning must also be considered. There are different temporal scales for water, energy and agricultural policies. Forward-looking water plans may use a 50-60 year time horizon, energy plans are often 20-30 years into the future and agricultural planning often uses a much shorter time horizon. Climate change and climate resilience adds another dimension that will require an inter-sectoral response. National governments have the opportunity to take advantage of the rapidly evolving climate change adaptation planning efforts to mainstream consideration of water, energy and food interactions and improve horizontal co-operation across ministries and departments. Strategic planning and risk-assessments are useful to address complex problems. Regulatory impact assessments already include environmental issues and could be broadened to address more environmental interactions.

Some countries are making efforts to achieve greater policy integration. For example, the EU, Australia and South Africa, are increasing their integration of climate and energy policies. However the extent to which the linkage to water issues is then made varies considerably, which is worrying as water is one of the main ways in which climate change is likely to impact the nexus. More positively, Colombia has developed an integrated system for disaster risk management and climate change adaptation. Most developing countries have an established practice of formulating multi-year development strategies that can provide an opportunity to incorporate green growth and green development. These national development strategies can also provide opportunities to include greater nexus considerations.

Understanding the Long-Term Trends and Interactions

The linkages in the nexus are complex and it is hard to say which link is most important or deserves most attention. Furthermore, long-term socioeconomic trends affect the nexus in multiple ways, strengthening certain synergies and trade-offs and weakening others. The water-agriculture link may be the most relevant right now, with 80% of global water withdrawals for agricultural use. However, the water-energy link may become more relevant in the future with increasing water withdrawal by non-agricultural users. Furthermore, climate change and population growth may both increase the competition for land and threaten food security. This may in turn lead to intensification of energy practices, increasing the demand for water and can affect land use patterns and energy use.

It is therefore possible that in the coming decades changes in environmental and economic circumstances will lead to restricted availability or reduced quality of land, water and energy resources, and will affect the economy through quantity and price changes. Large scale biofuel crop cultivation is one of the proposed means to slow-down and ultimately stabilise climate change, but opinions on whether it can accomplish this differ widely.

Few studies have analysed the linkages between land, water and energy simultaneously in an integrated framework and then translated these into projections for long-term economic impacts. Some studies have looked at linkages and trade-offs between individual pairs of the nexus bottlenecks. Other studies have looked at links between one resource and the economy. However, none have profoundly addressed all three components of the nexus together and their link with the economy.

The OECD (2013, 2014) is working to address this research gap with the CIRCLE project (Costs of Inaction and Resource Scarcity: Consequences for Long-term Growth) which is designed to explicitly address relevant linkages between land, water and energy simultaneously.3 The water-energy-food nexus is studied by modelling the biophysical impacts of socio-economic developments on land, water and energy, and their combined feedback on the economy. For this, a biophysical model, “Integrated Model to Assess the Global Environment” (IMAGE) model, operated by the Netherlands Environmental Assessment Agency PBL is used to simulate the environmental consequences of human activities. These environmental consequences can be translated into economic costs and economic growth using an economic model developed by the OECD known as “ENV-Linkages”.

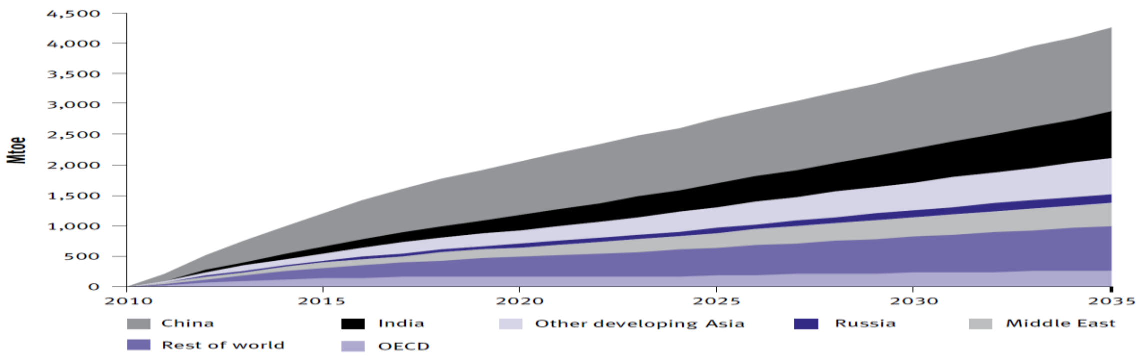
Understanding and modelling these interactions is crucial. However, modelling exercises will only be helpful for policy makers if they can usefully inform policy, planning and investment decisions. Researchers have highlighted the difficulty for even well-educated individuals to understand basic concepts essential for understanding complex environmental problems. This lack of understanding “not only prevents the design of effective cross-sector policies, but also blinds the community to the need for at least a minimum level of dynamical systems literacy in those entrusted with policy design.” Greater understanding on the part of policy makers of the system dynamics could therefore help to improve the ability of local and central governments to formulate appropriate policies in response to pressure on resources and environmental change.

MAINSTREAMING THE NEXUS IN INVESTMENT AND DEVELOPMENT

Based on 700 survey responses from a multi-stakeholder community, the World Economic Forum’s 2014 *Global Risks Report* placed water and food crises among their top 10 global risks, alongside climate change and a greater incidence of extreme weather events (WEF, 2014). Nexus discussions and resource scarcity has been referred to as creating a new sort of “resource realism” for businesses and investors. However, “investing in the nexus” to improve resilience is as difficult as the concept is hard to define and operationalise. A more realistic approach is for companies, investors, donors and shareholders to use a risk-based perspective to analyse water, energy and land-use risks present in their supply chains, project pipelines and investment portfolios. By encouraging consideration and understanding of the inter-linkages between water, energy and food, investment and asset management processes can support sustainability.

Efforts to mainstream sustainability concerns can be evaluated by addressing the ways that businesses and

Figure 9. Growth in Primary Energy Demand by Region in the New Policies Scenario (million tonnes of oil equivalent)



Source: OECD, 2011.

investors are responding to these risks as well as addressing the reporting and disclosure protocols that have emerged to encourage better management of water, energy and land-use issues. There has been a surge in the development of risk assessment tools, reporting frameworks and disclosures linked to water, energy and land-use. There has been particular growth in the development of "water stewardship tools" which are designed to measure water consumption, impacts and risks. Similarly there has been a sharp increase in water "foot printing" and water accounting tools.

Companies are increasingly aware of the business risk that water, energy and land can present and are taking action. Water scarcity risks have attracted particular attention as they can affect a wide range of industries including food and agriculture, chemicals, utilities, manufacturing, pharmaceuticals, and the energy sector. Since 2003, Coca-Cola and its bottlers have spent nearly USD 2 billion to reduce water use and improve water quality in the areas where they operate. According to Financial Times Research and data from the Global Water Intelligence, in the past three years, private companies have spent USD 84 billion on improving the way they access, conserve or transport water (Clarke, 2014). Operating costs are also increasing. In the mining industry for example, development costs have increased due to the need to invest in alternative water sources such as desalination and operational costs are on the rise due to the need to use energy-intensive water treatment and transport. Global credit ratings provider Moody's has described water scarcity as a "key risk" for mining companies that, without proactive management, will have negative credit-rating consequences with smaller mining companies facing particularly high risk.

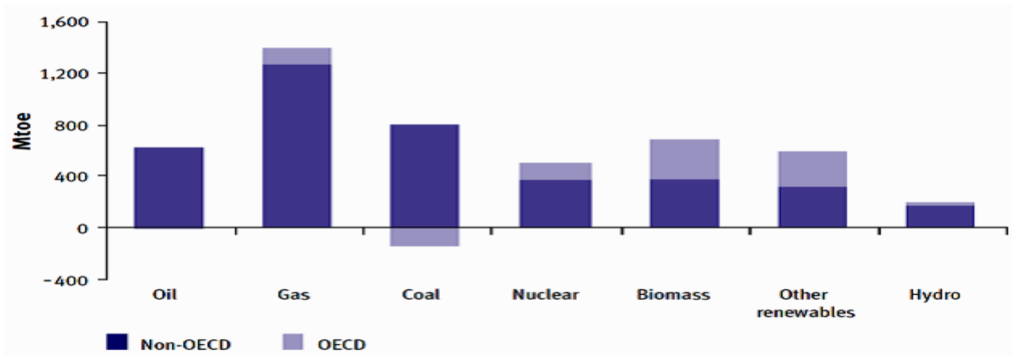
Project financiers can also promote consideration of water, food and energy sustainability into project design and development. Development banks are increasing their analysis of water issues. The IFC revised their environmental performance standards to increase due diligence of the water impacts of its loans) and the World Bank's *Thirsty Energy programme* is working to highlight the growing water needs for energy. Existing asset owners are already using their position as shareholders to push for greater reporting and disclosure that integrates nexus considerations. Moody's believes that capital markets will increasingly start to consider water risks in their investment and lending decisions and there may be signs that this is beginning to take root.

ENERGY-GLOBAL CLIMATE CHANGE NEXUS

Global Energy Trends

The International Energy Agency's (IEA) flagship publication the World Energy Outlook (IEA, 2011) provides a quantitative look at the risks and opportunities facing the global energy economy out to 2035. One of the key conclusions is that how we produce and use energy in the decades to come depends crucially on actions taken by governments around the world, the policy frameworks they put in place, and how the energy industry and energy consumers respond. In the World Energy Outlook's central scenario (the New Policies Scenario), world primary energy demand is projected to increase by 40 per cent between 2009 and 2035. Although overall demand for energy is set to keep on rising, there are major differences in trends by region and by fuel type. In 2009, China overtook the United States to become the world's largest energy consumer – a historic re-ordering of the global energy hierarchy. Looking forward, the emerging economies will continue to be the primary drivers of growth in global energy demand. Over the next two and a half decades, countries outside of the OECD are expected to account for 90 per cent of global population growth, 70 per cent of the increase in economic output and 90 per cent of the growth in energy demand. China and India alone are projected to account for around half the growth in global energy demand (Figure 9). The dynamics of energy markets will, therefore, increasingly be determined by decisions taken in Beijing and New Delhi. By contrast, demand for energy

Figure 10: Growth in World Energy Supply by Fuel and Region in the New Policies Scenario, 2009–2035 (million tonnes of oil equivalent)



Source: OECD, 2011.

scarcely grows in the countries of the OECD, with coal and oil demand projected to decline over the period. Over the next two and a half decades, countries outside of the OECD (2014) are expected to account for 90 per cent of global population growth, 70 per cent of the increase in economic output and 90 per cent of the growth in energy demand.

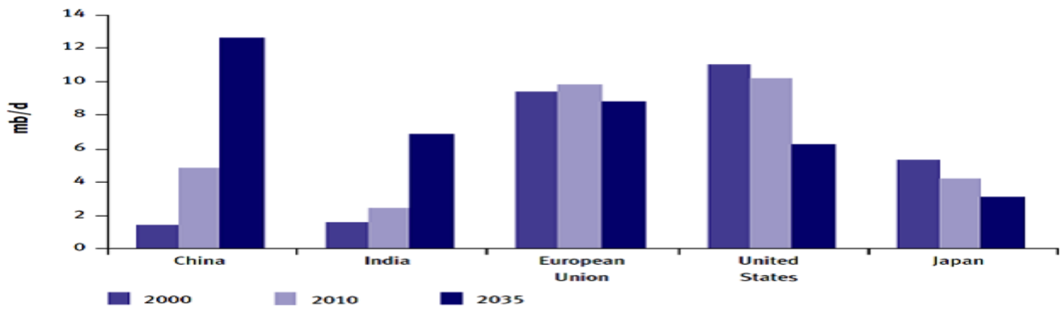
The age of fossil fuels is far from over, but their dominance declines. Fossil fuels – oil, coal and natural gas – are projected to remain the dominant sources of energy in 2035, despite a fall in their share of total energy demand from 81 per cent to 75 per cent. Of those fuels, demand for natural gas grows at the fastest rate (Figure 10). Oil demand grows more slowly, reaching 99 million barrels per day (mb/d) by 2035. Of all the energy sources, the use of modern non-hydro renewables (excluding biomass) grows most rapidly compared to today, by almost 8 per cent per year, more than quadrupling its share of total energy use from less than 1 per cent today to more than 4 per cent by 2035. In the power sector, renewable energy technologies, led by hydropower and wind, account for half of the new capacity installed globally to meet increasing demand.

Ever-increasing demand for mobility will drive oil markets. Rising incomes in China, India and other non-OECD countries will result in the ownership of vehicles soaring – we expect the global passenger vehicle fleet to double to 1.7 billion by 2035. Thankfully, doubling the vehicle fleet does not mean an equivalent rise in oil demand because the increase is moderated by improved fuel economy, a gradual rise in alternative fuel vehicles powered by electricity or natural gas, and increased use of biofuels. But as long as there are only limited possibilities to substitute for oil as a transportation fuel, this relentless rise in demand for mobility will continue to be a major factor underpinning global oil markets. Looking at the supply side, the cost of bringing oil to market is expected to rise as oil companies are forced to turn to more difficult and costly sources to replace lost capacity and meet rising demand. New sources of oil are coming from the deep offshore, or the 'light tight oil' that is now being developed in the United States, because of advanced drilling techniques and hydraulic fracturing. These technologies also bring new risks – in particular environmental risks – that the industry has to address. But the world still relies on the Middle East and North Africa for the bulk of its additional supply – the expected growth in output from this region to 2035 is equal to 90 per cent of the growth in global oil demand. The supply picture is therefore vulnerable to any shortfall in investment in this region.

While the critical nature of the Middle East and North Africa region for oil supply will continue, the focus in terms of global demand for oil imports will change. The United States is currently the largest oil-importing country in the world. But, a combination of increased transport efficiency and increased domestic oil supply promise a drastic reduction in the United States' oil imports (Figure 11). By 2015, oil imports to the European Union are projected to surpass those to the United States, and by around 2020 China becomes the largest single oil importing country. The European Union is already the largest importer of natural gas in the world and gas imports to China and other fast-growing Asian economies are also rising rapidly. These changing patterns of global trade imply shifting concerns about the cost of imports and about oil and gas security, and a further sea-change in the geopolitics of energy.

There are good reasons both on the demand and the supply sides to foresee a bright future, even a golden age, for natural gas. We expect that global demand for natural gas is set to catch up with that of coal by 2035, with most of the additional demand coming from countries outside the OECD, notably China, India and countries across the Middle East. Natural gas is a particularly attractive fuel for countries that are seeking to satisfy rapid energy demand growth in fast-growing cities. On the supply side, unconventional gas now accounts for half of the estimated resource base and it is more widely dispersed geographically than conventional resources, a

Figure 11: Net imports of Oil in selected Countries in the New Policies Scenario (million barrels per day)



Source: OECD, 2011.

fact that has positive implications for energy security. Unconventional production is expected to rise to account for one-fifth of total output by 2035, although the pace of unconventional development varies considerably by region with the United States, China and Australia taking the lead. Natural gas is the cleanest of the fossil fuels and so can play an important role in the transition to a low-carbon energy future. However, increased use of gas in itself (without carbon capture and storage) does not provide the answer to the challenge of climate change.

Global Climate Outlook

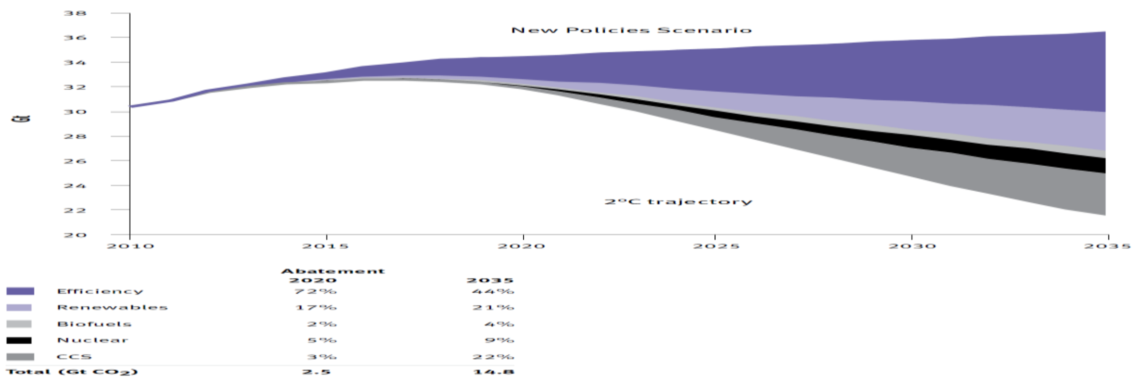
Overall, there is much more to be done to put the world on the path towards a more reliable and sustainable energy future. According to our analysis in the World Energy Outlook, the world is in real danger of missing the chance to reach its long-term target of limiting the global average temperature increase to 2 degrees Celsius. If stringent additional action is not forthcoming by 2017, then the world's existing capital stock – its power plants, buildings, factories and so on – will generate all of the CO_2 emissions permitted up to 2035 under a 2 degree Celsius scenario, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon, which would be extremely costly. The most important contribution to reaching global climate change objectives comes from the energy that we do not consume (Figure 12). A much greater focus on energy efficiency is vital – a real transformation in the way that we produce and use energy. Green technologies, nuclear power and technologies such as carbon capture and storage all have important roles to play as well. If there is a substantial global shift away from nuclear power, or if carbon capture and storage technology is not widely deployed already in the 2020s, this would make it harder and more expensive to combat climate change and put an extraordinary burden on other low-carbon technologies to deliver lower emissions.

Note: The central scenario in World Energy Outlook 2011 is the New Policies Scenario. The 2°C trajectory scenario (called the 450 Scenario in the World Energy Outlook) works back from the international goal of limiting the long-term increase in the mean global temperature to 2°C above pre-industrial levels, in order to trace a plausible pathway to this goal.

THE ENERGY-MIX

For many years, fossil fuels – including coal, crude oil and natural gas – have been the main source of commercial energy for industrial production, heating and transportation. Hydrocarbons, and especially petroleum, have also been used in the pharmaceutical, building and clothing industries, as well as for fertilizers, foodstuffs, plasticware and paints. The inclusion of other energy sources, such as nuclear and renewables – wind, solar, geothermal, water and biomass – in the energy matrix has been marginal, because of high costs and underdeveloped technologies. In the case of nuclear power, there are additional safety concerns, including the long-term disposal of radioactive waste. However, recognition of the damaging environmental impact from excessive dependence on fossil fuels, along with growing concerns about the supply of some fossil fuels to meet rising global demand for energy, has brought into focus the need for a cleaner and more diversified energy mix. Hence, renewable energy, including biofuels, has received growing attention. Furthermore, energy supply shocks, beginning with the oil crisis in 1973, have alerted policymakers, in developed and developing countries alike, of the need to move away from reliance on a single source of energy. The recent shocks, which caused the price of oil to reach a peak in July 2008 close to $150 per barrel, again served as a reminder of the benefits of a more diversified energy mix. Broadening the global energy mix poses severe challenges, which will require strategic policy measures and significant investments, including in the public sector, to support the development of new energy sources which are currently either too costly, or introduce their own negative externalities, as is the case with some biofuels. In addressing these challenges, policymakers need to develop a holistic and integrated approach to energy security that enables them

Figure 12: World energy-related CO_2 emissions in the 2 degrees Celsius climate scenario relative to the New Policies Scenario (gigatonnes)



Abatement : 2020-2035
Total (Gt CO_2) 2.5 14.8
Efficiency 72% 44%
Renewables 17% 21%
Biofuels 2% 4%
Nuclear 5% 9%
CCS 3% 22%
Source: OECD, 2011.

to evaluate realistically various trade-offs with other development policy objectives.

Global Energy Scenario – Historical and Current Energy-Mix and Future Challenges

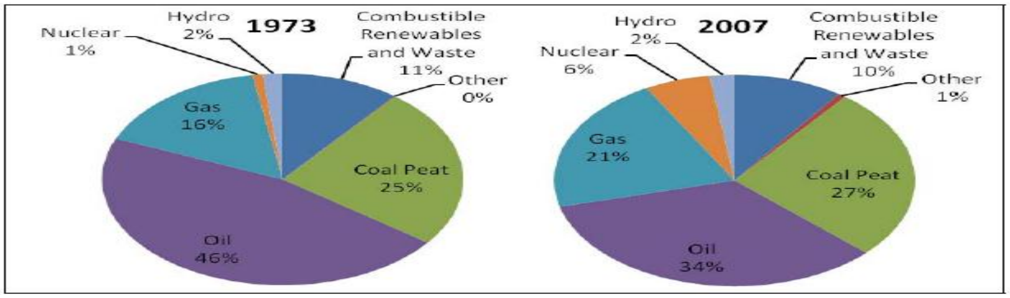
Historically, the global energy system has been dominated by fuels emitting high levels of greenhouse gases. First, firewood was the principal industrial fuel, but its use diminished after the discovery of coal, which burned more slowly and had a much higher calorific value. From the late 1800s, coal became the fuel of choice, used to power the Industrial Revolution. However, the use of oil expanded rapidly after 1945, supplanting coal in the 1960s as demand for transportation fuels increased. Today, the global energy system is much more complex, with many competing sources of energy and many high-quality and convenient energy carriers. Taken together, fossil fuels provide some 80 per cent of global energy needs, while fuelwood, hydropower and nuclear energy provide the rest. Over the past 35 years, natural gas has increased its market share to over one fifth (Figure 13) because it is abundant, efficient, has multiple applications and greenhouse gas emissions are much lower than those from coal or oil. Renewable energies have seen a similar increase (5 per cent) in market share over this period. However, coal has also made a comeback, despite being a highly polluting fuel, and demand for it could increase if clean coal technology matures.

Although conventional crude oil reserves are dwindling, the potential for oil sands, which already form part of total crude oil production, and coal are massive, and could sustain the fossils industry for some time subject to the pace of technological developments, which will in turn influence the costs of extracting oil from oil sands. Figure 1 also reveals that the share of oil in total energy supplies dropped by 10 per cent over more than three decades (1973–2007), but new data on world energy demand between 1990 and 2007 reveals that much of this reduction was between 1973 and 1990, and was therefore most likely due to the two oil crises. Indeed, the fall in share of oil in global energy demand over the period 1990-2007 was only 2.6 per cent –from 36.7 percent to 34.1 percent (IEA, 2009a).

Total world energy consumption, including renewable energy, is expected to increase by 45 per cent by 2030. An increase of such magnitude from current levels (Figure 14), would require an investment of $25 trillion–$30 trillion; that is more than $1 trillion a year for the next 20 years (Hayward, 2009). International Energy Association (IEA, 2009b) projections suggest that crude oil will remain the dominant source of energy worldwide, accounting for 77 per cent of the demand increase between 2007 and 2030. That translates in to an increase from around 85 million barrels per day (mb/d) in 2008 to 105 mb/d in 2030. Also, projections suggest 53 a per cent growth in demand for coal between 2007 and 2030, and 42 per cent for natural gas over the same period (IEA, 2009b).

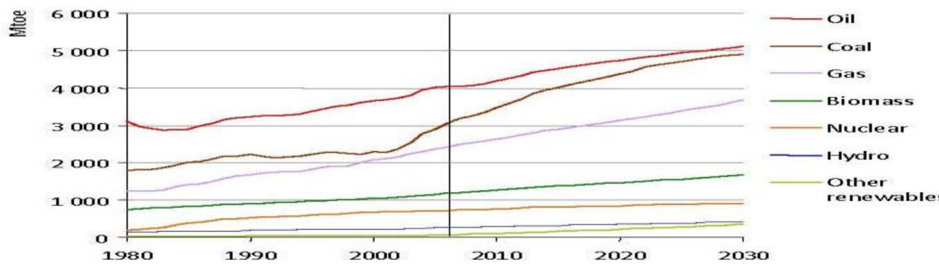
The big challenge posed by these projections is that the energy sector accounts for 60 per cent of global greenhouse gas emissions, and is therefore a major factor in global warming. At the same time, cheap and reliable energy is essential for sustained economic growth, improving living standards and eliminating poverty in the developing world. Indeed, a significant part of new investments in the energy sector over the coming

Figure 13. Total Primary Energy Supply - Scenario 1973 and 2007



Source: International Energy Agency :International Energy Agency (2009). World Energy Outlook.

Figure 14. World Primary Energy Demand



Source: Reference scenario, World Energy Outlook, 2008 (IEA, 2009b).

decades will take place in the developing world. Consequently, energy is the pivotal issue at the interface of the climate and development challenges.

A low-emissions energy mix could be derived from a range of energy sources. These include renewables, such as wind, geothermal, solar, water, and biomass. While some of these are fast becoming conventional sources of energy, at present, the low level of technological development and high costs associated with most of them limit the extent to which they can be incorporated into the global energy matrix on a substantial scale in the foreseeable future.

Wind energy is one of those currently widely used renewables. Installed capacity has been growing at an annual average rate of 17.1 per cent (0 Global Wind Energy Council: http://www.gwec.net/index.php?id=30&no_cache=1&tx_tt -news[tt_news]=232&tx_ttnews[backPid]=4&cH ash=c11503e4d8). In 2008, wind energy generated over 260 terawatt-hours (tWh) of clean power (the equivalent of more than 1.5 per cent of the global electricity consumption) in more than 70 countries (World Wind Energy Association report 2008: http://www.wwindea.org/home/images/stories/worldwinde ner -gyreport2008_s.pdf.).

Geothermal energy, originating from beneath the Earth's surface, is exploited only in a few places. The steam from geothermal wells is used to generate electricity and heating. Geothermal is a fast-growing renewable energy (20 per cent annually). Analysis suggests that by 2010 there could be as many as 46 countries using geothermal energy, generating as much energy as 27 coal-fired power plants (Dorn, 2008). Developing countries are the main producers, with 10 countries among the top 15 worldwide. In 2007, geothermal contributed only 0.4 per cent of total global energy supply (http://kn.theiet.org/sustainability/renewable-energy.cfm.).

Solar energy is harnessed from the sun using photovoltaic cells for electricity production or through solar heating collectors to heat water. It is an appropriate form of energy for many rural dwellers, who are often marginalized from grid systems because of the huge costs involved. The photovoltaic industry's growth has been aided by subsidies mainly in temperate developed countries such as Germany and Japan where installed capacity is 42 per cent and 21 per cent respectively of the world total. Forecasts suggest that solar electricity could be cheaper than electricity from conventional sources by 2015 due to two main factors – ongoing developments in Photovoltaic technology and rising price of fossil fuels (Keller and Ploss, 2009). The potential for *hydro energy* is huge but less than a third of the world's hydro resources have been developed due to the environmental sensitivities and the mammoth task in resettling communities that are affected in the process of damming rivers. In 2007, hydro-energy accounted for just 2 per cent of global energy supplies, virtually unchanged from 1973. Other forms of kinetic energy, including wave and tidal power, are at an early stage of development and are therefore not part of the global energy mix. A global renewable energy push will still have to be led by advanced countries (Jacobson and Delucchi , 2009).

Most of *biomass energy* is generated from plant material. Developing countries are the biggest consumers of biomass with the traditional biofuels such as wood accounting for about a third of all energy consumed in these countries. However, these are not efficient sources. Many sub-Saharan African countries depend on biomass for up to 90 per cent of their primary energy consumption. Biofuels for transport comprise ethanol and biodiesel. Ethanol is derived from crops such as corn, sorghum, barley or sugarcane while biodiesel is derived from vegetable and animal fat. Production of these fuels is heavily concentrated in a few countries. Brazil and the United States together accounted for more than 87 per cent of ethanol production in 2008. Most of the ethanol produced in the United States uses corn as its feedstock whereas Brazil relies on cheap sugarcane. In European Union (EU) countries such as Germany, France, and Italy, the dominant product is biodiesel. Together, these countries produced more than 35 per cent of global biodiesel in 2008. Fuels derived from palm oil, jatropha and other cellulosic biofuels have also become commercialized, but the rate of market penetration has been slow due to the high costs involved and new and underdeveloped technology. These two factors also restrict the share of cellulosic biofuels in the global energy mix. For example, studies suggest that it requires 3.3 gallons of oil to produce one gallon of ethanol from cellulosic material (Pimentel, 2009**)**. Overall, the biofuel output of the top five countries accounts for over 85 per cent of total global production. However, biofuels have not had a significant impact on the energy mix because global production is still relatively too small and the land requirements are too high. World total bio fuels production in 2008 reached 1.5 mbd (compared to 85 mbd of crude oil).

Climate Change, Energy Security and long-Term sustainability Challeges: A Global Consensus

Debate on the security implications of climate change has a history almost as long as the discussion of climate change itself, but has gained increasing importance in recent years. The question of security or even *national security* has become a key element in debate on the possible effects and policy responses to climate change. In academic discussion there are still open questions on the nature of the link between climate change and security. One fundamental question is the scope of the concept of security under consideration. The definition of the concept of security used in discussions of its link to climate change ranges broadly, from a traditional view focusing on narrowly defined national security interests to one which embraces a much broader definition, often called human security. For traditionalists, definitions of human security used in this context have become so broad as to be meaningless, but those who propose a wider scope for the concept argue that a narrow view fails to capture all the possible impacts of climate change. Another unresolved question remains degree to which climate change can be said to have an impact on security, for instance by causing conflict. One of the most common themes in the literature that argues for a link between climate change and security is that it will lead to increased conflict. The case of Darfur is the most frequently cited example of climate change being at least in part the cause of conflict (Wilkinson et al., 2007).

The challenge of delivering energy equity is therefore—broadly—to ensure that all people have access to the level of energy needed to provide for their security or wellbeing, while at the same time ensuring that our energy consumption behaviours do not jeopardise the wellbeing and security of others. Meeting this challenge is a two-fold process. First, it involves reducing existing energy poverty through the development of renewable and sustainable energy infrastructure. This raises a number of important technical as well as ethical questions, including which technologies can best be employed to meet energy needs most sustainably and who should pay any additional costs associated with meeting energy needs through the provision of renewable energy infrastructure (given that reason for having to meet energy needs through more costly sustainable generation and distribution infrastructure based on renewable fuel sources is largely a function of the over-consumption of fossil fuels by developed countries). Second, ensuring that our energy consumption behaviours do not jeopardise the wellbeing and security of others will require a major shift in the way that affluent people today utilise existing energy resources. The ethical principles and approaches that ought to guide the development of energy policy and the distribution of energy resources and services will be considered in further detail in the next chapter.

Addressing Long-term Energy Security and Sustainability Challenges

Current demographic, economic, social, and technological trends – if not counterbalanced by strong new government policies – pose major challenges to the long-term sustainability of the global energy system. If governments do not implement policies beyond those already planned between now and 2030, it is projected that:

energy consumption will increase by over half (53%);

the energy mix will remain fairly stable and dominated by fossil fuels (80% share); energy-related CO_2 emissions

(Box 1).

Box 1. Energy security and sustainable development

Energy security is a broad concept that focuses on energy availability and pricing. Specifically, it refers to the ability of the energy supply system – suppliers, transporters, distributors and regulatory, financial and R&D institutions – to deliver the amount of competitively-priced energy that customers demand, within accepted standards of reliability, timeliness, quality, safety and environmental impacts, under a wide range of geopolitical, economic, social, technological and weather circumstances.

Traditionally, energy security has been defined in the context of the geopolitical risks to external oil supplies. Today, it is a broader concept, encompassing all energy forms, all the external (foreign) and internal (domestic) links bringing the energy to the final consumer, and all the many ways energy supplies can be disrupted – including equipment malfunctions, system design flaws, operator errors, malicious computer activities, deficient market and regulatory frameworks, corporate financial problems, labour actions, severe weather and natural events, aggressive acts (*e.g.* war, terrorism and sabotage), and geopolitical disruptions.

In practice, the most worrisome disruptions or potential disruptions are those linked to: 1) extreme weather events; 2) mismatched electricity supply and demand; 3) regulatory failures; and 4) concentration of oil and gas resources in certain regions of the world. Insecure energy supplies inhibit development by raising energy costs and imposing expensive (sometimes life threatening) cuts in services when disruptions actually occur.

The energy supply sector can best advance sustainable development by producing and delivering secure and environmentally-friendly sources of energy and by increasing the efficiency of energy use. These overarching qualities are frequently stated in terms of the 3E's – energy security, economic development and environmental protection. The current methods of meeting these criteria involve ensuring fuel diversity, supplier diversity, sound transmission and distribution infrastructure, efficient conversion and delivery technologies, and low- and zero-carbon technologies.

will increase by over half (55%); and
large populations of the world's poor will continue to lack access to electricity (about 1.5 billion) and modern cooking and heating services (about 2.5 billion).

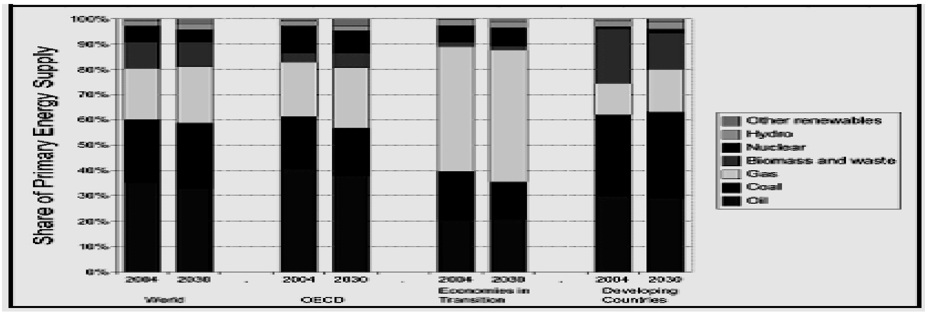
In this scenario, energy consumption increases from 11 200 Mtoe (millions tons of oil equivalent) in 2004 to 17 200 Mtoe in 2030. Over 70% of this growth is expected to come from developing countries, which overtake OECD countries as energy consumers sometime around 2014. Nearly half of the increase in global primary energy use goes to generating electricity and one-fifth of the increase (almost entirely in the form of oilbased fuels) to meeting transport needs. Growth in energy use and emissions is expected to be particularly marked in some sectors. The sectoral contributors to growth in energy consumption are expected to be power generation (35%), industry (15%), transport (12%) and buildings (6%) in developing countries, followed by power generation (11%) and transport (6%) in OECD countries.

Improving efficiency and reducing carbon dioxide (CO_2) emissions should receive early attention in these high growth areas, because these goals are easier and cheaper to attain at the time of new construction than at later retrofit stages. It is predicted that the global energy mix will remain fairly stable and dominated by fossil fuels to 2030 due to the size and inertia of the energy system and the inability to change it quickly. In this scenario, no fuel's share of the mix changes by more than a few percentage points.

Fossil fuels remain the largest source of world energy – accounting for about 80% of global demand in 2004 and 81% in 2030. The consumption of each fossil fuel grows at different rates, so their shares of the total shift slightly – oil falls from 35% of the total in 2004 to 33% in 2030; coal rises from 25% to 26%; and gas rises from 21% to 23%. Concerns about continued high consumption of oil and gas raise questions of supply security
China and India account for almost four-fifths of the incremental demand for coal. Renewable energy and nuclear power shift to a similarly small degree. Hydropower's share of primary energy use rises slightly. The share of biomass decreases as developing countries switch to modern commercial energy, offsetting the growing use of biomass as feedstock for biofuels production and for power generation. Non-hydro renewables –including wind, solar and geothermal – grow the quickest, but from a small base (Figure 15).

While greenhouse gas (GHG) emissions and the ensuing climate change are not the only environmental problems confronting the energy sector, they are the most universal and most pressing. In the reference scenario, energy related CO_2 emissions increase from 26.1 Gt CO_2/year in 2004 to 40.4 Gt CO_2/year in 2030. Over three-quarters of this growth comes from developing countries, which overtake OECD countries as the biggest regional emitter soon after 2010. China, which overtakes the United States as the world's biggest emitter before 2010, accounts for 39% of the global increase between 2004 and 2030. Its emissions more than double between 2004 and 2030, driven by strong economic growth and heavy reliance on coal in power generation and industry. India accounts for 10% of the increase in global emissions. The sectoral contributors to CO_2 emissions growth are forecast as coal-based power generation (32%), oil use in transport (13%), coal use in non-power sectors (9%), gas-based power generation (8%) and oil used in non-power sectors (7%) in developing countries, followed by oil use in transport (7%) and coal-based power generation (6%) in OECD countries. These projections concerning energy and environmental trends are not inevitable; there are many

Figure15: Fuel Profile of Primary Energy use (2004 and 2030)



Note: The Graph is drawn based on Reference Scenario
Source: World Energy Outlook (IEA, 2006a, b &c)

policies that if implemented could change them. According to the Alternative Scenario based on enlightened policies, it is possible to substantially alter the course of energy developments in the next half century and to make the energy system more sustainable. To achieve this, countries need to adopt all of the policies related to energy security and energy-related CO_2 emissions that they are currently considering.

These policies include efforts to improve efficiency in energy production and use, increase reliance on non-fossil fuels, and sustain the domestic supply of oil and gas within net energy-importing countries. They would yield substantial savings in energy consumption and reductions in CO_2 emissions. Moreover, these benefits would be achieved at a lower total investment than if such action is postponed. While suppliers' investments decrease, consumers' investments increase but this is more than offset by lifecycle energy cost savings. The cost of fuel saved by consumers is estimated at USD 8.1 trillion, more than offsetting the extra demand-side investments required to generate these savings. Policies encouraging more efficient production and use of energy could contribute almost 80% of the avoided CO_2 emissions in 2030, with the remainder gained from fuel substitution.

More efficient use of fuels, mainly by cars and trucks, accounts for almost 36% of avoided emissions; more efficient use of electricity in a wide range of applications (*e.g.* lighting, air-conditioning, appliances and industrial motors) for 30%; greater efficiency in energy production for 13%; renewables and biofuels for 12%; and nuclear for the remaining 10%. Another critical policy response is greater investment in energy-related research and development (R&D), in part because new supply-side energy technologies need to be operating on a commercial scale from 2030 or earlier. Scenarios show that it is possible to bring emissions back to current levels by 2050, but this would entail large amounts of extra R&D and widespread deployment of cleaner, more efficient technologies. There is no "silver bullet" technology that alone can attain the emissions target, but more energy efficient production and end-use technologies are indispensable.

IMPORTANCE OF BIOENERGY IN ENHANCING GLOBAL FOOD SECURITY

Global energy demand is growing rapidly. The total current commercial energy use amounts some 470 EJ. About 88% of this demand is covered by fossil fuels. Energy demand is expected to at least double or perhaps triple during this century.At the same time, concentrations of greenhouse gases (GHG) in the atmosphere are rising rapidly, with fossilfuel bound CO_2 emissions being the most important contributor. In order to stabilize related global warming and climate change impacts, GHG emissions must be reduced drastically to less than half the global emission levels of 1990. In addition, security of energy supply is fully back on the agenda as a global issue. Supplies of conventional oil and gas reserves are increasingly concentrated in politically unstable regions and increasing the diversity in energy supplies is important for many nations to secure a reliable and constant supply of energy. To reverse these trends to what may be called a sustainable development pathway, a wide range of major transitions is needed: first of all energy systems and .tackling. climate change is necessary by massive improvement of energy efficiency and a shift to renewable energy sources. Second, agriculture worldwide requires a new .green revolution. to absord the growing demand for food (and in particular protein) and at the same time lower pressure on available lands and natural resources (such as water). This requires large scale improvement in agriculture towards sustainable practices and more efficient management. Linked to this is fighting poverty. 70% of the world.s poor live in rural areas. In this regard, many more shifts are needed; e.g. with respect to protection of biodiversity, sustainable management of soils and water resources. With respect to energy, a secure and stable supply that is also affordable is a prerequisite for sustainable developm

-ent, in particular again for LDC.s. In this global context, it is suggested that the use of biomass for energy (as well as material) can play a pivotal role. Biomass use for energy, when produced in a sustainable manner, can drastically reduce GHG emissions compared to fossil fuels. Most countries have various biomass resources available or could develop a resource potential, making biomass a more evenly spread energy supply option across the globe.

It is a versatile energy source, which can be used for producing power, heat, liquid and gaseous fuels and also serves as carbon neutral feedstock for materials and chemicals. Especially due to rising prices for fossil fuels (especially oil, but also natural gas and to a lesser extent coal) the competitiveness of biomass use has improved considerably over time. In addition, the development of CO_2 markets (emission trading), as well as ongoing learning and subsequent cost reductions for biomass and bioenergy systems, have strengthened the economic drivers for increasing biomass use, production and trade. Biomass and bioenergy has become a key option in energy policies. Security of supply, an alternative for mineral oil and reduced carbon emissions being key reasons. Targets and expectations for bioenergy in many national policies and long term energy scenario.s are ambitious, reaching 20-30% of total energy demand in various countries, as well as worldwide.

The linkages between bioenergy and food security are complex. On the one hand biomass production competes with food production for land and other agricultural production factors. On the other hand, biomass production may contribute to rural development, for example by increasing local employment and energy supply. Thus, implementing bioenergy production in developing countries can lead to either an improvement or a deterioration in the food security conditions. The impacts of bioenergy developments on food security depend on many factors that are country and case specific. Examples of these factors are the type of biomass used, the type of energy carrier produced, the type of land for biomass production, developments in agricultural management and developments in the global food markets.

Food security exists when all people, at all times, have physical, social and economic access to sufficient amounts of safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. There are four dimensions to food security: availability, access, stability and utilization. Availability of adequate food supplies refers to the capacity of an agro-ecological system to meet overall demand for food (including animal products, livelihoods and how producers respond to markets). Access to food refers to the ability of households to economically access food (or livelihoods), defined in terms of enough purchasing power or access to sufficient resources (entitlements). Stability refers to the time dimension of food security. Stability of food supplies refers to those situations in which populations are vulnerable to either temporarily or permanently losing access to resources, factor inputs, social capital or livelihoods due to extreme weather events, economic or market failure, civil conflict or environmental degradation, and increasingly, conflict over natural resources. Utilization of food refers to peoples. Ability to absorb nutrients and is closely linked to health and nutrition factors, such as access to clean water, sanitation and medical services.

MAJOR LINKAGES WITH FOOD INDUSTRIES: PRICES AND INCOME

Key is how bioenergy production impacts on food security through changes in market based incomes and food prices. In many circumstances these are likely to be the quantitatively most important effects, however, there is no doubt that bioenergy production may have effects on food security that are not mediated by income and prices. With regard to incomes and prices, it is obvious that income is a critical determinant of food security for the poor. The more income that a given household or individual has, the more food that can be purchased, both in terms of quantity and quality. Food prices are also important determinants, but the precise effects of food prices on food security are more complex. To determine the effects of food prices on food security, however, it is important to distinguish between net food producers and net food consumers. Generally speaking higher food prices can substantially hurt net food consumers as is clearly observed in many countries today. On the other hand, farmers who are net food producers are likely to benefit from higher prices, which, other things being equal, will tend to increase their incomes. Thus, there will always be some people for whom food security improves, while others experience a deterioration in food security. The exact net outcome will depend on the socio-economic structure of society, as well as on the specific commodities whose price increases, and the relative position in the income distribution of the farmers who produce the commodities that have experienced the price increase. For example, poor farmers might be net producers of a commodity whose price increased. At the same time, the farmer might also be a net consumer of commodities whose price increased.

Competition for Production Inputs

Bioenergy production will nearly always compete for inputs with food production including feed. Inputs include land, labor, water and fertilizer. Food crops that are used for bioenergy production compete directly with food supplies. Moreover, the competition for inputs places upward pressure on food prices, even if the feedstock itself is a non-food crop or is grown on previously unused land. On the contrary, improved bioenergy production systems that allow for synergies with food production exist. For example, intercropping of jatropha with annual food crops can potentially increase food yields, while at the same time producing biomass for energy. Agroforestry systems can deliver both food and biomass for construction, fibre and fuel use, as well as secure high levels of biodiversity and there are many other examples. The competition between bioenergy and food production for inputs depends on the developments in the agricultural sector and consequent variations in agricultural productivity. Higher prices for food products or strategies that stimulate policies for developments in agricultural management might lead to an increase in agriculture efficiency as the increased demand leads to higher investments in the agricultural sector. As a result, food production in the agricultural sector could improve using less of the resources at hand for the production of a given amount of bioenergy.

World Market Integration with Bio-Energy

As world commodity markets become more integrated, bioenergy production in one country will have important effects on food security in other countries as changes in food prices on international markets affect domestic markets. However, countries may prevent these effects on domestic markets by agricultural market policies related to trade and domestic prices. Moreover, self-sufficient areas that don.t have access to markets can be excluded from these effects. The effect will depend on domestic trade policies and infrastructure. Bioenergy production may affect food security in small developing countries even if the country concerned is not involved in bioenergy production of its own. The effect is quite simple: higher prices on international commodity markets due to, for example, increased demand for corn as an ethanol feedstock in the United States, will in many cases spill into commodity markets in developing countries. Therefore, it is important to evaluate food security impacts of national bioenergy strategies against the background of global market developments. These spill-over effects are caused by the increased global demand on food commodities and the resulting increased prices on the world market. Without additional domestic policies, these world market prices translate to the domestic markets.

RECOGNISING ENERGY AND FOOD SECURITY LINKAGES

Key Concepts for Food Security

Some 70 percent of the 854 million hungry people in the world live in rural areas and depend on agriculture, often concentrated in regions that are particularly vulnerable to environmental degradation and climate change. An estimated 820 million are in developing countries, 25 million in countries in transition, and 9 million in industrialized countries. Hunger claims up to 25,000 lives every day, two thirds of them children under the age of five, and is currently the leading threat to global health, killing more people than AIDS, malaria, and tuberculosis combined. Although the proportion of undernourished in the world has declined from 20 percent to 17 percent since the mid-1990s, the absolute number of hungry people has remained the same. Global progress towards halving the proportion of hungry people by 2015 remains slow and largely uneven. Only Latin America and the Caribbean, amongst developing regions, have reduced the prevalence of hunger at a rapid enough pace to reach the Millennium Development Goals (MDG) target.

Country Typologies

Growth rates of agricultural production and consumption in developing countries have outpaced those of industrialized economies in recent years. This has not been the case, however, for most of the Least Developed Countries (LDCs), where agricultural output has not kept pace with population growth and increased domestic demand. Preliminary analysis of the impact of bioenergy on food security should thus highlight differences between developing, least developed, and low-income food deficit countries (LIFDCs). These two latter groups are typically the most food insecure, given high dependence on staple food imports and exports of primary tropical commodities. LDCs have the highest proportion of chronically undernourished populations, and have become increasingly reliant on imports of basic commodities to ensure food security. For many, this has also resulted in increased exposure to international market price fluctuations, increasing overall food insecurity.

Further development of bioenergy systems will increasingly highlight the direct linkages between food security and energy security. These linkages function as an additional source of uncertainty in global production and marketing systems; markets that are already more susceptible to greater variability in pricing and production due in part to trade liberalization and structural adjustments in food and agricultural sectors. Natural disasters and lack of productive input factors, such as fertilizer or water resources, also constrain or result in lost agricultural output, and lowers overall food availability. The competition for more arable land and water resources directed to biofuel production may lead to higher and less stable food prices, for countries that are both net food importers and exporters. This may be particularly true for lowincome, food deficit countries (LIFDCs) that already have a large proportion of undernourished and are net importers of basic foods, and may face serious problems of food access within vulnerable populations. Poor households tend to spend a larger proportion of income on food than other items, including energy, and thus, may be particularly challenged by rising food prices, globally and locally.

Linkages between Prices, Biofuels and Food Security

Current and expected trends in energy prices may catalyse further growth in bioenergy production and more rapid adoption of bio-based fuels. Biofuels represent an important and growing source of demand for agricultural commodities. Recent FAO research notes that prices for fossil fuels may essentially establish floor and ceiling prices for agricultural commodities used as feedstock. Major producers of biofuels, such as Brazil, the United States, the EU and Canada are either expected to reduce exports of basic feedstock commodities (cereals or oilseeds) and increase biofuel imports. This can have serious economic, environmental and food security implications for many developing countries, particularly countries that have large proportions of poor food insecure people living in rural areas. Agricultural commodity prices have long been influenced by energy prices, because of the importance of fertilizers and machinery as inputs in commodity production processes. The possibility of increased competition for agricultural, water and other natural resources for bioenergy systems instead of food production is already evident. However, given potentially significant markets for bioenergy, competition for resources could induce result in price increases that adversely affect the ability of lower income consumers to purchase food.

Rising commodity prices, while beneficial to producers, will mean higher food prices with the degree of price rise depending on many factors including, as mentioned, energy prices, with negative consequences for poor consumers. Expanded use of agricultural commodities for biofuel production will strengthen this price relationship and could increase the volatility of food prices with negative food security implications. Developing guidelines to analyse how bioenergy can contribute to rural development, as well as formulate policy to ensure that the food security concerns of the rural poor, particularly female smallholders and household heads, is vitally important to ensure that the outcomes of rapid bioenergy development are positive. There are indications that increased production of biofuels will further link prices of fossil fuels with biofuel feedstock. Prices of sugar and molasses already show high correlations with world oil prices.

Increased production of biofuels adds another layer of uncertainty and risk to volatile price relationships by linking food and oil prices; inelastic demand (through biofuel consumption mandates) comprising an increasing share of a given crop.s market also gives rise to greater price variability and market volatility. Increased price volatility may be more detrimental to food security than long-term price trends, to the extent that the poor are usually less able to adjust in the short term. Increased trade in biofuels has the potential to mitigate some of this price volatility. However, the expected price increases due to greater demand for biofuel crops may induce farmers to increase production and thereby mitigate some of these price effects in the longer term. Appropriate trade policies could potentially minimize tensions between biofuel and food production by allowing trade to flow internationally in response to fluctuations in domestic supply and demand, thus helping to stabilize prices.

Bioenergy and the four Dimensions of Food Security

Availability of adequate food supplies refers to the capacity of an agro-ecological system to meet overall demand for food (including animal products, livelihoods and how producers respond to markets). Food availability could be threatened by biofuel production to the extent that land, water, and other productive resources are diverted away from food production. The degree of potential competition between food, feed and fuel use of biomass will hinge on a variety of factors, including agricultural yields and the pace at which next-generation biofuel technologies develop. As second-generation technologies based on lignocellulosic feedstock become commercially viable, this may lessen the possible negative effects of land and resource competition on food availability. The market for biofuel feedstock offers a new and rapidly growing opportunity for agricultural producers and could contribute significantly to higher farm incomes. Modern bioenergy could make energy services available more widely and cheaply in remote rural areas, supporting productivity growth in agriculture or other sectors with positive implications for food availability and access to food. Access to food refers to the ability of households to economically access food (or livelihoods), defined in terms of enough purchasing power or access to sufficient resources (entitlements). Bioenergy developments will have an impact on those populations vulnerable to food insecurity based on food access issues, to the extent that food prices rise faster than real incomes, reducing purchasing power and in turn, increasing food insecurity.

Global food commodity prices are expected to increase in the near to medium-term due to expanded biofuels production. Price increases have already occurred in major biofuel feedstock markets, for example, sugar, corn, rapeseed oil, palm oil, and soybean. In addition to raising feedstock prices, increased demand for energy crops might elevate the prices of basic foods, such as cereals, which comprise the major proportion of daily dietary intake of the poorest and least food secure. Thus, possible income gains to producers due to higher commodity prices may be offset by negative welfare effects on consumers, as their economic access to food is compromised. This appears to be the case for corn in 2006 and early 2007, as rising demand for biofuel production (ethanol) in the United States reduced exports, pressured prices, and in turn, threatened access to food for lower income net food purchasers in Mexico. *Stability refers to the time dimension of food security*: Stability of food supplies refers to those situations in which populations are vulnerable to either temporarily or permanently losing access to resources, factor inputs, social capital or livelihoods due to extreme weather events, economic or market failure, civil conflict or environmental degradation, and increasingly, conflict over natural resources. Temporal distinctions between chronic and transitory food insecurity may be important to understand in the context of rapid bioenergy development. Chronic food insecurity is a long term or persistent inability to meet minimum food consumption requirements, lasting for more than six months of the year.

Transitory food insecurity is a short-term or temporary inability to meet minimum food requirements, usually linked to the hungry (or lean) season, a more limited timeframe with some indication of capacity to recover from shocks. Further growth in biofuels could exert additional pressures on stability of food supplies as price volatility from the petroleum sector is more directly and strongly transmitted to the agricultural sector, increasing the risk of more severe chronic and transitory food insecurity.

HOW ENERGY CONSUMPTION AFFECTS FOOD SECURITY

Energy is needed in all steps along the agrifood chain: in the production of crops, fish, livestock and forestry products; in post-harvest operations; in food storage and processing; in food transport and distribution; and in food preparation. Direct energy includes electricity, mechanical power, solid, liquid and gaseous fuels. Indirect energy, on the other hand, refers to the energy required to manufacture inputs such as machinery, farm equipment, fertilizers and pesticides. The type of energy we use in the agrifood chain and how we use it will in large part determine whether our food systems will be able to meet future food security goals and support broader development objectives in an environmentally sustainable manner.

Over the last several decades, the availability of cheap fossil fuels has made a significant contribution to feeding the world. The ‘green revolution’ of the 1960s and 1970s addressed food shortages, not only through improved plant breeding, but also by tripling the application of inorganic fertilizers, expanding the land area under irrigation and increasing the use of fossil fuels for farm mechanization, food processing and transport (FAO, 2011a). However, cheap energy sources appear to be becoming progressively scarcer and energy markets more volatile, and this has triggered higher energy prices. Our ability to reach food productivity targets may be limited in the future by a lack of inexpensive fossil fuels. This has serious implications both for countries that benefited from the initial green revolution and for those countries that are looking to modernize their agrifood systems along similar lines. Modernizing food and agriculture systems by increasing the use of fossil fuels as was done in the past may no longer be an affordable option. We need to rethink the role of energy when considering our options for improving food systems. Historical trends indicate an evident link between food prices and energy prices (FAO, 2011b). Between 2007 and 2008, world oil prices dramatically increased, reaching close to US$ 150 per barrel at its highest peak (Cleland , 2010**)**. A food sector that is less dependent on fossil fuels could help stabilize food prices for consumers and reduce financial risks for food producers and others involved in the food supply chain.

Energy Security is Important to Food Security

Improving energy access to impoverished communities is essential if the poverty reduction targets set out in the Millennium Development Goals (MDGs) are to be met. Almost 3 billion people have limited access to modern energy services for heating and cooking, and 1.4 billion have zero or limited access to electricity (UNDP/WHO, 2009). Without access to electricity and sustainable energy sources, communities have little chance to achieve food security and no opportunities for securing productive livelihoods that can lift them out of poverty.1 1 Energy services include lighting, heating for cooking and space heating, power for transport, water pumping, grinding and numerous other services that fuels, electricity, and mechanical power make possible.

Today there is a large gap between energy demand and access, and demand will certainly increase as countries develop. Average per capita energy use in low-income countries is a third of that of middle-income countries, which is in turn almost a fifth of per capita energy demand in high-income countries. According to a United Nations Development Programme (UNDP) report on the role of energy in reducing poverty, no country in modern times has substantially reduced poverty without a massive increase in its use of commercial energy and/or a shift to more efficient energy sources that provide higher quality energy services (UNDP, 2009). From a household perspective, access to modern energy services is still extremely problematic in many developing countries. The International Energy Agency (IEA) estimates that a fifth of the world’s population lacks access to electricity, and that two-fifths rely on traditional biomass for cooking (IEA, 2010). The use of traditional biomass in open fires or with simple cooking stoves is not

only less efficient and more polluting than modern energy options, but it is also unreliable,
not easily controllable and subject to various supply constraints. The poor in developing countries pay much more in terms of health impacts, collection time and energy quality for the equivalent level of energy services as do their counterparts in the developed world.

From a rural development perspective, access to energy is fundamental for the provision of goods and services that can improve agricultural productivity and bring new opportunities for generating income. Increasing energy services in rural areas has the potential to spur agricultural development by increasing productivity, for example through irrigation, and improving crop processing and storage. It could also strengthen the development of non-farm commercial activities, including micro-enterprises, and create opportunities for other livelihood activities beyond daylight hours (DFID, 2002). Energy development, especially renewable energy, also has the potential to create green jobs in rural communities, in areas such as fuel crop cultivation and the provision and maintenance of energy services. This will have indirect impacts on agricultural productivity and risk management due to increased household incomes and diversification out of agriculture.

Renewable energies such as bioenergy, solar, wind, hydro and geothermal can be used in agrifood systems as a substitute for fossil fuels to generate heat or electricity for use on farms or in aquaculture operations. If excess energy is produced, it can be exported off the property to earn additional revenue for the owners. Such activities can bring benefits for farmers, landowners, small industries and rural communities. FAO projections indicate that by 2050 a 70 percent increase in food production over 2005-2007 levels will be necessary to meet the expanding demand for food. This is equivalent to the additional production of around 1 000 tonnes of cereals and around 200 tonnes of meat and fish. These production gains are largely expected to come from increases in productivity of crops, livestock and fisheries (FAO, 2009a). Furthermore, as populations expand and economies grow, the global demand for energy and water is also expected to increase by 40 percent (IEA, 2010, WEF, 2007 a&b, 2011).

If the world is to fulfill its commitments to halving hunger and poverty by 2015 and helping low-income countries meet their basic energy needs by 2030, these food, water and energy challenges must be overcome. It is clear that in our efforts to build a world without hunger, we will need more energy. FAO's '*Energy-Smart Food for People Issues Paper'* (FAO, 2011a) provides a comprehensive analysis of the energy status of the food sector from the perspective of demand and supply. It examines in detail energy uses in each of the agrifood chain components and identifies opportunities for implementing energy-smart approaches. The issue paper concludes that higher costs of oil and natural gas, insecurity regarding the limited reserves of these non-renewable resources and the global consensus on the need to reduce greenhouse gas emissions, could hamper global efforts to meet the growing demand for food, unless the agrifood chain is decoupled from fossil fuel use.

Energy, Agri-Food Systems and Climate Change

Primary food production and the food supply chain, including landfill gas produced from food wastes, contribute approximately 22 percent of total annual greenhouse gas emissions (FAO, 2011a). An additional 15 percent of greenhouse emissions results from land use changes, particularly changes linked to deforestation brought about by the expansion of agricultural land (IPCC, 2007). Energy-related carbon dioxide emissions along the agrifood chain are produced from the combustion of fossil fuels to run machinery, generate heat and electricity for food storage and processing, and from the use of petroleum fuels for food transport and distribution (FAO, 2011a). Energy is essential for food security and development, but current food production and energy use patterns are unsustainable if climate change targets are to be met.

FAO's Energy-Smart Food for People and Climate (ESF) Programme

In keeping with the 2011 study's recommendations for a major long-term multipartner programme on energy-smart food systems, FAO's ESF Programme focuses on three thematic areas:
energy efficiency,
energy diversification through renewable energy and
energy access and food security through integrated food - energy production.

The ESF Programme aims to help countries promote energy-smart agrifood systems through the identification, planning and implementation of appropriate energy, food security and climate-smart strategies that spur agricultural growth and rural development (UNEP, 2013). The ESF Programme is currently raising awareness about the dependency of global agrifood systems on fossil fuels, the implications this dependency has for food security and climate and the potential for agrifood systems to alleviate this problem by becoming a source of renewable energy. The Programme is also generating information to fill knowledge gaps.

Energy Consumption and GHG Emissions in the Food Sector

The food sector accounts for around 30 percent of the world's total energy consumption (FAO, 2011a). Primary farm and fishery production2 accounts for around one-fifth of this energy demand. In developed countries,

Figure 16: Indication of Global shares of end-use Energy demands throughout the Food supply-chain

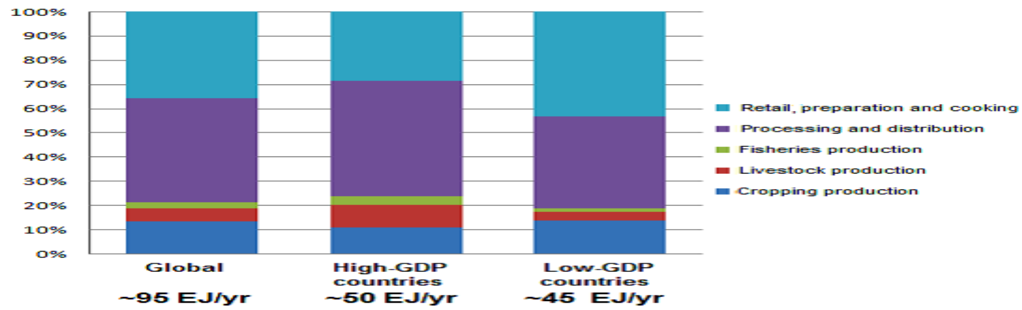
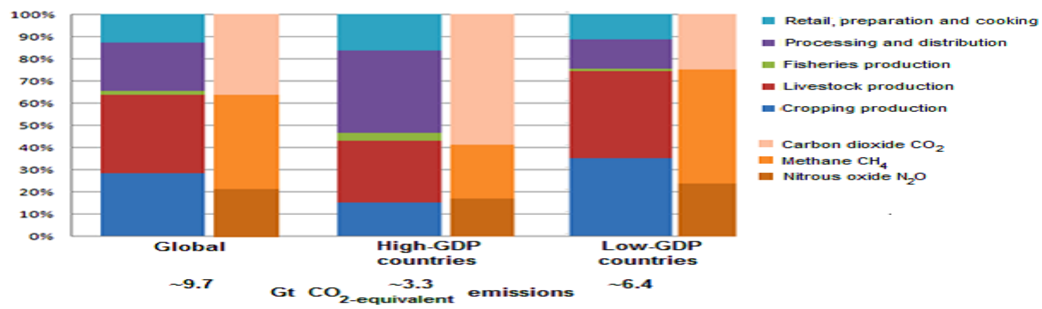


Figure 17: Global shares of GHG emissions along the Food Supply-Chain with breakdown by Gas and also for Developed and Developing Countries



energy used for processing, transport and food preparation is usually around three to four times the amount used for primary production. In developing countries, the energy demand for primary production is typically around 10 percent, for food transport and processing 15 percent, and for cooking and preparation up to 75 percent (Figure 16). Indication of global, shares of end-use energy demands throughout the food supply chain showing total final energy for the sector and a breakdown between developed and developing countries Livestock production shows noticeable differences between developed and developing countries. Developing countries consume around 1 MJ of fossil fuel per MJ of animal product, while developed countries consume around 4.3 of MJ fossil fuel per MJ of animal product. Capture fishing is one of the most energy-intensive methods of food production. The global fishing fleet captures around 80-90 Mt of fish and invertebrates each year and consumes around 620 liters of fuel per tonne of catch.

Small-scale enterprises produce around half of the total fish catch using a fleet consisting of about 4.3 million small vessels. Two-thirds of these vessels are powered by internal combustion engines that run on fossil fuels. The rest of these boats, mainlyin Asia and Africa, use sails and oars (Figure 16).

The entire food chain accounts for around 22 percent of total GHG emissions, including landfill gas produced from food wastes3. Globally, methane from rice paddies and ruminant livestock4 combined with nitrous oxides from nitrogenous fertilizers, soil and animal wastes have a greater impact on climate change than energy-related carbon dioxide emissions.

Primary production accounts for around 14 percent of the total global GHG emissions. This is mainly from methane emissions, which in developing countries are twice as high as those from developed countries. However, when calculated on a per capita basis, emissions in developing countries are considerably lower. A greater share of carbon dioxide emissions come from developed countries. These emissions result from the use of fossil fuels to generate heat and electricity for food storage and processing, as well as for transport and distribution (IPCC, 2007a).

Improving Energy Efficiency in Food Security Systems

Becoming energy-smart involves improving energy efficiency to reduce energy consumption without affecting productivity. For several decades, options for increasing energy efficiency in larger-scale food systems have expanded. However, subsistence farmers in developing countries may have few options to become more energy efficient simply because they have little or no access to energy to begin with.

Energy conservation and efficiency measures can be achieved at all stages of the food chain. These measures can bring either direct savings through technological or behavioural changes or indirect savings resulting from co-benefits derived from the adoption of agro-ecological farming practices.

Conservation Agriculture

Conservation agriculture is an approach to farming that seeks to improve farm management by using crop rotations to enhance the soil nutritional status. It applies principles of soil conservation and usually incorporate zero tillage or low tillage practices. Conservation agriculture lowers the demand for inorganic nitrogen, reduces pests and minimizes soil disturbance. Reduced energy inputs are usually a co-benefit of conservation agriculture. No-till or low-till methods can reduce fuel consumption for cultivation by between 60 to 70 percent (Baker *et al., 2006)*.

These methods also improve soil water retention, reduce soil erosion by incorporating crop residues into the surface and minimize soil carbon losses. Historic carbonlosses through conventional cultivation are estimated to be between 40–80 Gt and are increasing by a rate of 1.6±0.8 Gt per year, mainly in the tropics (GoS, 2011).

Irrigation

The mechanical pumping of water occurs on approximately 10 percent of the world arable land area (around 300 Mha) and consumes around 0.225 EJ/yr. A significant amount of this energy is needed to power pumps (Smil, 2008). In addition, another 0.05 EJ/yr of indirect energy is required to manufacture and deliver 5 irrigation equipment. Irrigated agriculture contributes 40 percent of the world's food (FAO, 2002). In many part of the world, water scarcity threatens agricultural production. There is a real need to lower water intensities in food production. Increasing the efficiency of water use is also energy-smart, as it reduces the demand for pumping. Energy savings from existing irrigations systems can come from improving basic operating conditions, mending leaks and replacing worn or improperly sized pumps. Both water and energy inputs can be reduced by sowing crops to avoid anticipated periods of water deficit and by using mulch. Water management policies that promote the introduction of more efficient irrigation methods, such as precision irrigation, low-head drip irrigation, waste water recycling, are energy-smart.

Fertilizer Use

Energy embedded in the production of inorganic fertilizer is globally significant. Nitrogen fertilizer production alone accounts for about half of the fossil fuels used in primary production (GoS, 2011). Farmers can save indirect energy by reducing the amount of fertilizers applied through more precise applications through the use of computer-aided technologies, such as biosensors for soil fertility monitoring and trace gas detection. In developed countries, since the mid-1980s, a combination of these techniques has achieved significant reductions in fertilizer use. In the USA for example, between 1979 and 2000 fertilizer applications have been reduced by around 30 percent (Heinberg and Bromford, 2008). A shift towards organic fertilizers and the cultivation of nitrogen-fixing plants, can also reduce indirect energy inputs. This would also serve to lower GHG emissions and avoid excess nitrates being discharged into aquifers and surface waters.

Storage and Refrigeration

It is estimated that food storage involves between 1-3 MJ/kg of retail food product (Smil, 2008). The food choice expectations of people living in developed countries are made possible by affordable refrigeration systems across the entire food supply chain. Introducing similar systems for developing countries will be difficult and will require large amounts of energy. Avoiding refrigeration dependence is difficult when economic development depends on exporting food to more industrialized countries. Possible solutions are bulk preservation with transport only to local markets and the use of passive evaporative-cooling technologies rather than active cooling that depends on electricity supply. When they become economically viable, stand-alone solar chillers are another potential option. Refrigerated storage can account for up to 10 percent of the total carbon footprint for some products when electricity inputs, the manufacturing of cooling equipment, and GHG emissions from lost refrigerants are taken into account (Cleland, 2010).

Transport and the Public Distribution

In 2000, over 800 Mt of global food shipments were made (Smil, 2008). Globalization in the past two decades appears to have increased the average distance travelled by food products by 25 percent. Given the fluctuating prices for fossil fuel prices, transport and distribution are particularly vulnerable components of the food chain. Locating production and handling of food closer to areas of high population density can help reduce energy consumption for transport (Heller and Keoleian, 2000). However, since long distance transport by ship or rail can be done at relatively low ratios of MJ per tonne per km, producing specific crops and animal products in locations where productivity is naturally high can lead to energy savings that compensate for the relatively little extra energy required for their transport to distant markets.

FOOD PREPARATION

In developing countries where relatively little energy is used to produce food, the share of energy used in food preparation can be very high. Cooking typically consumes

5-7 MJ per kg of food. However, in developing countries it can be 10-40 MJ per kg (FAO 2011, forthcoming). Traditional biomass used for energy (fuelwood, crop residues and animal dung) is widely used in developing countries for domestic uses, particularly cooking and heating. Inefficient cooking on open fires and the associated health risks from smoke inhalation are well documented. Compared with open fires, the use of more efficient biomass cooking stoves can reduce the demand for traditional fuelwood by half (IPCC, 2011).

Post-Harvest Food Losses and Waste Management

About one-third of the food produced is lost or wasted (Gustavsson *et al*., 2011). These losses occur at all stages of the supply chain, amounting to around 1200 Mt per year. When food is wasted, the energy used to produce the food is also wasted. Overall, the energy embedded in global annual food losses is thought to be around 38 percent of the total final energy consumed by the whole food chain.

Food waste in European and North American countries is between 95 to 115 kg per capita per year. In sub-Saharan Africa, South Asia and South-East Asia where food is relatively scarce, food losses are between 6-11 kg per capita per year.

These losses result from inadequate harvesting techniques, poor storage facilities, limited transportation infrastructure and ineffective packaging and market systems. Financial and technical limitations are hampering efforts to reduce these losses. Educating smallholder farmers on how to reduce food losses could be a relatively cost-effective manner for improving rural livelihoods. But significant work to change consumers' attitude is also needed, and this might prove challenging.

Energy Access to Livelihoods in Food Systems

Both renewable energies and increased energy efficiency can contribute to energy access.

When bioenergy and other renewable energies are available, they can be used locally to supply much needed energy for farming and food processing, alleviate energy poverty and spur rural development. Opportunities exist for the small-scale production of biofuels to power agricultural machinery and vehicles to transport food products to the local market. For example, pure vegetable oil (oil that is extracted from plant material and use as fuel) can be used directly in diesel engines to generate electricity or to run farming equipment.

However, trade-offs may need to be made between optimizing energy efficiency and keeping energy affordable for the most impoverished sections of society, especially in rural areas.

Increasing energy availability can help meet basic human energy needs, provide energy services to support the establishment of small and medium enterprises outside the food sector and help diversify incomes. A balance needs to be found between improving access to new energy sources and increasing the efficiency of existing energies. The decision will depend on local conditions and the economic trade-offs involved in for each option. By subsidizing the retail price paid for imported fossil fuels or by introducing measures that support the deployment of renewable energy technologies in rural areas, governments can help improve access to energy for agricultural communities.

INTEGRATED FOOD-ENERGY SYSTEMS (IFES)

FAO's work on Integrated Food-Energy Systems (IFES) has shown that food and energy can be produced in parallel on farms to meet both energy and food needs. This can be done either through optimizing the use of land by combining energy and food crops or through the optimal use of biomass residues produced in food systems to generate energy (Bogdanski et al., 2010a). These system offer a range of opportunities for fulfilling the three key objectives of energy-smart food systems: greater energy efficiency, increased use of renewable energy and improved energy access. Several types of IFES follow a landscape approach that support sustainable crop intensification and improve energy efficiency in primary production. The IFES framework can also provide a balance between large scale businesses seeking to maximize profit and longterm

mixed farming systems. Such a framework can also be used to develop of regional-scale energy and food production systems. In certain cases, IFES can be implemented without costly capital investment.

Policies Towards more Energy-smart Food systems

Policy-makers need to adopt a long-term view to make the needed paradigm shift to energy-smart food systems. But just because this shift will not be accomplished in the short term does not mean that we can afford to wait. The key question at hand is not, 'If or when we should we begin the transition to energy-smart food systems?', but rather

'How can we get started and make gradual but steady progress?' Political will needs to be mobilized to ensure that key decisions on investment and policies are taken and implemented effectively. FAO is prepared to take a leading role and assist member countries to address the energy-food-climate nexus.

This is why FAO recommends the establishment of a multi-partner programme on 'Energy-smart food for people and climate'. Such a programme would make an important contribution to the recently launched UN initiative 'Sustainable Energy for All' and to the achievement of a 'Green Economy', which will be promoted at Rio+20.

Recognizing Shared Goals

The options for making food systems more energy-smart are intertwined with other development goals. Creating a greater understanding of these mutually supportive relationships can contribute to more coordinated policy formulation among government ministries responsible for food, agriculture, energy, health, transport, economic development and the environment. This multi-sectoral cooperation can advance a holistic landscape approach to energy-smart food systems that link agricultural production and natural resource management with poverty reduction through improved product supply chains.

Building Multi-Stakeholder Dialogue

Existing policy frameworks and national energy policies in developing countries often do not respond to the energy needs and capacities of impoverished communities. Questions related to energy access - Is the energy affordable? Is the technology adaptable? - need to be addressed when developing new policies. From the social perspective, co-benefits, such as heightened security of water supplies, healthier landscapes and greater biodiversity should be also considered in any policy decisions. Land tenure issues also require careful consideration, particularly for bioenergy production. In recent years there has been a growing interest in large-scale land acquisition for securing a future supply of food and for biofuel production (Cotula, et al., 2010). This development has raised concerns about land tenure security, as the most vulnerable segment of the population depend on land and other natural resources for their livelihood and food security. The move toward energy-smart food systems cannot be accomplished without substantive multi-stakeholder dialogue on options for energy production and consumption and the policies and institutional arrangements needed to achieve the desired results.

WATER, FOOD, ENERGY AND THE GREEN ECONOMY

Global warming and other factors have resulted in a strong movement towards a sustainable or ‘green’ economy across all sectors of the world economy. The United Nations Environment Programme defines a green economy as one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. A green economy can be thought of as one which is low carbon, resource efficient and socially inclusive. In a green economy, economic growth is based on sustainable development, with the current focus being on the following six main sectors: Renewable energy;
Green buildings, including green retrofits for energy and water efficiency;
Clean transportation utilising alternative fuels, hybrid and electric vehicles;
Water management, including water demand management and conservation, water reclamation, purification and recycling such as industrial and domestic effluent (grey water);
Waste management, including recycling, municipal solid waste salvage, brownfield remediation and sustainable packaging; and Land management, including organic agriculture, habitat conservation and restoration, urban forestry and parks, reforestation and afforestation and soil stabilisation.

THE WATER-FOOD-ENERGY NEXUS

Climate change will inevitably impact almost every economic sector, but none more so than those reliant on increasing water and energy resource utilisation. The interlinked and complex relationship between water, food and energy is depicted below;

Water, Energy and Food are inextricably linked

Both water and energy are essential to every aspect of life – social equity, ecosystem integrity and economic sustainability. Water is used to generate energy, and energy is used to provide water. Both water and energy are used to produce crops and crops can in turn be used to generate energy through biofuels.

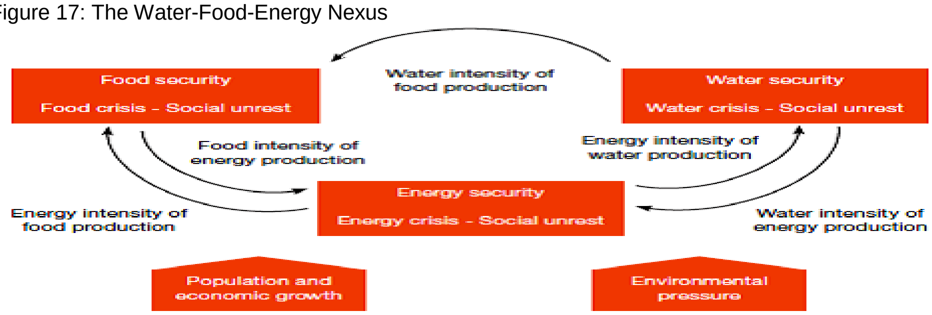
Global Water, Energy and Food Demand are increasing

Water, energy and food demand varies proportionately to changes in income and lifestyle (socio-economic development). At low income levels, energy and water are used for basic needs such as drinking, cooking and heating, and in rural areas also for watering vegetable gardens. But as income increases, people use more energy and water to meet their new lifestyle and dietary needs. In an increasing spiral, growing demand for more energy drives demand for more water, and demand for water drives demand for more energy, while demand for more food drives demand both for more water and energy.

Based on this spiral of cause and effect, the following increases in demand are projected for the year 2030:
Food: 50% (UN Food and Agriculture Organisation);
Energy: 40% (International Energy Agency); and
Water: 30-40% (International Food Policy Research Institute)

Business, in cooperation with civil society, needs to continue to improve its water conservation and efficiency,

Figure 17: The Water-Food-Energy Nexus



Source: World Economic Forum (adapted)

as well as its energy and food production efficiency to enable sustainable growth. The dynamic interaction between society and its energy needs, as well as the constraints of nature, specifically the quantity and quality of water resources, has resulted in the relationship between energy and water use getting more attention from policymakers. Worldwide, they must grapple with measures to transition from heavy dependence on fossil fuels and to aggressively address global climate change by capping carbon emissions.

CLIMATE CHANGE AND WATER AVAILIBILITY

In its report on climate change and water, the UN's Intergovernmental Panel on Climate Change (IPCC, 2011) describes climate change as an 'additional burden' to providing water services. This would appear to be a gross understatement in relation to the accompanying catalogue of potential impacts, which range from 'salinisation of coastal aquifers' to 'different kinds of pollutants' introduced by floods. The IPCC report recognises that developing countries cannot possibly afford expensive adaptation strategies and may have to resort to 'unsustainable practices such as increasing groundwater over-exploitation'.

Climate change could fundamentally alter the delicate ecology of the water cycle, with devastating impact on freshwater dependence. Climate change will most likely:
Increase water demand for agriculture due to prolonged dry periods and severe drought;
Increase water demand for hydration needs for billions of farm animals due to higher atmospheric temperatures;
Increase quantities of water needed for industrial cooling due to increased atmospheric and water temperatures;
Contaminate coastal surface and groundwater resources due to rising sea levels, resulting in saltwater intrusion into rivers, deltas and aquifers;
Increase water temperatures, leading to more algal and bacterial blooms that will further contaminate water supplies;
Increase extreme precipitation and flooding, which will increase erosion rates and wash soil-based pollutants and toxins into waterways; and Contribute to environmental health risks associated with water – for instance, changes in precipitation patterns are likely to increase flooding, and as a result mobilise more pathogens and contaminants.

ADAPTATION AND MITIGATION STRATEGIES

Climate change will have an effect on all spheres of life. Businesses across all industries will face various new risks and constraints due to these effects, necessitating organisations to adopt a new type of risk matrix as well as innovative adaptation and mitigation strategies. In a recent global PwC survey on climate change, Appetite for change: Global business perspectives on tax and regulations for a low carbon economy, the majority of businesses that participated in the survey indicated that:
Government action on climate change will increase the importance of regulatory compliance, reputation management and stakeholder relations;Corporate climate change strategies will affect operations, key performance indicators and innovations around new products and services; and A growing number of businesses are developing strategies to manage the uncertainty surrounding climate change, but they remain hopeful that government and business can work together to create consistent policies that will halt global warming.In order to adapt to climate change and the demands of a green economy, businesses will have to mitigate the risks associated to climate change. These risk mitigation strategies will not only have to deal with the physical attributes of climate change, but will also have to comply with green economy regulations that include aspects such as meaningful emission targets, carbon and environmental taxes, investment and other incentives, as well as the formulation of direction, policies and regulations.

NEW ISSUES OF HUMAN SECURITY: ENERGY-CLIMATE-WATER-FOOD NEXUS

Today, millions of people experience insecurity as a result of new and complex issues threatening human welf

-are and dignity, such as climate change and the contested or inefficient use of energy and water, which are all beyond the original seven human security components *including* economic, food, health, environmental, personal, community and political security that were introduced in the 1994 UNDP Human Development Report.

Energy-Climate Change-Water-Food Nexus

Energy and climate change significantly impact water and food security. From a human security perspective, sourcing energy supplies from fossil fuels (coal, oil and natural gas) and shale gas has been inextricably connected to air pollution, water stress, and global climate change which is linked to extreme weather phenomena that have already killed or affected millions of people around the world. Climate change, a consequence of fossil energy-related carbon emissions, remains a challenge to water and food security as well. It endangers mountain glaciers, which serve as the world's biggest freshwater banks, feeding rivers and supplying water to two billion people in Asia alone. It causes agricultural drought and undermines water supplies from reservoirs and rivers that are used to irrigate farmlands. Worsening water scarcity could trigger significant annual grain losses affecting world food production and consumption. Severe weather phenomena, such as storms, could destroy food transport and distribution infrastructure resulting in the disruption of food supply chains and affecting food access and availability.

Reducing overreliance on high-carbon energy sources is central to climate change mitigation strategies. Yet energy remains crucial in ensuring water and food security. Production and distribution of modern freshwater systems for agricultural purposes requires a substantial amount of energy. High efficiency irrigation systems may save water but may also lead to higher energy demand. Moreover, while intensive water irrigation boosts food production, it can also undermine river flows and reduce water supply for hydropower dams. Rising energy prices could also affect food production, trigger food price volatility, and compromise availability and access to food. One instance of this was the rapid energy price hike in 2006/2007 which partly caused a food price crisis in 2007/2008. It was the oil price hikes which heightened the costs of food production (e.g., fertilizers and other crop production facilities) and the food supply chain (transports and packaging) which both require petroleum or natural gas to sustain production and consumption. Indeed, this illustrates the complex interplay of the rising demand for energy and the impacts of climate change on water and food security (UN Water, 2014).

Broadening and Deepening Human Security Paradigm

While the international community recognises the interconnectedness of energy, climate change, water and food, these challenges currently remain addressed in isolation. The human security paradigm facilitates a comprehensive approach through enhanced dialogue, collaboration and coordination amongst the non-state, national and multilateral actors, ensuring that co-benefits and trade-offs are contemplated and that pertinent safeguards are institutionalised. In the context of the post-2015 development agenda and in light of relevant initiatives to set a unified development agenda via sustainable development goals, it is hoped that the broad and deep application of the human security approach can help galvanise non-state, national and multilateral efforts to effectively address emerging human security issues (UNEP, 2013**)**.

NEXUS OVERVIEW AND THE FRAMEWORK

A recent initiative led by the World Bank entitled *'Thirsty Energy'* aims to support its client countries in addressing issues surrounding the energy-water part of the nexus. The publication provides a general overview of the global challenges and trade-offs involved in the energy-water nexus. It investigates the water requirements of different power generation options, but does not provide much in the way of technical data on these water requirements of different energy technologies. However, the report does provide a clear, basic description of the various types of cooling systems used in power plants. It highlights potential technical and institutional solutions for improving management of the nexus, including a summary of alternative power plant cooling systems to reduce water use, alternative water sources to fresh water and integrated water and energy planning. The report concludes that "integrated energy-water modelling allows resource planners to consider whether water supply today and in the future will be sufficient to meet the cooling requirements of different power plants" (World Bank, 2010, 2013).

The United Nations (UN) 'World Water Development Report (WWDR)-2014' was launched recently which includes a publication on the energy-water nexus. This report provides probably the most extensive analysis of the nexus within the literature to date, drawing upon information, data and analyses from a broad range of literature on the subject. The report investigates water demands, energy requirements for water provision, water availability, and the demand for water from power generation. It also expands the nexus to include issues related to food and agriculture, broadening the scope of the nexus. Furthermore, the WWDR examines regional aspects relating to the water-energy nexus. It suggests that the public policy response to the interconnectedness of energy and water, and related domains, requires a hierarchy of actions aimed at creating an enabling enviro

-nment to allow the changes necessary for the development of water and energy resource systems to be implemented. These actions include: coherent policy development; legal and institutional frameworks to promote coherence; ensuring reliable data and statistics to make and monitor decisions; encouraging awareness; supporting innovation and research into technological development; making sure finance is available; and allowing markets and businesses to develop (UN, 2014). The report also concludes that there is a marked difference between the speed of change within the two domains of water and energy. The energy sector is driven by evolving markets and technological development, and energy issues are high on the political agenda. The report suggests that actors in the water sector need to increase their governance reform efforts, otherwise the sector will suffer as a result of direct pressures from the energy sector. These failures in the water sector could then perversely lead directly to failures in energy and other related sectors.

The International Energy Agency (IEA, 2012, 2013) *'World Energy Outlook 2012'* report dedicates a chapter to the energy-water part of the nexus. Chapter 17 of the report investigates issues such as global water requirements for energy production and the availability of water in different geographical regions of the world, under the different future IEA energy scenarios, indicating 'regional stress points' for water. The Chapter also provides a clear summary of the different cooling techniques used in thermal power generation, and how the differences between these techniques impact water withdrawal and consumption factors. It gives a visual overview of the water use of different primary energy production sources and electricity generating technologies (in turn split by the cooling system used).

It shows some useful examples of the water impacts of power production in different regions of the world, which emphasises the current and growing importance of the nexus especially in those regions.

The report suggests that a more water-constrained future due to population growth, global economic growth, and climate change, will impact reliability and costs in the energy sector. It suggests that the water requirements of fossil fuel-based and nuclear power plants can be reduced substantially with the adoption of advanced cooling systems, but this will be at the expense of increased capital costs and lower plant efficiency.

Furthermore, it concludes that energy efficiency, wind and solar PV can contribute to a low-carbon future without significantly putting further pressure on water resources.

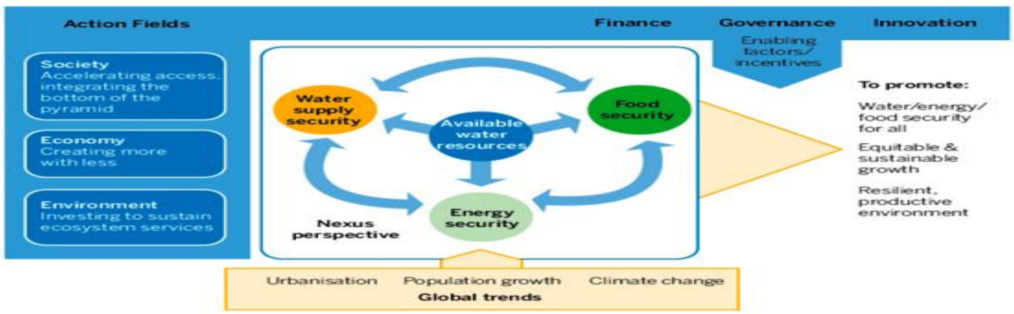
Moreover, regional availability and access to water may become a more serious issue for unconventional gas and power development in China and the United States, fossil fuel-based power plants in India, production in the Canadian oil sands, and maintaining reservoir pressures supporting oil output in Iraq.

The Stockholm Environment Institute (SEI) report '*The Water, Energy and Food Security Nexus: Solutions for the Green Economy',* gives a broad understanding of how the nexus approach "…can enhance water, energy and food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors" (SEI, 2011). The paper is an attempt to fill some of the knowledge gaps surrounding the nexus, and presents an array of opportunities available for improving energy, water and food security by using a nexus approach.

The World Energy Council Report in 2010, entitled *'Water for Energy',* inspects the energy-water part of the nexus assessing the scale of the challenge and the steps that need to be taken to ensure that water is available for energy demands. It includes data on the water requirements of energy technologies and regional water needs. The report concludes that we can probably meet the future water demands of energy production, but we need water issues to be integrated into policy-makers decisions, and a new paradigm of international cooperation between governments, between businesses, and between governments and businesses. 10 The 'Water Security: The Water-Food-Energy-Climate Nexus' book, launched in 2011 by the World Economic Forum (WEF, 2011) draws upon a range of viewpoints (from Non-Governmental Organisation's (NGOs), academics, entrepreneurs, etc.) to identify the challenges we face in managing the world's future water needs, and the implications of these challenges to our social, political, and economic well-being if we fail to take action. It seeks to deepen the understanding and raise awareness of the nexus, and examines solutions to the global water scarcity issue.

A 2012 Chatham House Report entitled 'Resources Futures' offers a general perspective on the global linkages between resource systems emphasising that the world is experiencing intensified resource stress. The report highlights the attention given to the nexus of energy, water, and food, and how integrated resource management and governance is advocated across sectors and regionally. While the report doesn't give any new insights into the nexus itself, it does confirm that natural resource systems are under increasing pressure from global, structural forces such as the interconnectedness of the resource systems themselves, and the distribution of power and income across the world. The GRACE Communications Foundation report, released in 2013, 'Food, Water and Energy: Know the Nexus' incorporates the food dimension into the nexus and focuses upon how research on the subject is being addressed in the United States. It provides a broad overview of the three elements of the nexus, but does not provide much in the way of data or analysis. Water withdrawals for energy, and industrial processes and municipal applications, are projected to grow considerably over the next decades, jointly surpassing

Figure 18: The Nexus Framework



Source: SEI, 2011.

irrigation as the primary water user by 2050 (Bruinsma, 2011). The interdependence between energy, water and food is considered to be of increasing importance within the literature, even though research in the area is still limited. Figure 18 below provides a visual representation of the nexus framework and how water availability is crucial in determining Energy and Food security.

Much of the current literature highlights world population and economic growth projections, as well as changing lifestyles and consumption patterns, as the crucial factors leading to an increase in demand for energy, water and food resources in the future (SEI, 2011; IEA, 2012). There is also a rapidly growing global middle-class, particularly in emerging economies. In Asia alone, this sector of society tripled in size between 1990 and 2005 to 1.5 billion people. The consumption patterns of this growing middle-class are in particular putting increased pressure on the world's resources, including energy, water and food. Developing country economic growth is expected to be the main global driver of resource demand, averaging 6% compared to 2.7% in developed countries (World Bank, 2013). The Food and Agriculture Organisation (FAO) has estimated that feeding a population in excess of 9 billion by 2050 will require a 60% rise in agricultural production and 15% increase in water withdrawal (FAO, 2011). Total global water withdrawal is expected to increase by around 55% by 2050, placing more pressure on fresh water availability and leading to projections of more than 40% of the population living in areas of water stress by 2050 (UN, 2014).

Energy and Water Nexus

1.3 billion people in the world still do not have access to electricity (IEA, 2012). Worldwide energy consumption is projected to increase by almost 50% by 2035, and electricity demand is expected to grow by approximately 70% by 2035 (UN, 2014). Most of this increase will be in non-OECD countries (IEA, 2012). According to the IEA 'reference scenario', which projects current energy trends into the future; China, India and the Middle East would double their primary energy demand by 2035, while demand in Africa and Latin America would increase by around 40%. It should be noted, however, that there are other scenario projections in the literature that suggest a significant reduction in energy demand growth rates due to intensive demand management measures being adopted (WWF, 2011).

The declining availability of fresh water will have an increasing impact on the energy sector. According to the OECD, the energy sector required 15% of global fresh water withdrawal in 2010 (OECD, 2014). By 2030, global demand for water, including from energy, is predicted to outstrip supply by approximately 40% (World Bank, 2010). More recent estimates by the World Energy Council (WEC) have indicated that emerging economies such as China, India and Brazil will double their energy consumption within the next 40 years. The amount of electricity generated in Latin America is expected to increase fivefold over the next 40 years, tripling the amount of water required (WEC, 2010). The water footprint of different energy sources can therefore be expected to become an increasingly competitive issue especially in regions where water stress is more pronounced. For example, a recent study by the World Resources Institute (WRI) suggested that more than one-third of commercially viable shale gas deposits worldwide are in areas that are either dry or have water supply constraints. Out of 20 countries in the WRI study, 8 have deposits of shale gas in areas that face either 'high' or 'extremely high' water stress. The projected increase in the demand for energy will inevitably place increasing pressure on water withdrawal and consumption, predominantly via cooling systems in thermal power generation, but also via non-conventional power sources, in particular hydropower and biofuels. A large increase in the contribution of biofuels to total energy supply would place high demands on land and water resources.

Bioenergy and Water Nexus

Bioenergy is generated from biomass e.g. agricultural crops, forestry products, agricultural and forestry wastes and by-products, manure, microbial matter, and waste from industry or households. Bioenergy includes different forms of energy including heat and electricity from burning biomass, and biofuels. First generation biofuels are produced using the starch, sugar, or oil from a crop. Second generation biofuels are generated from feedstock such as crop wastes or forestry residues. Third generation biofuel is the production of biodiesel from algae (IEA, OECD, 2013). The IEA and OECD Joint Research Centre (JRC) report ‘Bioenergy and Water’ highlights that sustainable water management is essential in the development of bioenergy, while taking into consideration a global increase in food production over the coming decades, and other uses of water resources. The IEA Technology Roadmaps of ‘Bioenergy for Heat and Power’ and ‘Biofuels for Transport’ suggest that primary bioenergy supply could increase from 50 Exa Joules (EJ) today to some 160 EJ by 2050. By 2050 bioenergy could provide around 7.5% of global electricity generation; heat from bioenergy could provide 15% of final energy consumption in industry and 20% in the building sector; and ECN-E--14-046 Nexus overview 13 biofuels could provide 27% of world transport fuels (IEA, OECD, 2013).

The Technology Roadmaps indicate that energy from biomass has the potential to contribute heavily to greenhouse gas (GHG) reductions leading up to 2050 and beyond (as much as 3.6 Gt CO2e per year in 2050 compared to a business-as-usual scenario (IEA, OECD, 2013)). This will be dependent upon the type of feedstock used, and how efficiently and sustainably it is produced.

Demand for bioenergy adds to the pressure on water resources particularly in important agricultural areas of the world where water scarcity is a concern, for example in India and China. Water scarcity could be a major barrier to bioenergy expansion (Berndes, 2002; Gerbens-Leenes et al., 2008).

However, there are also opportunities for producing bioenergy in areas where water scarcity is more pronounced, which may open up new opportunities to improve the productivity of water use (Berndes, 2008).

The impact of bioenergy development on water will depend heavily upon the types of bioenergy system that are adopted. Using residues and by-products from agriculture and forestry, and organic consumer waste for bioenergy has clear efficiency advantages because the same water is being used to produce the waste, residues, and by-products as is used to produce the bioenergy. Currently, these resources constitute a large proportion of available biomass for energy, but they are unlikely to meet biomass demand in the future.

IPCC energy scenarios suggest bioenergy deployment levels in 2050 of between 80 to 150 EJ per year for a 440-600 parts per million (ppm) CO2e atmospheric target to be met, and 118 to 190 EJ for a less than 440 ppm CO2e target. The energy content in the global harvest of major crops (cereals, oil, sugar, roots, tubers, and pulses) is only approximately 60 EJ per year. This suggests that there is a significant gap, which indicates that a major part of the supply of bioenergy feedstock would have to be produced specifically for bioenergy needs. This has implications in terms of additional water requirements in order to grow the feedstock.

Technological advancements in water management and agricultural productivity offer potential ways to improve water conservation, and bioenergy may offer opportunities in terms of new types of crop production that use water more efficiently. Water use efficiency varies depending on the crop type due to varying climatic conditions, growing periods and agronomic practices (IEA, OECD, 2013). The demand for bioenergy can be met while improving water availability and use. For example, where water scarcity prevents the growth of sufficient conventional food and feed crops, plants that are tolerant to such arid conditions can be cultivated instead; and plants that can grow in conditions of high salinity are also being investigated as bioenergy crops. There is considerable scope globally for bioenergy development to improve the productivity of water, and policy should be developed to promote optimal use of land, water and biomass to meet the combined demands of food, materials and energy demands (IEA, OECD, 2013).

A particularly policy relevant question highlighted in the JRC paper is whether, and to what extent, water should be used for food, fibers or fuel (IEA, OECD, 2013). In areas where population is rising rapidly, such as China and India, this question is even more relevant due to the increasing demand for food. Bioenergy production requires large amounts of water which makes that water unavailable for food production; therefore there is an important trade-off to consider for policy-makers in these sectors.

Alternative renewable energy sources have lower water footprints; the water footprint of bioenergy is much larger than for fossil, nuclear, wind and thermal solar energy (IEA, OECD, 2013), but if bioenergy development is the chosen pathway then feedstock should be produced in a way that limits its water footprint.

Another report entitled ‘The Bioenergy and Water Nexus’ (UNEP, Oeko-Institut and IEA Bioenergy Task 43, 2011) investigates how the production and use of bioenergy products is likely to influence water resources in the future, and how society can mitigate the impacts by sustainably developing the use of these resources. The report examines the impact that bioenergy feedstock production and conversion may have on water resources. It makes several recommendations of how to manage water resources going forward, including taking a holistic approach and long-term perspective; designing and implementing effective water-related policy instruments; basing decisions on impact-assessments to ensure sustainable water management; and promoting technological development to help mitigate pressure on water resources. The report highlights that further research is needed on the subject including filling gaps in data especially in developing countries.

Wind Energy and Water Use Efficiency

The link between energy and water could be viewed by analysts in several different ways. For example, to some it may mean that wind turbines can be built on dikes or dams. However, here we focus on the water use of wind energy, a technology which uses virtually no water. In fact replacing thermal and nuclear power stations with wind energy could be one potential method of conserving water. Wind energy avoided 387 million m^3, avoiding costs of up to EUR 734 million, in Europe in 2012 alone. According to the European Commission's (EC) 2050 Energy Roadmap projections, in 2030 wind energy will avoid between 1.22 and 1.57 billion m^3 of water, and avoid costs of water use of between EUR 3.34 and 4.4 billion (European Wind Energy Association (EWEA, 2014). Non-thermal technologies, such as wind, have the lowest operational and lifecycle water consumption per unit of electricity generated. Wind turbines usually only require small amounts of water for cooling purposes (generator, transformer, inverter) and blade washing (DOE, 2006), and even then the blades can be washed by the rain (EWEA, 2014). Figure 19 shows the potential water use that can be avoided by deploying wind at a rate that is aligned with converting to renewables on a scale projected by the EC's Roadmap for 2050.

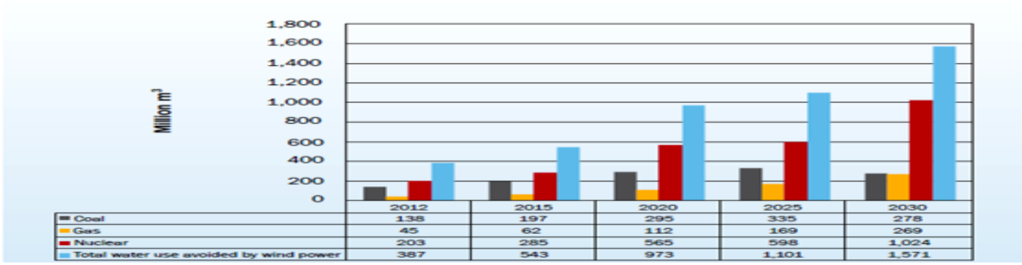
Due to the fact that, especially in some regions, water-scarcity is of growing concern intensified by population expansion and climate change, the water savings that wind energy can provide offers opportunities for using wind as an alternative energy source in areas where conditions for wind energy generation are favorable.

The Water-Energy-Food Nexus in the context of Climate change

Rainfall projections for the country predict a change in rainfall intensities characterised by the decreased frequency of low-intensity rains and longer dry periods between rainfall events (Christensen et al. 2007). These changes increase the likelihood of floods and droughts. Downscaled climate models suggest higher precipitation in the east of the country, a shorter winter season in the southwest and less rain in the far west (Hewitson et al. 2005). Projections by the UK Met office (2011) suggest as much as a 20% decrease in the far west and overall projects a general decrease in rainfall. This is of specific concern, given that South Africa is approaching physical water and has developed most of its water resources. Moreover, the availability of natural water resources across the country is very unevenly distributed, with more than 60% of the surface flows arising from only 20% of the land area (Basson et al. 1997). In simple terms, most rainfall is taken up as green water (the rainfall absorbed by plants and the soil), thus impacting dryland agriculture, whereas blue water (the rainfall in water bodies and groundwater) impacts the energy system, water infrastructure, irrigation and food processing. Although stress on the blue water system is better understood, most rainfall is stored as green water and the impact of less green water may put further pressure on blue water reserves as irrigation becomes more prevalent. Evapotranspiration rates increase with rising temperatures, changes in radiation, humidity and wind speed, which can reduce the water available in reservoirs and reduce the green water available to agriculture (Milly et al. 2008). While there are few direct impacts, rising temperatures will result in increased evapotranspiration rates which could increase the amount of water lost in cooling (mainly applicable to coal and nuclear power plants). Renewable energy has lower water usage requirements, which will be an important consideration for future energy planning in waterscarce areas of the country. Changes in wind patterns, cloud cover and rainfall can impact on renewable energy production, with hydropower particularly vulnerable to a drier future climate. Indirectly, climate change can increase the amount of energy required by the country as a result of adaption policies. Increased irrigation, for example, is a likely response to reduced water supplies in areas where rainfall is expected to decrease. Similarly, hotter temperatures will increase the demand for air-conditioning. Some adaptive strategies will have trade-offs. For example, biofuels require additional water to grow the plant feedstock and take arable land away from food production. The inter-relationship betwwn Energy and water in the context of Climate chage is illustrated in Figure 20

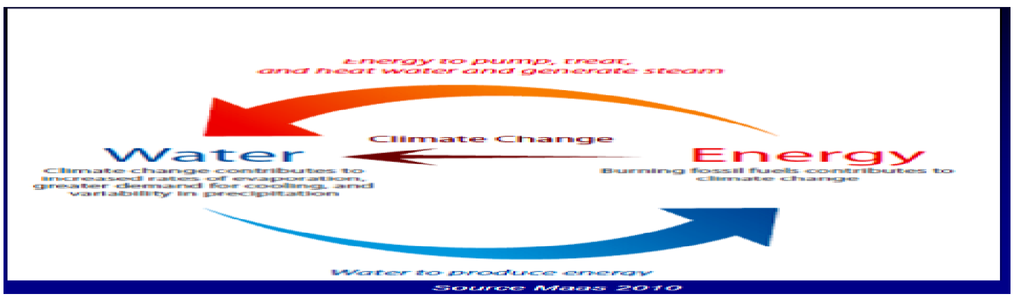
The most direct impact climate change is expected to have on food security is through changes in crop and livestock productivity. Higher temperatures and humidity are known to reduce yields of agricultural crops and tend to encourage weed and pest proliferation. Higher CO_2 concentrations favour weeds more than agricultural crops. For climate variables such as rainfall, soil moisture, temperature and radiation, crops have thresholds beyond which growth and yield are compromised (Porter & Semenov 2005). For example, cereals and fruit tree yields can be damaged by a few days of temperatures above or below a certain threshold (Wheeler et al. 2000). A vast body of studies and assessments (Chijioke et al., 2011; FAO, 2008; HLPE, 2012) has illustrated how climate change is likely to affect food security). Agricultural production, prices and infrastructure will change, limiting the amount and quality of food produced (Wlokas 2008). Rising temperatures and changes in rainfall patterns have a direct effect on

Figure 19: Avoided Water use by Deployment of Wind Energy by 2030: EC's Roadmap for 2050.



Source: EWEA, 2014.

Figure 20: Inter-relationship betwwn Energy and Water in the context of Climate Chage



crop yields, as well as an indirect effect through changes in the availability of irrigation water. In the context of South Africa, a study by the UK Met Office (2011) showed that there has been widespread warming over South Africa since 1960 in both summer and winter, and that between 1960 and 2003 the number of warm days and nights became more frequent while cool days and nights became less frequent. This confirms that there is already a discernable warming trend.

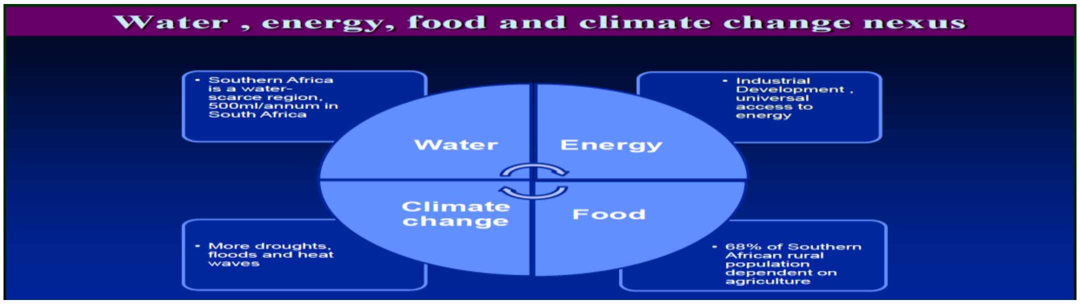
Research on climate change also shows that a sharp increase in temperature is already being experienced in the Western Cape Province. Future climate projections show that this upward trend is expected to continue and that rainfall is expected to decline or to be distributed differently throughout the seasons (Provincial Government of the Western Cape, 2011). There are also indications that climate change could cause increased variability of rainfall over the eastern parts of the country (mainly subtropical wet zone), and a further decrease in rainfall from the west (desert and arid zones) and over the Western Cape region (winter rainfall zone) (DWAF 2002).

Warmer climate conditions may necessitate allocating a higher proportion of water resources to agriculture. The country already has a relatively low allocation of 60% of total water available for agriculture, compared with a global average of 70%. Finally, variations in rainfall patterns increase the likelihood of short-run crop failures and long-run production declines. The inter-relationship amongst water,energy, food and climate change is shown in Figure 21.

FOOD, AGRICULTURE AND WATER RELATIONSHIP

Food production and its associated supply chain account for approximately one-third of the world's total energy consumption (UN, 2014). Although water productivity varies widely among different crops, as a rule of thumb to produce 1 calorie of food energy takes on average approximately 1 liter of water (FAO, 2009). Water consumption via agricultural processes is projected to increase by approximately 20% by 2050 (UN, 2014), which will inevitably further increase the stress on available water resources. Furthermore, modernisation and developments in the agricultural industry have served to intensify agricultural processes, which have in turn increased the energy-intensity of the sector. In its *'Understanding the Nexus'* report, SEI explains the strong correlation between crop and oil prices, which reflects the energy dependency of agriculture (SEI, 2011). Agriculture and food are closely linked to bioenergy and future planning for each of these sectors has implications for the others. The water demands of bioenergy are heavily dependent on the growing and processing of feedstocks such as crops, which in turn has implications for agriculture, land use and food. Growth of feedstocks for bioenergy is in direct competition with food production, and the intensity of this competition will increase as

Figure 21: The Inter-relationship amongst Water, Energy, Food and Climate change



Source: SEI, 2011

demand for food increases along with a growing world population. However, there are also synergies between bioenergy and food production systems that can bring about win wins for both the energy and food sectors (UNEP, Oeko-Institut and IEA Bioenergy Task, 43, 2011).

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