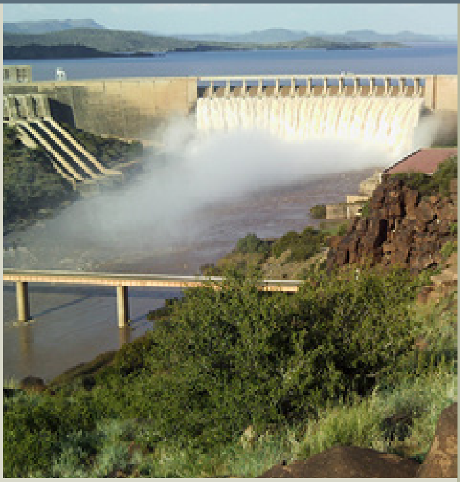
Summary for Policymakers

# Mitigating Risks and Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries



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# Mitigating Risks and Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries

## Summary for Policymakers

PREPARED FOR THE

United Kingdom Department
for International Development

BY THE

Sustainability Institute and School of Public Leadership
Stellenbosch University, South Africa

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**DECEMBER 2015**

The **Department for International Development** (DFID) leads the UK government's fight against world poverty. Through its network of offices throughout the world, DFID works with governments of developing countries, charities, no-government organisations, businesses and international organisations, like the United Nations, the European Commission and the World Bank, to eliminate global poverty and its causes. DFID's work forms part of a global promise, the eight UN Millennium Development Goals, for tackling elements of global poverty by 2015. DFID's Climate and Environment Department (CED) is helping to establish DFID as a world leader in demonstrating results, impact and value for money from supporting developing countries to tackle climate change. CED's goal is to demonstrate that low-carbon, climate resilient and sustainable development is necessary and achievable.

The **School of Public Leadership** (SPL) at Stellenbosch University provides solutions through unique research, graduate, postgraduate and executive programmes adding public value for the public good within a global and African context. The SPL relates dynamically, intellectually and professionally to the three pillars of effective and ethical public leadership – good governance, environmental management and sustainable development. Rigorous research is the proven method of finding solutions to global, national and local challenges at the SPL.

The **Sustainability Institute** (SI) was established in 1999 as an educational institution to advance learning for sustainable living. Located in the Lynedoch Eco-Village near Stellenbosch, it focuses on combining practice with theory in a way that integrates ecology and equity in support of a sustainable South Africa, with special reference to reducing and eradicating poverty. The SI has built a name for itself through its Masters Programme in Sustainable Development Planning and Management, offered in partnership with the SPL at Stellenbosch University. SI Projects is a business unit of the SI that offers its clients sustainability expertise shaped by the insights generated through the Masters programme and the latest research conducted by its students and associates.


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The authors wish to thank the Department for International Development for funding this research project. We are grateful to several reviewers for their helpful comments and suggestions for improvement, including Professor Tim Benton (Leeds University), Professor Nilay Shah (Imperial College), and Mr Simon Ratcliffe (DFID). However, the authors are solely responsible for any errors or omissions and for the views expressed in the report, which should not necessarily be attributed to the Department for International Development, the Sustainability Institute or Stellenbosch University. This Summary for Policymakers is a condensed version of the full report, which contains extensive referencing to the academic and policy literature.

# Contents

# Abbreviations

| | |
|---|---|
| DFID | Department for International Development [United Kingdom] |
| FISP | Fertilizer Input Subsidy Programme |
| FAO | Food and Agriculture Organization [United Nations] |
| GDP | Gross Domestic Product |
| GNI | Gross National Income |
| IPCC | Intergovernmental Panel on Climate Change |
| IEA | International Energy Agency |
| IRENA | International Renewable Energy Agency |
| LIC | Low-income country |
| LMIC | Lower-middle-income country |
| PPP | Purchasing Power Parity |
| PV | Photovoltaics |
| UNEP | United Nations Environment Programme |
| UMIC | Upper-middle-income country |
| US$ | United States Dollar |
| WEF | World Economic Forum |
| WDI | World Development Indicators |

# Units of Measurement

| | |
|---|---|
| Kcal | Kilocalories |
| kg | Kilogram |
| km | Kilometre |
| $km^2$ | Kilometres squared |
| kWh | Kilowatt hours |
| $M^3$ | Cubic metres |

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# EXECUTIVE SUMMARY

## Introduction

- In an increasingly resource-constrained world, the energy-food-water 'nexus' – defined as the interconnections among these three systems that are vital for human survival – is emerging as increasingly important in the discourse on sustainable development.
- Treating energy, food and water systems independently of each other can result in critical system linkages and vulnerabilities being underappreciated and can possibly lead to the formulation and implementation of ineffectual or even counterproductive policies and measures.
- The overarching aims of this study are: (1) to understand the dynamic interactions occurring among energy, food and water systems with a view to identifying the key vulnerabilities and risks facing developing countries in terms of nexus security; and (2) to inform planning and policy in developing countries to mitigate these risks and to promote economic efficiency, social equity and environmental sustainability in food, energy and water provision to their citizens via a transition to more sustainable and resilient systems.
- The analysis is conducted at a global scale and also within three country case studies that represent agrarian, industrial and 'ecological' socioecological regimes.

## Linkages and Drivers in the Energy-Food-Water Nexus

- Energy, food and water systems need to be understood in terms of their entire value chains, including production, processing, storage, distribution, consumption and waste disposal stages, and their supporting infrastructures.
- Energy inputs – most notably petroleum products and electricity – are required at all stages of the food system value chain, as well as at various stages of the water system. Water is essential for agricultural production and food processing, and for various forms of energy production and power generation. A number of agricultural crops are converted into bioenergy. Certain energy industries and high-input agricultural production can have adverse impacts on water and soil quality.
- Demand-side drivers acting on the nexus include population growth, economic growth, rising affluence, shifting consumption patterns, urbanisation and globalisation. Supply-side drivers include the depletion of conventional fossil fuel reserves (resulting in increasing reliance on more polluting and water-intensive unconventional oil and gas resources), and the degradation of soils, fresh water supplies and ecosystems. Climate change is anticipated to exert increasing pressure on water resources and have destabilising impacts on agricultural production and certain forms of energy generation.
- Malawi illustrates a largely agrarian regime that depends mainly on low-productivity, rainfed agriculture and biomass energy, with low rates of access to electricity, adequate nutrition and improved water sources.
- South Africa illustrates an industrial regime that depends heavily on fossil fuels to power high-input, mechanised agriculture and industries, and complex water supply infrastructures. The fossil energy-intensive food and energy systems pose severe threats to the quality of water resources they depend on.
- Cuba illustrates aspects of an emerging 'ecological' regime that includes extensive agroecological farming and growing use of renewable energy sources, but has weaknesses in terms of reliance on imported grains and liquid fuels.

## Nexus Risks and Vulnerabilities

- The major catalytic risks to nexus security are: (1) extreme weather events including droughts and floods; (2) oil price shocks; (3); food price shocks; (4) geopolitical tensions; and (5) financial speculation in commodity markets.

- Nexus impacts and vulnerabilities do not result only from local causes; they can come about due to 'societal teleconnections', i.e. long-distance relationships such as the embeddedness of individual countries within integrated international trade and financial systems.
- Nexus linkages and feedback loops create a web of interconnecting – and reinforcing – risks and impacts. One likely end result of these threats to food, energy and water security is heightened social instability within countries and regions.
- The risks and vulnerabilities faced by rural dwellers can differ considerably from those encountered by their urban counterparts.
- Agriculture plays a dominant role in most low-income country (LIC) economies. The high levels of dependence on traditional biomass energy means that LICs are vulnerable to deforestation, energy poverty (especially a lack of access to electricity) and low-productivity agriculture.
- Lower-middle-income countries (LMICs) are at varying stages of transition from the biomass-based agrarian regime to a fossil fuel-based industrial regime, and there is a great deal of variability in the nexus indicators across this diverse group of countries.
- Most upper-middle-income countries (UMICs) are performing quite well in terms of basic energy, food and water security access and availability/consumption, with the exception of several southern African nations that have high levels of income inequality and poverty. The level of dependence on fossil fuels – and thus exposure to oil price shocks – is very high in most UMICs.
- There is a high degree of variability in the values of many of the indicators across countries, even within each of the three income categories. Key indicators of availability of and access to energy, food and water are quite strongly related to the level of income per capita and inversely related to the poverty rate. However, many of the other nexus risks and vulnerabilities are spread widely and unevenly across countries depending on local context.

### Policy Recommendations for Resilience and Sustainability

- Nexus mitigation strategies should begin with efforts to build well-functioning institutions, effective governance systems and integrated policy frameworks, as these are prerequisites for the design of effective policies and the implementation of viable technical solutions to tackle nexus risks and vulnerabilities. Both vertical and horizontal coordination within governments is essential to ensure better policy coherence and effectiveness, while cooperation must be sought with stakeholders from all sectors of society to ensure sustainable and equitable governance of resources.
- Individual nations must devise strategies to build resilience to teleconnection impacts arising from their embeddedness in global trading systems and should engage in multilateral forums to improve international policy coordination in managing the nexus.
- Individual nexus interventions will be much more coherent and effective if they are designed and implemented within an overarching paradigm aimed at a transition to 'inclusive green economies'. This involves expanding access to food, water and energy services while transforming economic systems to be more resource efficient, less carbon intensive, and less damaging to the environment.
- Policy instruments include public investment infrastructure and innovation, economic incentives such as taxes and subsidies, regulatory mechanisms such as efficiency and emission standards, and education and awareness programmes.
- A wide range of technical measures can be adopted to mitigate nexus-related risks and improve energy, food and water security in developing countries. For example, an expansion of small-scale agroecological farming can help to reduce reliance on energy in agriculture. A transition to renewable energy sources – especially solar photovoltaic, wind and geothermal power – can help to reduce the water dependence of energy systems. Protecting and restoring ecosystems such as wetlands can help to boost water security.
- There can be significant spatial differences in appropriate nexus mitigation strategies and policy interventions. In rural areas, the key issue is optimising land use to provide a range of services, while in urban areas the emphasis is on creating resource-efficient, low-carbon cities.
- The main priority for countries with a largely agrarian regime is to expand access to food, energy and water among their populations, while limiting negative impacts on ecosystems.
- In countries with largely industrial regimes that rely heavily on fossil fuels, the key nexus security challenges are to limit the vulnerability to international energy price volatility, reduce

energy and resource intensity, and reduce the negative impacts of fossil fuel use on soils and water resources.

- Cuba provides an example of a country that achieved a significant reduction in the energy intensity of its food system while increasing nutritional quality and quantities, through concerted policy actions and positive social responses.

## Conclusions

- The risks inherent in energy-food-water nexus interconnections are likely to intensify in the coming decades as a result of growing demand, tightening resource constraints, and intensifying impacts of climate change.
- Nexus mitigation interventions will form a critical part of societal transitions toward greater resilience and sustainability in the face of global and local environmental, resource and population pressures.
- Policy interventions should aim to identify win-win solutions that harness synergies and maximise co-benefits across the energy-food-water nexus.
- Policymakers must deal with unavoidable trade-offs by assembling relevant scientific information and involving stakeholders in consultative processes to inform policy decisions.
- There is considerable scope for more specific and detailed research and policy formulation in the developing world, especially at the country level but also at regional and global levels.

# 0. INTRODUCTION

## 0.1 Rationale and Overview of the Nexus

The issues of energy, food and water security have recently risen to global prominence as they affect increasing numbers of people in an interconnected world. All individuals and societies rely on energy, food and water to survive and prosper, and yet there are hundreds of millions of people who lack reliable access to these basic necessities in sufficient quantities and of adequate quality. Furthermore, it is anticipated that demand for energy, food and water will grow strongly in the coming half-century, driven by population growth, economic growth, shifting consumption patterns and urbanisation. The lack of availability or poor quality of certain key resources, including fossil fuels, water and land, will increasingly constrain the ability to meet this demand in the future (Fischer-Kowalski & Swilling 2010; Sorrell, Spiers, Bentley, Brandt & Miller 2010; UNEP 2014). At the same time, the global climate is changing – average temperatures are rising and extreme weather events are increasing in frequency, threatening energy, food and water systems (Intergovernmental Panel on Climate Change [IPCC] 2014).

However, the crucial point is that it is not just that energy, food and water resources are becoming scarcer, but that the interconnections and interdependencies among these three fundamental requirements for human life are emerging as increasingly important. The energy-food-water 'nexus' is

**Table 0-1: Main life-cycle elements in energy, food and water systems**

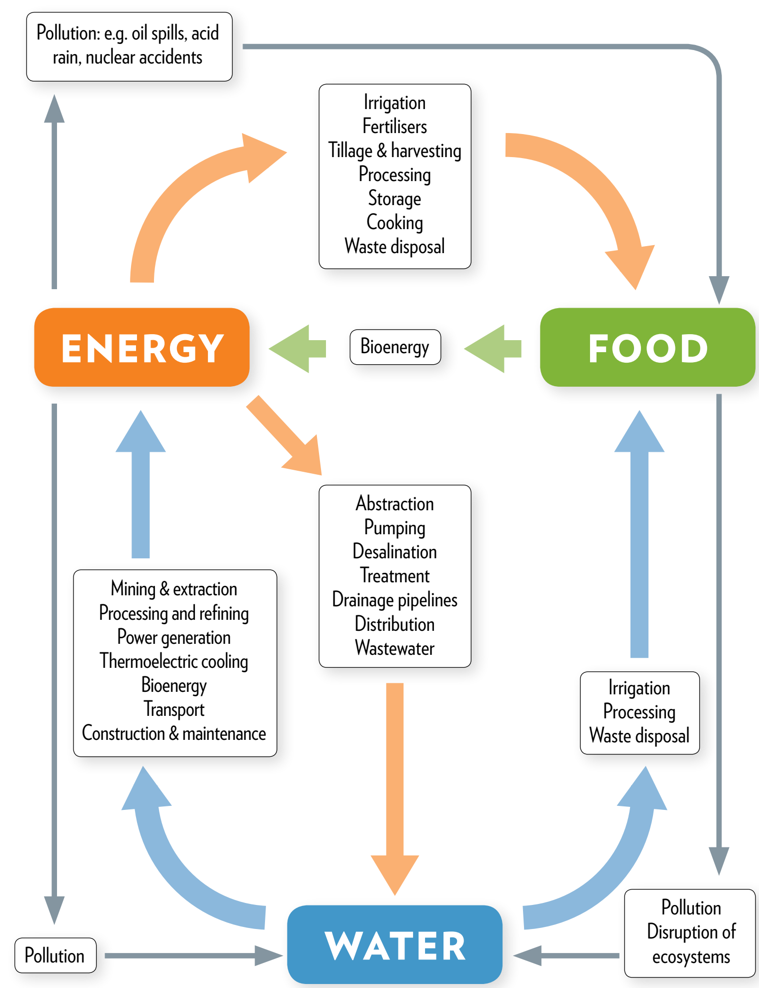
| BASIC ELEMENTS OF SYSTEM | ENERGY SYSTEM | FOOD SYSTEM | WATER SYSTEM |
|---|---|---|---|
| PRIMARY RESOURCES | ■ Biomass<br>■ Fossil fuels, uranium<br>■ Wind, solar, hydro, geothermal | ■ Soils, nutrients (Nitrogen, Phosphorous and Potassium (N, P, K), lime), manure, water, energy | ■ Precipitation, rivers, lakes, aquifers |
| PRODUCTION | ■ Extraction of primary fuels and minerals<br>■ Machinery, drilling rigs, etc. | ■ Pesticides<br>■ Machinery, tractors, human labour, draught animals | ■ Water abstraction from surface and groundwater sources |
| STORAGE | ■ Pumped storage, hydro schemes, batteries | ■ Grain silos, refrigeration plants | ■ Reservoirs, dams, water tanks |
| PROCESSING | ■ Oil refining, gas to liquids, coal to liquids<br>■ Power generation | ■ Food processing and manufacturing | ■ Treatment, purification,<br>■ Desalination |
| DISTRIBUTION | ■ Oil and gas pipelines<br>■ Electricity transmission | ■ Roads, railways, ports<br>■ Shops, markets | ■ Pipelines, pumps, reticulation systems |
| CONSUMPTION | ■ Energy access<br>■ Pricing structures<br>■ Health implications of energy sources | ■ Calorific intake, nutritional content, dietary patterns, cultural preferences, nutrition and health | ■ Water access<br>■ Pricing structures<br>■ Health implications of water quality |
| WASTE | ■ Mining waste<br>■ Greenhouse gas emissions from fossil-fuel combustion<br>■ Spent uranium fuel | ■ Nutrient flows, on-farm agri-waste, food waste<br>■ Eroded soils, siltation<br>■ Embodied water<br>■ Embodied energy<br>■ Greenhouse gases | ■ Water-borne sewage systems<br>■ Treatment of waste water |

defined as the interconnections between energy, food and water systems. In this report, 'systems' are understood in terms of their entire value chains (including production, processing, storage, distribution, consumption and waste disposal elements) and supporting infrastructures (see Table 0-1).

Some of the main interdependencies that characterise the nexus are as follows (see Figure 0-1):

- Energy inputs are required at all stages of the food system value chain, including electricity to pump water for irrigation, for cold storage of agricultural produce and refrigeration of processed food; diesel fuel to power tractors for tillage and harvesters; fossil fuel-based synthetic fertilisers and pesticides to produce crops and antibiotics to treat livestock; electricity and heat energy required for food processing; fuel for transporting and distributing food products; heat energy required for cooking; and fuel for transporting food waste to disposal sites.
- Energy is critical at many stages of the water system value chain, including extraction from lakes, rivers and aquifers; desalination; water treatment; construction of dams and reservoirs for water storage, and pipelines and pumping for distribution; and waste-water treatment.
- Energy generation depends on water for the extraction of fossil fuels; construction of energy infrastructure; processing of coal and refining of oil; generation of hydroelectricity and geothermal power; cooling within thermal power stations, concentrated solar power plants and nuclear reactors; and production of bioenergy.
- A number of agricultural crops (such as corn, canola, sugar and palm oil) are converted into bioenergy.
- Water is essential not only for agricultural production, but also for food processing and waste disposal.
- Agricultural production and food processing may negatively affect water quality via pollution and interference with ecosystem services that are critical for the hydrological cycle.
- Energy industries can have detrimental impacts on soil and water quality, for example via pollution such as oil spills, sulphur dioxide emissions and acid mine drainage.

**Figure 0-1: An overview of the energy-food-water nexus**




SOURCE: Adapted from IRENA (2015, fig. 1.1, p.24)

In recent years, spurred on by the oil and food price spikes of 2007-2008 and 2011-12, the nexus has emerged as an important issue within international development, sustainability and policy discourses. Increasingly, it is understood that treating energy, food or water systems and security (see definitions in Table 0-2) independently of each other can result in critical system linkages and vulnerabilities being underappreciated and can possibly lead to the formulation and implementation of ineffectual or even counterproductive policies and measures.

**Table 0-2:** Definitions of food, energy and water security

| | |
|---|---|
| FOOD SECURITY | "... all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO 2014). |
| ENERGY SECURITY | "... the uninterrupted availability of energy sources at an affordable price" (International Energy Agency [IEA] n.d.). |
| WATER SECURITY | "... the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water 2013a). |

## 0.2 Aims and Research Questions

This research report was commissioned and funded by the United Kingdom's Department for International Development (DFID) to contribute to this emerging nexus field of enquiry, with a particular emphasis on developing countries. The three major research questions, addressed in Parts 1, 2 and 3 respectively, are as follows:

- What are the key issues, including global and national drivers, which we might see in the coming 5 to 10 years, in the linkages between energy and water use and food security in developing countries?
- What are the main risks and vulnerabilities faced by different types of developing countries with regard to the energy-food-water nexus?
- What strategies, policies and measures can governments in developing countries adopt to reduce energy-related risks to food security and to make energy-food-water systems more resilient and sustainable?

A subsidiary objective is to develop analytical frameworks that stakeholders can build on to conduct more detailed assessments of country-specific vulnerabilities of their energy, food and water systems, and to formulate more nuanced and tailored strategies to boost the resilience of these systems. As such, the report is intended to serve as a reference work for policymakers, planners and researchers, primarily those working in developing countries, but also for those working in multilateral agencies and for the international aid community.

## 0.3 Methodology

This study is based primarily on three types of research method. The first is a desktop literature review that draws on relevant academic articles, reports and policy documents concerning the energy-food-water nexus both globally and in specific developing countries that are used as case studies. The second is a quantitative analysis of data on vulnerability indicators together with a qualitative risk assessment for energy, food and water security. The third is the use of policy analysis to derive recommendations for mitigating risks and vulnerabilities.

The analysis of the nexus is conducted at two levels. First, since all developing countries are to some extent or other connected to the world economy, a global analysis of the nexus is presented. Second, recognising that developing countries span a wide spectrum of economic sophistication and exhibit a great degree of variability in the key characteristics of their energy, food and water systems, a national-level typology is applied that divides developing countries into different categories so as to yield more nuanced analysis and more specific policy recommendations. This typology draws on a relatively new field of research that considers the interactions between human societies and natural systems within integrated social-ecological systems (Fischer-Kowalski 1998; Fischer-Kowalski & Haberl 2007). A central concept in this literature is the 'metabolism' of a society, which refers to the ways in which energy and materials (including water, minerals and biomass) are used to satisfy collective human needs and wants. Three socio-metabolic regimes are considered, each one based on a particular way of obtaining and using energy and materials (Sieferle 2001; Fisher-Kowalski & Haberl 2007).

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**A coal-fired power station in South Africa**

© J WAKEFORD

**The basis of Malawi's agrarian regime: wood and maize**

This report analyses three case studies representing each of the following three regimes:

- The **agrarian regime** is based on 'active' use of solar energy, which involves deliberate intervention by humans in the process of transforming solar energy, using breeding techniques and mechanical devices to exploit cultivated plants and livestock. The division of labour is limited by the need for most of the population to engage in agriculture and forestry to produce a net energy surplus to sustain the non-agricultural population. **Malawi** is used as a case study (largely) illustrating the agrarian regime.
- The **industrial regime** is based on the exploitation of fossil fuels (coal, oil and natural gas) and is characterised by mechanised production processes, extensive transport networks and predominantly urbanised societies. Agriculture is also mechanised and involves the application of fossil fuel derivatives in the form of synthetic fertilisers, pesticides and other inputs. **South Africa** is used as a case study of the industrial regime within a developing country context.
- There are indications of an **'ecological' regime** emerging in various parts of the world, based (largely) on renewable energy sources and agroecological or organic food-production systems, and mimicking closed-loop ecological systems and processes. **Cuba** is used as a case study to illustrate this regime, particularly with reference to its (agroecological) food system.

1.

# SCOPING THE ISSUES AND DRIVERS IN THE ENERGY-FOOD-WATER NEXUS IN DEVELOPING COUNTRIES

Part 1 analyses nexus linkages (i.e., inter-dependencies and spill-over effects among energy, food and water systems) and drivers (including economic, social, geopolitical, environmental and technological factors) first at a global level, and then for each of the three case studies (Malawi, South Africa and Cuba).

## 1.1 Global Analysis of the Energy-Food-Water Nexus

Energy and food systems operate on global scales. This is fundamentally because of integrated global markets that allow international trading in certain energy carriers (particularly oil, but also liquefied natural gas and coal), as well as in a wide range of food commodities (notably grains such as wheat, maize and rice, as well as soya beans and meat products). Other energy types (such as solar and wind power, and some forms of biomass energy) may be traded on a regional basis, but are not truly global commodities. This is also strictly true in the case of water, although there are substantial 'virtual' flows of water that is embedded in food products (and other manufactured goods) that are traded globally.

Fossil fuels continue to dominate the global energy mix, with oil being of singular importance, especially as the transport fuel of choice. **The energy system requires substantial water inputs at various stages of the energy production and consumption chain, including primary extraction, processing/transformation, power generation, and indirectly in the construction and maintenance of energy infrastructure.** Water use varies greatly by energy type, with biofuels being the most water intensive (see Table 1-1). **Biofuels derived from food crops make only a very small contribution to global energy supplies, but can have a large impact on international food prices.** Energy production and consumption (especially of fossil fuels) can have a variety of negative impacts on both underground and surface water quality.

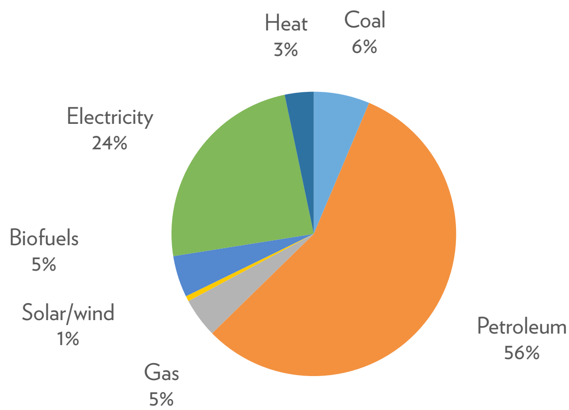
**The globalised food system, which is dominated by large-scale industrialised commercial agriculture, food manufacturing and extensive trade and distribution of food products across national and international territories, is highly energy intensive all along the value chain and accounts for up to 30% of the world's total energy use.** Mechanised industrial agriculture is responsible for a large share of energy consumption, but it is the processing and distribution stage that uses the most energy – up to 70% of the total. The energy carriers that the agriculture system relies most heavily on are petroleum fuels and electricity (see Figure 1-1). In terms of water dependencies of the food system, the production stage is the heaviest user, responsible for 70% of the world's freshwater use, and up to 90% in some countries. The huge increase in agricultural yields and food supplies over the past century – which have sustained a rapidly growing world population – are largely attributable to the growing use of fossil fuels to power machinery and produce synthetic fertilisers and pesticides, and to pump water for irrigation. Furthermore, the food system has negative impacts on water availability and quality: over-pumping of water for irrigation has led to groundwater depletion, while pollution from various stages of the food value-chain degrades water quality.

**Table 1-1: Water inputs for production of various energy sources**

| ENERGY TYPE | CONVENTIONAL OIL AND GAS | OIL SANDS | BIOFUELS |
|---|---|---|---|
| Water requirements (litres [l]/gigajoule) | 1-10 | 100-1 000 | 10 000-100 000 |

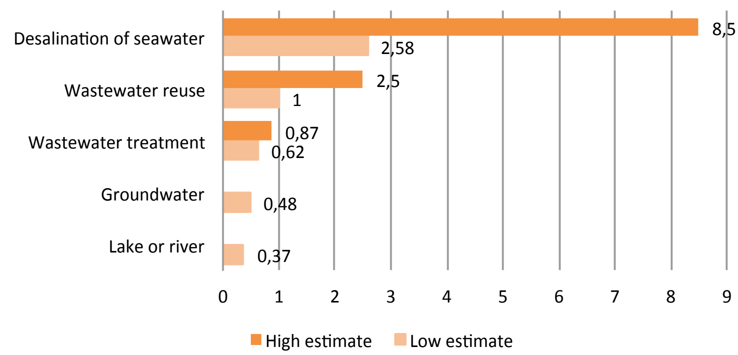
SOURCE: Hoff (2011); World Economic Forum [WEF] (2011)

**Figure 1-1:** **Shares of world energy consumption in agriculture by energy type, 2012**




SOURCE: IEA (2015)

**Figure 1-2:** **Energy (kWh) required to provide 1 m³ of potable water**




SOURCE: Based on UN-Water (2014, fig. 2.2)

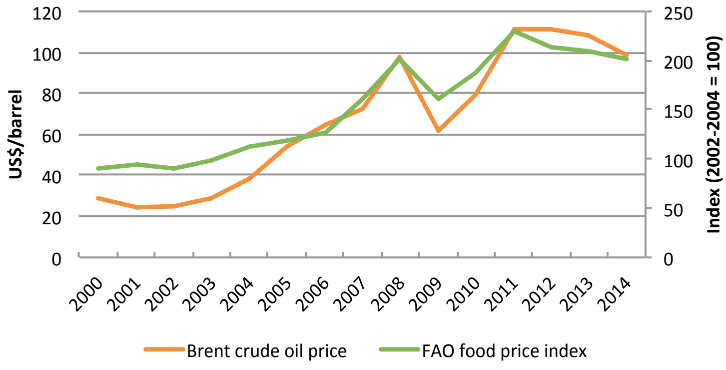
NOTE: Estimates do not include the distance water is transported or water efficiency levels.

**Water systems depend heavily on energy at many stages along the water supply/use chain, including abstraction and conveyance (pumping), desalination, treatment and purification, wastewater management, and construction of water infrastructure.** Different sources of water require varying energy inputs (Figure 1-2). On the other hand, poor water quality can negatively impact on food production and certain types of energy generation. At a global level, some 2.8 billion people live in areas of high water stress; growing water scarcity and degradation are increasingly recognised as major threats to human development.

**There are several systemic demand- and supply-side drivers operating at a global level that affect all components of the nexus** (see Table 1-2). On the demand side, these include: economic growth, increasing affluence and associated changes in lifestyles and consumption patterns; population growth and changing demographic profiles; urbanisation, which tends to go hand-in-hand with rising resource intensity; and globalisation. Common supply-side drivers include resource depletion and increasing scarcity (e.g. of fossil fuels, arable land and fresh water supplies) and environmental degradation (including pollution). Climate change is both the result of processes in the energy-food-water nexus (e.g. fossil fuel combustion, land use changes and methane releases from dams) and a cause of instability and insecurity in some parts of energy, food and water systems – most notably water supplies and crop yields.

**These demand and supply pressures are manifesting in volatile prices of internationally traded energy and food commodities, and these price swings are amplified by a financial sector prone to speculation and boom-and-bust cycles.** Furthermore, the prices of energy and food commodities have been linked together through biofuel markets and because of the critical role played by energy inputs in the food supply chain (see Figure 1-3). Thus food and energy security – both critically affected by international prices – are inextricably linked together. Globalisation has brought both benefits and new threats to countries with vulnerable economies whose agricultural sectors, for example, are not resilient to international price shocks and volatile commodity markets. Another result of resource pressures is mounting geopolitical tensions – and fortunately in some cases cooperation – over access to water, land, food and energy. Technological developments are to some extent helping to alleviate the pressures on scarce resources by improving efficiencies, although such gains are counteracted by the 'rebound effect', whereby income saved as a result of efficiency gains is spent on other energy-intensive goods and services.

**Figure 1-3:** International crude oil and food prices




SOURCE: BP (2015) and FAO (2015a)

The confluence of these major global drivers – economic growth, population expansion, urbanisation, geopolitics, technological development and climate change – implies that the future could look very different to the past. New pressures and challenges will arise within the nexus that will need to be carefully managed on international, national and local scales.

**Table 1-2:** Key global drivers in the energy-food-water nexus

| DRIVERS | ENERGY SYSTEM | FOOD SYSTEM | WATER SYSTEM |
|---|---|---|---|
| ECONOMIC | ▪ Economic growth: rising energy demand<br>▪ Oil price volatility and shocks<br>▪ Oil market speculation | ▪ Economic growth driving food demand<br>▪ Food price shocks<br>▪ Globalisation of food system<br>▪ Financial speculation in food commodity markets<br>▪ Energy price fluctuations<br>▪ Supermarketisation | ▪ Economic growth leading to growing water demand |
| SOCIAL | ▪ Inequality of access to energy<br>▪ Energy poverty<br>▪ Population growth<br>▪ Urbanisation<br>▪ Changing tastes (energy-intensive goods and services) | ▪ Population growth<br>▪ Urbanisation<br>▪ Inequality of access<br>▪ Hunger and malnutrition<br>▪ Poverty<br>▪ Changing diets<br>▪ Food protests and social instability | ▪ Inequality of access to water<br>▪ Water insecurity<br>▪ Population growth<br>▪ Urbanisation |
| GEOPOLITICAL | ▪ Energy resource conflicts<br>▪ Regional power pools<br>▪ Strategic energy trade deals | ▪ Foreign direct investment in agriculture<br>▪ Land grabs<br>▪ Food export bans<br>▪ International agricultural trade practices | ▪ Cross-border water conflicts<br>▪ Virtual water trade and 'water grabs' |
| ENVIRONMENTAL | ▪ Conventional fossil fuel depletion<br>▪ Expansion of unconventional fossil fuels production<br>▪ Carbon emission caps or carbon taxes<br>▪ Pollution concerns | ▪ Climate change impacts (e.g. temperature and rainfall) on crop yields<br>▪ Soil erosion and land degradation<br>▪ Depletion of rock phosphate reserves | ▪ Global climate change impacts on rainfall, runoff, evaporation<br>▪ Water pollution (e.g. from agriculture, industry, mining)<br>▪ Aquatic ecosystem degradation |
| TECHNOLOGICAL | ▪ Energy efficiency<br>▪ New energy production & storage technologies<br>▪ Rebound effect | ▪ Crop and livestock breeding<br>▪ Genetically modified organisms<br>▪ New chemical inputs | ▪ Water efficiency<br>▪ New water technologies (e.g. desalination)<br>▪ Rebound effect |

## 1.2 Agrarian Typology Case Study: Malawi

WIKIMEDIA COMMONS: SWATHI SRIDHARAN (ICRISAT):

**Cooking on a wood fire in Karonga District, Malawi**

Given the predominance of its largely subsistence agricultural sector, especially in terms of providing livelihoods for the majority (77%) of the population, Malawi constitutes a useful example of a country that is still functioning mainly within an agrarian socio-ecological regime. As Malawi's extremely low per capita GDP (US$780 in purchasing power parity terms in 2013) suggests, the agrarian regime has enormous limitations. At the heart of this is the country's overwhelming reliance on traditional biomass for almost 90% of its primary energy supply and the extremely limited electricity network, which serves just 9% of the population. The extensive use of fuel wood in turn has negative impacts on soil and water resources through deforestation and soil erosion. Food security is tenuous for most of the population, partly because of the low productivity of traditional agriculture, which provides barely enough for many households' own consumption, let alone a marketable surplus to generate income and alleviate poverty (which afflicts 72% of the population). Food security is also jeopardised by the direct dependence for much of agricultural production on rainfall and the lack of irrigation infrastructure. Climate change already appears to be having an impact on Malawi's rainfall patterns, which are becoming more erratic. These issues illustrate how the nexus manifests in a predominantly rural, underdeveloped context.

In an effort to transcend the limitations of the agrarian regime, Malawi's government has in recent years introduced a significant fertiliser subsidy programme in order to boost crop yields. The programme aims to both improve food security and boost foreign exchange reserves through increased agricultural exports. While this programme appears to have raised yields (in particular of maize), the increasing dependence on imported fertilisers presents the country with new challenges and risks. These include exposure to teleconnections such as global fertiliser price shocks and exchange rate weakness, as well as the detrimental effects of excess fertiliser use on water resources – which in turn can affect energy production (for instance, by stimulating plant growth that reduces water flows to the country's main hydropower facility).

## 1.3 Industrial Typology Case Study: South Africa

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**Harvesting grain, Limpopo, South Africa**

South Africa is classified by the World Bank as an upper-middle income country, with a per capita GDP (in purchasing power parity terms) of US$12 867 in 2013 (World Bank 2015b). Given its relatively sophisticated industrial systems, South Africa provides a useful example of a largely industrial socio-ecological regime within a developing country context. The country's energy, food and water systems all depend on complex, interlinked infrastructures that are mostly underpinned by fossil fuel resources. Coal alone provides 70% of primary energy and powers 90% of electricity, while oil contributes about 14% of energy supply and 98% of transport energy. About 95% of agricultural output originates from industrialised commercial farming that relies heavily on external inputs derived from fossil fuels. Less than 5% of employed people work in the agriculture sector. Most households and industry get their water from municipal water systems with infrastructure for abstraction, treatment, distribution and wastewater treatment.

The main challenges for energy security are oil import dependence (and resulting vulnerability to global oil price fluctuations), the urgent need to expand electricity generation capacity with a more diversified (and lower carbon) primary energy mix, and rapidly rising electricity prices. Declining availability and rising cost of high-quality coal could be a significant factor in the coming years. Food security is presently mainly an issue of affordability at the household level, as the country is able to meet its overall food requirements through domestic production and imports. However, the high level of dependence of food production on energy – especially petroleum fuels, but also electricity – exposes the food system to systemic shocks from energy price spikes or supply disruptions. Furthermore, industrial farming is degrading the nation's limited arable soils.

Despite the numerous challenges within the energy and food systems, their dependence on increasingly scarce and degraded water resources could be their biggest limiting factor in the medium to long term. Ironically, perhaps, it is the industrialised, fossil energy-intensive food and energy systems that pose the greatest threats to the water resources they depend on – particularly given the spatial overlap of key arable land, water and coal resources. This is the dilemma of the industrial regime, and it implies that difficult trade-offs will have to be faced in terms of the allocation of water among competing sectors.

## 1.4 Ecological Typology Case Study: Cuba



**Inner city food garden. Cuba**

Up until 1990, Cuba's economy and agriculture sector were largely powered by fossil fuels supplied at subsidised prices by the Soviet Union. Following the collapse of the Soviet Union, these subsidies and preferential trading in energy and food supplies came to an abrupt halt and Cuba entered a period called the 'Special Period in Peacetime'. The country's GDP declined by 35% between 1989 and 1993 and in the following 20 years the country was forced to become largely self-reliant in food and energy production, with these systems undergoing major revolutions. Cuba has achieved major energy efficiencies, with its total energy consumption falling by 52% between 1990 and 2012. A quarter of the population still lives in rural areas, partly as a result of measures that were put in place to curb a rural exodus and encourage the uptake of farming. About 3 million hectares of land are farmed using agroecological practices, which were adopted in an effort to reduce reliance on energy in the agriculture sector. This agroecological model has demonstrated its viability in terms of certain types of food production, with yields of numerous agricultural products outperforming those of the industrial model. Agroecological farming has also boosted energy efficiency and conservation, while reducing impacts on water resources. Thus far, however, agroecological farming has important limitations in terms of cereal, dairy and meat production.

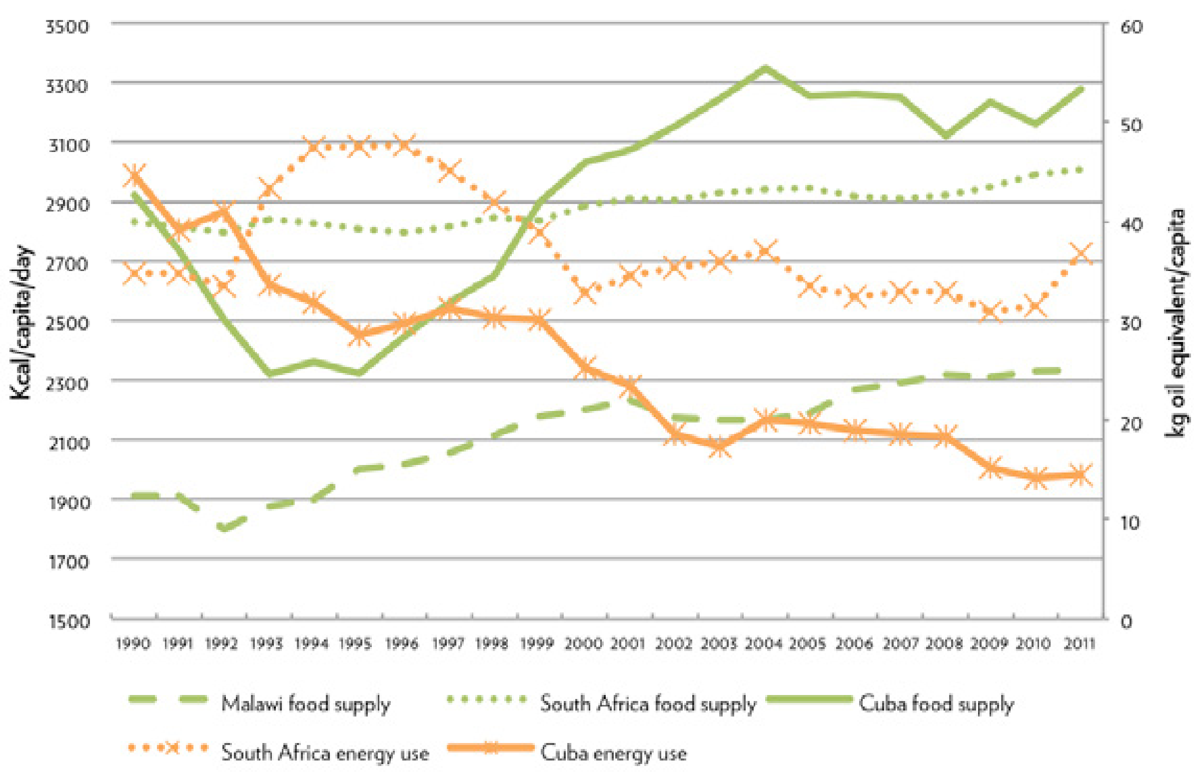
As a result of these transformations, Cuba provides perhaps the best available example of an agroecological socio-economic regime and has valuable lessons to offer regarding land and energy sector reform and policymaking aimed at enhancing resilience, food autonomy and human well-being. Despite the impressive strides made towards achieving food and energy self-sufficiency, however, Cuba remains economically dependent on food and fuel imports, among other products. Fuel comprises an average of 35%, and food 15%, of total imports. This dependence also carries geopolitical implications as Cuba currently sources most of its oil from Venezuela. Furthermore, there is evidence that Cuba's agricultural sector is becoming dualistic, with the (re)emergence of an industrial/biotechnological facet, as testified by the expansion of maize and soya monocrops and the advent of genetically modified crops. Cuba has also demonstrably embarked on a path of increased fossil-fuel consumption, as it strives to find and produce more indigenous oil and venture capital projects in the sector increase.

## 1.5 Comparison of the Case Studies

While the three case studies are not precise depictions of their assigned socio-metabolic regimes, partly because they are to varying degrees embedded in a globalised economy, they provide a more nuanced and detailed illustration of how the nexus dynamics play out in different contexts. They also provide some guidance as to the increasingly difficult trade-offs governments and societies will need to make over the coming decades as energy, food and water systems come under increasing pressure from national and global drivers.

The food-energy nexus differences between Malawi, South Africa and Cuba are nicely illustrated in Figure 1-4, which shows the level of food supply (in kilocalories per capita per day, kcal/cap/day) and energy consumption in the agriculture sector (in kilogrammes of oil equivalent per capita) in each country.[1] In Malawi, the per capita food supply is substantially lower than in the other two countries, but has been growing fairly steadily throughout the period 1992-2011 – partly, no doubt, as a result of increasing fertiliser use. In South Africa, food supply per person has grown very slowly, while energy use in agriculture has been relatively stable since 2000. Cuba's food supply in 1990 was very similar to that in South Africa, but plummeted in the early 1990s during that country's 'Special Period' as oil imports were drastically curtailed. Once the transition to agroecological farming got underway, however, per capita food supply recovered strongly from the mid-1990s, before stabilising around 2004 at a level considerably higher than that in South Africa. Meanwhile, the per capita level of energy use in Cuba's agriculture sector has followed a declining trend throughout the period, and by 2011 was just 40% of the level in South Africa. These data clearly demonstrate that Cuba has found a much more energy-efficient way of meeting its citizens' dietary requirements compared to South Africa.

**Figure 1-4: Per capita energy use in agriculture and food supplies in Malawi, South Africa and Cuba**




SOURCE: FAO (2015b), IEA (2015)

1 Data on energy consumption in agriculture are not available for Malawi.

2.

# NEXUS RISKS AND VULNERABILITIES FACED BY DEVELOPING COUNTRIES

## 2.1 Qualitative Assessment of Risks and Vulnerabilities

### 2.1.1 Global nexus risks and vulnerabilities

**Energy, food and water security each face risks and vulnerabilities on the global level emanating from internal drivers within the relevant system itself, as well as from the linkages and dependencies on the other two systems.** The risks and accompanying impacts may be realised at regional, national and local scales. A summary of the global risks is presented in Table 2-1.

**The major catalytic risks for the nexus are: (1) extreme weather events including droughts and floods; (2) oil price shocks; (3); food price shocks; (4) geopolitical tensions; and (5) financial speculation in commodity markets.** These risk categories represent the major societal teleconnections that arise as a result of the embeddedness of countries within a world trading system; impacts get transmitted to individual countries through global trade networks. Underlying drivers/trends that feed into the risks include demand growth (driven by urbanisation and growing populations, economies and middle classes) and supply-side factors such as climate change, environmental degradation, resource depletion and the growth of the biofuel market. As Figure 2-1 makes clear, the nexus linkages and feedback loops create a web of interconnecting – and reinforcing – risks and impacts. One likely end result of these threats to food, energy and water security is heightened social instability within countries and regions.

**The risks and vulnerabilities faced by rural dwellers can differ considerably from those faced by their urban counterparts.** This is partly because rural areas tend to be the location for much of the 'up-stream' end of energy, food and water value chains, while much of the processing occurs in cities and towns. In rural areas, climate change and variability is a major threat, especially in the case of rainfed agriculture. In urban areas, the major nexus risks relate to the extensive, interdependent infrastructure systems (such as powerlines, roads and pipes) that are needed for the distribution of energy, food and water, and the wastes and emissions from consumption patterns that are generally more intensive than in rural areas.

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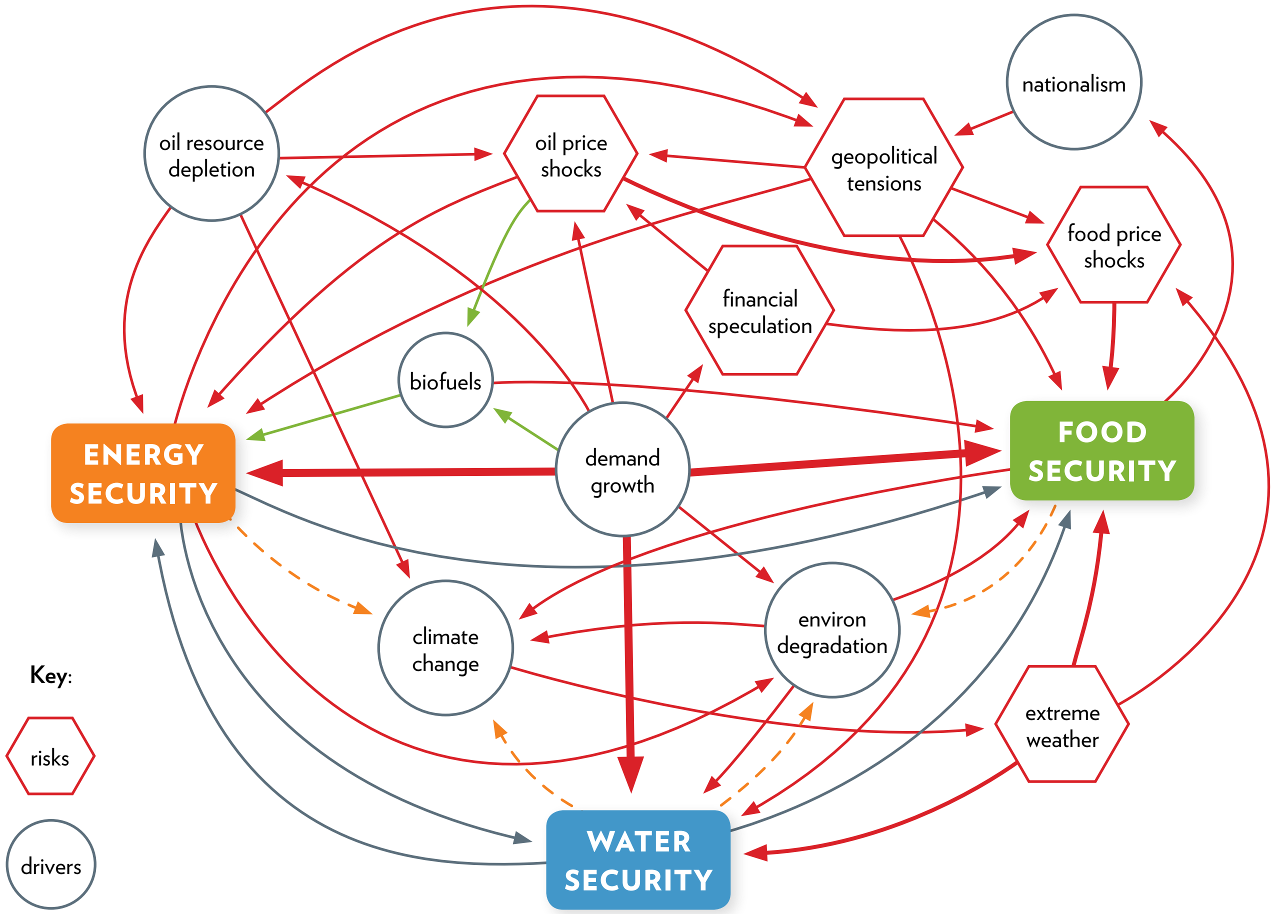
**Water distribution during drought**

**Figure 2-1: Interconnected global nexus risks**




NOTES:

- The red arrows indicate the negative impacts that a driver or risk has on other drivers, risks or energy-food-water security aspects.
- Demand growth is placed centrally and has thicker connecting lines because it is such a fundamental driver of food, energy and water insecurity by placing increasing pressure on these systems to deliver.
- The black arrows indicate the main nexus linkages, for example, that water security is necessary for food security since it is essential for crop cultivation. Usually, a deterioration in one security aspect (such as water) has negative consequences for another (such as energy).
- The green arrows indicate that the relevant driver or risk tends to promote an increase in biofuel use, which in turn can boost energy security (provided the net energy return is positive).
- The dotted orange arrows indicate that improvements in one domain of energy-food-water security could have negative unintended consequences (e.g. for the climate or environment), depending on the how these improvements are generated.
- There are several positive feedback loops, for example:
  i. Deteriorating food security can lead to a rise in nationalist sentiments, which stoke geopolitical tensions, which in turn threaten food security (e.g. if countries limit food exports or engage in land grabs).
  ii. Climate change results in extreme weather events, which threaten water security, which in turn may limit hydropower generation, which could lead countries to rely more heavily on fossil fuels, which exacerbates climate change.
  iii. Extreme weather events resulting from climate change can trigger food price spikes, which threaten food security and can result in more intensive use of fossil fuels in agriculture, which in turn can contribute to further emissions and climate change.

**Table 2-1: Summary of global nexus risks and vulnerabilities**

| ARISING FROM: / RISKS TO: | ENERGY SYSTEM DRIVERS AND LINKAGES | FOOD SYSTEM DRIVERS AND LINKAGES | WATER SYSTEM DRIVERS AND LINKAGES |
|---|---|---|---|
| ENERGY SECURITY | ■ Energy (oil) price shocks, arising from:<br>– Geopolitical disruptions to energy supply (e.g. oil, gas or electricity).<br>– Depletion of conventional fossil fuel resources, especially oil.<br>– Rising costs to produce oil and gas.<br>– Financial market commodity speculation.<br>– Ageing infrastructure and lack of investment in new capacity.<br>– Rapid demand growth in emerging markets.<br>■ Climate mitigation could impose restrictions on fossil fuel combustion. | ■ Dependence on bioenergy sources derived from food crops raises energy access and affordability risks.<br>■ Low net energy yield of many bioenergy sources, implying higher energy prices.<br>■ Increasing demand for energy from food systems to meet growing global food demand.<br>■ Limits on land and water availability for growing bioenergy.<br>■ Climate change impacts on biofuel production. | ■ Water scarcity and impaired quality could constrain energy supplies, including hydropower and thermal power.<br>■ Increasing demand for energy from water systems, and growing competition for water supplies with other sectors.<br>■ Rising water temperatures threaten thermal power stations.<br>■ Possible increases in water prices due to water scarcity and demand growth would raise energy production costs.<br>■ Possible stricter regulations on water use for energy. |
| FOOD SECURITY | ■ Energy price shocks can raise food prices.<br>■ Energy supply disruptions can negatively affect food production, storage and distribution, and increase food waste.<br>■ Increasing competition for biomass waste.<br>■ Biofuels may threaten food security via competition for land and water. | ■ Rising food demand driven by growing population and rising incomes.<br>■ Constraints on arable land; eroding soils.<br>■ Global warming can affect crop yields.<br>■ Food prices are subject to financial speculation and price shocks are transmitted globally. | ■ Water scarcity and impaired quality could constrain food production and processing.<br>■ Competition from other water uses could drive up water prices for agriculture.<br>■ Droughts and floods driven by climate change can impair food production. |
| WATER SECURITY | ■ Energy supply shocks can disturb water extraction, treatment and distribution.<br>■ Increasing demand for water from energy systems, possibly exacerbated by climate mitigation (e.g. expansion of biofuels).<br>■ Threat of rising energy costs feeding through to water prices.<br>■ Pollution of water resources from energy extraction and processing.<br>■ Spatial mismatch between energy and water systems. | ■ Increasing demand for water from food systems and to meet food security goals.<br>■ Water demand competition arising from foreign leasing of land for agriculture.<br>■ Degradation of water resources from agriculture (e.g. fertilisers and pesticides) and food processing.<br>■ Disruption of water-related ecosystem services from conversion of wetlands & forests to farmland. | ■ Population and economic growth place additional strain on water supplies.<br>■ Geopolitical conflict over access to transboundary water resources.<br>■ Financial constraints on water infrastructure development.<br>■ Impacts of climate change (e.g. changing rainfall patterns, more frequent droughts and floods, melting glaciers, etc.).<br>■ Degradation of water quality from economic activities. |

### 2.1.2 Agrarian typology: key lessons from Malawi

- In Malawi's (largely) agrarian socioecological system, there are two main nexus vulnerabilities: (1) the low productivity of its largely subsistence agricultural sector (together with large post-harvest food losses) results in a high level of food insecurity; and (2) the over-reliance on traditional biomass fuels has major impacts, including deforestation, soil erosion, siltation and the resulting interference with water supplies and hydropower generation.
- Increasingly erratic rainfall patterns, linked to climate change, pose a threat to water security, food production (especially considering the overwhelming reliance on rainfed agriculture) and hydropower generation.
- Malawi's efforts to mitigate its food security risks, principally by expanding the use of fertilisers, brings other risks such as exposure to external fertiliser (and energy) price shocks and exchange rate weakness, as well as the detrimental impacts of fertiliser use on aquatic ecosystems (e.g. eutrophication).

### 2.1.3 Industrial typology: key lessons from South Africa

- In the short- to medium-term, the major nexus vulnerability in South Africa is that its food system is highly dependent on energy inputs and is thus vulnerable to increased prices and interruptions to supplies of both liquid fuels and electricity. Energy shocks quickly get transmitted to food prices, which threatens food security for poorer households in particular.
- In the longer term, a primary nexus-related risk that is characteristic of the industrial typology concerns the degrading effect that the extensive use of fossil fuels (e.g. for energy production and agriculture) has on water and soil quality. This is especially a concern in South Africa because of the spatial overlap of major coal fields, arable land and key river systems.
- Although depletion of fossil fuel resources could pose a threat to South Africa's industrial regime in the longer term, water appears to be the major limiting resource in the medium term. The most pressing vulnerabilities in other countries will depend on the relative scarcity/abundance of different primary resources.

### 2.1.4 Ecological typology: key lessons from Cuba

- The aspects of Cuba's energy, food and water systems that exhibit characteristics of the 'ecological metabolism' generally help to reduce nexus-related risks. For example, renewable energy poses limited threats to food and water systems – although a notable exception is the reliance on sugar bagasse for power co-generation. Agroecological food production has limited reliance on external inputs derived from fossil fuels and thus shields the country from external energy and food price shocks.
- Nevertheless, Cuba's overall energy system is still heavily reliant on oil (and to a much lesser extent natural gas), which implies significant energy security risks in terms of exposure to oil price shocks and geopolitical dependence on subsidised imports from Venezuela. Furthermore, the (renewed) growth of industrial agriculture is raising economic and ecological risks related to energy-intensive inputs such as fertilisers and irrigation water. Constraints on water availability and risks posed by climate change affect both the ecological and industrial components of Cuba's energy-food-water systems.



**Flooding in Mozambique**

## 2.2 Quantitative Indicators of Nexus Vulnerability

Data for a range of energy, food and water security indicators for a sample of 96 developing countries were drawn the World Bank's *World Development Indicators* (World Bank, 2015b) and the Food and Agriculture Organisation's FAOSTAT and AQUASTAT databases (FAO 2015b, 2015c). The countries are grouped into three income categories as defined by the World Bank (2015a), namely low-income countries (LICs), lower-middle-income countries (LMICs), and upper-middle-income countries (UMICs). Table 2-2 presents average values of the energy-food-water nexus indicators across the three income categories.

The main results for the three income categories are as follows:

- Agriculture plays a dominant role in most LIC economies and accounts for over 40% of employment in all countries for which data are available. The high levels of dependence on traditional biomass energy means that LICs are vulnerable to deforestation, energy poverty (especially lack of access to electricity) and low-productivity agriculture. In most LICs, access to electricity is very limited, the average food supply is low, more than 20% of the population are undernourished, and access to safe drinking-water is a significant challenge.
- LMICs are at varying stages of transition from the biomass-based agrarian regime to a fossil fuel-based industrial regime, and there is a great deal of variability in the indicators across this diverse group of countries. A significant number of LMICs still have major challenges with respect to access to electricity, adequate nourishment and safe drinking-water, and levels of energy, food and water consumption are generally quite low.
- Most UMICs, which are further down the road of industrialisation, economic diversification and development, are performing quite well in terms of basic energy, food and water security access and availability/consumption. The main exceptions are several southern African nations (Angola, Botswana and Namibia) that have high levels of income inequality and poverty. The level of dependence on fossil fuels – and thus exposure to oil price shocks – is very high in most UMICs.

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**Pivot irrigation, Vanrhynsdorp, South Africa**

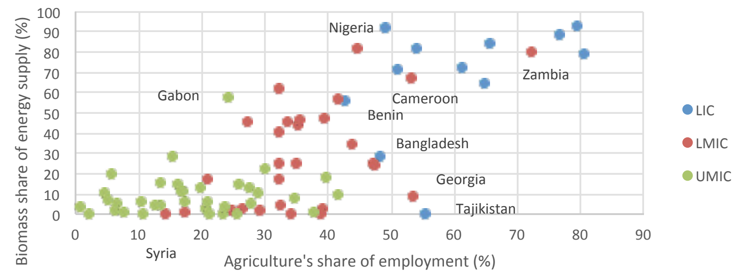
**Table 2-2:** Average values of indicators across country categories

| Indicator | Units | LICs | LMICs | UMICs |
|---|---|---|---|---|
| SOCIOECONOMIC | | | | |
| Poverty headcount ratio at US$1.25 a day (PPP) | % of population | 50 | 17 | 4 |
| Agriculture value added | % of GDP | 32 | 16 | 8 |
| Employment in agriculture | % of total employment | 65 | 36 | 19 |
| ENERGY SECURITY | | | | |
| Energy use per capita | kg oil equivalent | 364 | 738 | 1 753 |
| GDP per unit of energy use | PPP $/kg oil | 5 | 8 | 10 |
| Biomass energy | % of energy | 68 | 31 | 11 |
| Fossil fuels | % of energy | 25 | 61 | 82 |
| Nuclear and alternative energy | % of energy | 6 | 9 | 7 |
| Access to electricity | % of population | 25 | 78 | 93 |
| Electric power consumption | kWh/capita | 314 | 925 | 2 611 |
| Net energy imports | % of energy use | 3 | -42 | -55 |
| Pump price for diesel fuel | US$/litre | 1.30 | 0.99 | 1.09 |
| FOOD SECURITY | | | | |
| Food supply | kcal/capita/year | 2 352 | 2 633 | 2 951 |
| Prevalence of adequate nourishment | % of population | 77 | 85 | 91 |
| Agricultural irrigated land | % of agric. land | 12 | 12 | 7 |
| Agricultural machinery | tractors/sq km | 1 | 112 | 199 |
| Fertiliser consumption | kg/ha arable land | 26 | 92 | 214 |
| Cereal yield | kg/ha | 1664 | 2497 | 2801 |
| Average value of food production | I$/capita | 155 | 255 | 352 |
| Cereal import dependency ratio | % | 21 | 23 | 26 |
| Value of food imports over total exports | % | 66 | 18 | 14 |
| Droughts, floods, extreme temperatures | % of population | 3 | 1 | 1 |
| WATER SECURITY | | | | |
| Total water withdrawal per capita | $m^3$/inhab/year | 219 | 514 | 689 |
| Population with access to safe drinking-water | % of population | 68 | 85 | 93 |
| Renewable internal freshwater resources | $m^3$/capita | 7 090 | 7 362 | 12 087 |
| Dam capacity per capita | $m^3$/capita | 951 | 1 265 | 1 215 |
| Annual freshwater withdrawals | % internal resources | 9 | 192 | 86 |
| Water productivity | 2005 US$ GDP per $m^3$ | 11 | 12 | 20 |
| Annual freshwater withdrawals, agriculture | % of total withdrawal | 67 | 70 | 54 |
| Annual freshwater withdrawals, domestic | % of total withdrawal | 25 | 16 | 24 |
| Annual freshwater withdrawals, industry | % of total withdrawal | 8 | 13 | 23 |

**Source: Calculated from data drawn from FAO (2015a), FAO (2015b) and World Bank (2015b)**

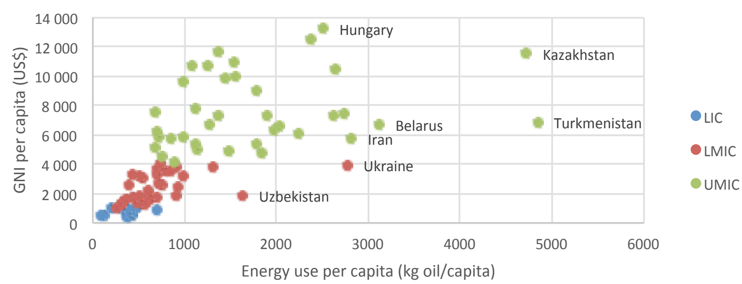
- Some general observations can be made based on the analysis of indicators for the entire group of 96 developing countries:
- **There is a high degree of variability in the values of many of the indicators across countries, even within each of the three income categories.** Although some broad patterns can be identified for some of the indicators, there are many outliers (i.e. countries with very large or very small indicator values). More detailed, country-level research is needed to interrogate the reasons underlying the large variations observed in the many of the indicators.
- **Very few countries achieve a high level of per capita energy consumption without relying heavily on fossil fuels.** However, a high proportion of fossil fuels in the energy mix does not guarantee a high level of energy consumption. Reliance on biomass energy is strongly and positively correlated with the level of poverty, as well as agriculture's share of GDP and employment (see Figure 2-2).
- **Key indicators of availability of and access to energy, food and water are quite strongly related to the level of income per capita, inversely related to the poverty rate, and correlated with each other** (e.g. see Figure 2-3, Figure 2-4 and Figure 2-5). Poorer countries tend to have lower levels of consumption of basic necessities and fewer of their people have access to adequate nutrition, electricity and safe drinking-water. Thus many (especially low-income) countries could effectively tackle vital aspects of nexus security by reducing levels of poverty and inequality.
- **Many of the other nexus risks and vulnerabilities are spread widely and are not concentrated within a select group of countries.** This most likely reflects the complexity of the determinants of energy, food and water security and the greatly varying characteristics of the countries (e.g. population size, income level, geography, climate, natural resource endowments, etc.).
- Although energy is an important input into agriculture, **the fact that a particular country has abundant energy resources (such as oil or natural gas) does not automatically translate into either energy or food security.** In many cases this is because the energy-rich country exports most of its fossil fuels and there is extensive inequality in access to the proceeds of oil and gas revenues, together with widespread poverty.

**Figure 2-2: Relationship between biomass dependence and agriculture's share of employment**



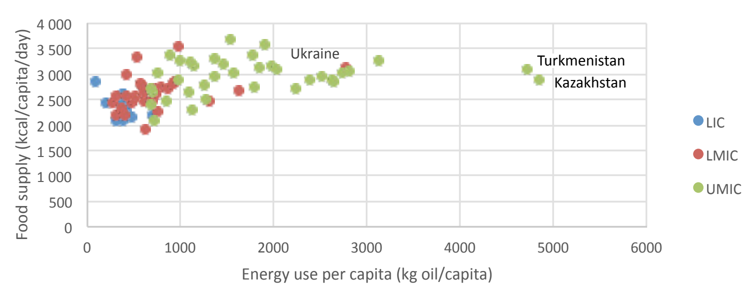

SOURCE: World Bank (2015b)

**Figure 2-3: Relationship between income and energy use per capita**



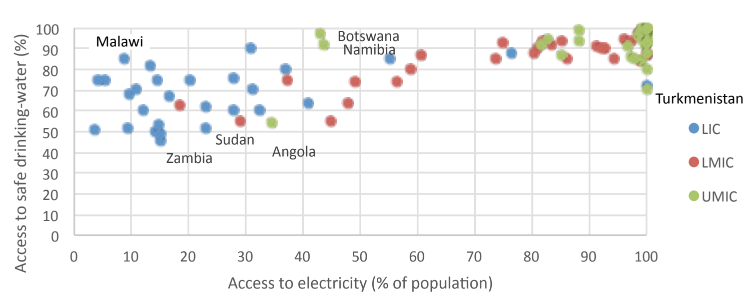

SOURCE: World Bank (2015b)

**Figure 2-4: Availability of energy and food in developing countries**




SOURCE: FAO (2015a) and World Bank (2015b)

**Figure 2-5: Relationship between access to electricity and safe drinking water**




SOURCE: FAO (2015a) and World Bank (2015b)

# 3. POLICY RECOMMENDATIONS FOR NEXUS RESILIENCE AND SUSTAINABILITY

This part considers ways to build the resilience of energy-food-water systems to a variety of shocks, including international energy and food price or supply shocks, as well as possible impacts of climate change. The recommendations are informed by a set of overarching policy goals that rest on the three pillars of sustainable development:

- Improve **social inclusiveness** by enhancing food, water and energy security for people living in developing countries, especially for those in the poorest segments.
- Boost **economic productivity** by raising the productivity of resource use and reducing waste.
- Improve **environmental sustainability** by protecting and restoring ecosystems and enhancing their resilience to shocks.

By adopting the following policies and measures, societies can undertake a gradual transition to fundamentally new, more sustainable socioeconomic systems and greener economies that decouple energy and water consumption from economic growth and particularly from an increase in food production.

## 3.1 Generic Recommendations

Although context-specific factors mean that there are no blueprint solutions to nexus challenges, there are a number of generic recommendations for mitigating nexus risks that can be made on the basis of existing international research and practical experience.

### 3.1.1 Strengthening institutions, governance and policy coherence

Well-functioning institutions, effective governance systems and integrated policy frameworks are prerequisites for designing effective policies and implementing technical solutions to tackle nexus risks and vulnerabilities. These all create the enabling environment within which public, private sector and civil society actors can take informed decisions that better align with the socioeconomic and environmental goals outlined above. The following strategies and measures are applicable to some degree or other to all developing countries, although clearly to a greater extent in cases where current institutional capacity and coordination is weaker.

*Building institutional capacity*

The complexity of nexus issues and the many trade-offs involved in nexus policy choices implies a need for building strong institutions with effective capacity that can adapt in a flexible manner to rapidly changing conditions. Capacity-building programmes should promote multi- and transdisciplinary approaches and focus on the nexus as a basis for sound policymaking, and offer learning and management opportunities that develop abilities for systems thinking and the application of nexus assessment tools. Sector-specific initiatives will also be needed, such as programmes for natural resource and environmental management.

*Enhancing institutional and policy coordination*

Responding to – and in some instances preventing – nexus challenges means that a silo approach to policymaking within governments needs to be transcended. At the national level, there needs to be horizontal coordination across relevant ministries and sectors (such as agriculture, water, energy and environment) to enable collaboration in planning, the formulation of policies, management and monitoring. Vertical coordination between different levels of government also needs to be enhanced, especially if decision-making occurs at different levels or scales in different, but related, sectors – such as centralised energy planning and local water resource allocation.

*Adopting a nexus approach to policymaking and planning*

Another imperative is to adopt a coherent nexus approach that is underpinned by sound science. At the broadest level, governments should adopt a 'green economy' paradigm that strives for socially inclusive, economically efficient and environmentally sustainable development. More specifically, adopting a nexus approach to policymaking would entail formulating resilient development trajectories that explicitly take into account the interconnections between energy, food and water systems, and


**Solar cooker demonstration, Malawi**

manage the trade-offs that inevitably arise. A nexus approach must also integrate climate mitigation and adaptation policies and strategies with energy-food-water security policies.

*Employing nexus assessment tools*

Nexus assessment tools can assist nexus-oriented decision-making by measuring the impact of policy interventions on different sectors, and quantifying the implications for natural resource use and environmental impacts. Investment is needed to collect standardised and consistent datasets to operationalise nexus assessment tools.

*Enhancing cooperation among stakeholders*

Effective management of nexus challenges requires cooperation among stakeholders at all levels (international, national, and local) and across all sectors of society (including government, the private sector, international and regional organisations, civil society, academic institutions and non-governmental organisations). Not all nexus analyses will produce easy win-win solutions for various resource conflicts, and many will produce only negative trade-offs. In these situations, scientists must ensure that policymakers and stakeholders have all the information needed about impacts, costs, externalities, and so on, to enable the public sector and society to decide on preferred options.

*Improving international cooperation*

International and regional cooperation is vital to overcoming potential or actual intercountry rivalries and tensions over access to critical transboundary resources such as water, and to manage foreign direct investment in the agriculture sector to avoid 'land grabs' that harm local communities. Similarly, countries need to work towards international policy frameworks that foster cooperation on international trade in agricultural products (and by implication, embedded energy and water) to ensure that spikes in food prices triggered by extreme events (e.g. geopolitical or weather events) do not get amplified and impact on import-dependent countries.

*Ensuring sustainable and equitable governance of resources*

Enhancing food, energy and water security requires that governments manage their countries' resources both fairly and sustainably for the long-term benefit of their citizens. Governance systems can be improved by including participatory processes; bolstering accountability, transparency, monitoring and anti-corruption measures; and recognising human rights. While some direct forms of government investment will be necessary to support the achievement of energy, food and water security goals, distorting subsidies should be avoided.

### 3.1.2 Promoting inclusive green economies

A number of generic policy recommendations that address green economy goals are broadly applicable to energy, food and water systems:

*Expanding access to water, food and energy services*

Nexus vulnerabilities need to be addressed directly as part of national economic development and poverty alleviation strategies. Governments can start by including national energy, food and water security targets along with more traditional targets for socioeconomic development such as GDP growth and employment. More concretely, expanding access to energy and water will require investments in infrastructure, which may take different forms in rural and urban areas. Expanding access to food requires ways to ensure adequate access to arable land and other inputs so that people can produce food and/or income-generation opportunities to enable households to purchase food.

*Improving resource productivity and minimising waste*

One essential way of closing the existing and projected gap between demand for and supply of energy, food and water is to raise the productivity of resource use. This entails increasing the efficiency with which resources are used at all stages of the production-use chain so that more of the desired outcome (improved energy, food and water security) can be attained with less resource use. Several types of policy instruments can be employed to help raise resource productivity, including public investments, regulatory tools (e.g. efficiency standards) and economic incentives (e.g. smart incentives, taxes on pollution and subsidy reform). Governments can launch education and awareness programmes that provide information about nexus connections and resource use, and encourage greater efficiency. Policymakers should promote a minimum waste and recycling policy at national and local levels, and foster a culture of using remaining waste as a resource in multi-use systems.

*Conserving and restoring ecological infrastructure and reducing pollution*

It is essential to protect and rebuild ecosystems to ensure continued delivery of the ecosystem services that underpin energy, food and water security. This requires reducing pollution as well as taking measures to improve soil quality, and rehabilitating or protecting wetlands, forests and other natural systems that help regulate the hydrological cycle. There are two basic policy instruments that can be used to reduce pollution. The first is economic incentives, such as environmental taxes that address negative externalities and 'get the environmental prices right'. The second consists of regulations designed to limit unsustainable activities and behaviours; for example, by prescribing minimum standards for waste treatment or emissions, or proscribing the most polluting activities.

*Managing demand for resources*

To complement the largely supply-side options discussed above, governments can also address the increasing pressure on scarce resources by managing the growth in demand for energy, food and water (and other goods and services that depend on them). This is particularly relevant in wealthier developing countries where the basic needs of most citizens are already being met and living standards are higher. Consumer behaviour and consumption patterns can be managed through a combination of awareness campaigns, economic incentives and regulations.



**Water break at school, Ethiopia**

Table 3-1 summarises the main generic types of policy tools that can be implemented by national or local governments to encourage and facilitate the adoption of technologies and practices that mitigate nexus risks. The appropriate combination of policy instruments will depend on the specific priorities, institutional capacity and local context within each country. Some instruments (e.g. taxes, loan guarantees and many regulations) can be used in the short to medium term, while others (e.g. infrastructure investments and training programmes) are of a longer-term nature. Many policies are relevant to the national scale, while other interventions are applicable on a local or regional scale.

**Table 3-1: Summary of policy instruments to support nexus resilience and sustainability**

| | |
|---|---|
| PUBLIC INVESTMENT | ■ Public spending and investment (expenditure switching)<br>■ Infrastructure designed for resource efficiency and recycling (e.g. public transport, smart grids, greywater reticulation)<br>■ Restoration of ecological infrastructure<br>■ Procurement<br>■ Innovation and research and development expenditure<br>■ Training programmes<br>■ Extension services for agriculture<br>■ Public finance (e.g. grants, low-interest credit, microfinance, loan guarantees, public-private partnerships) |
| ECONOMIC INSTRUMENTS | ■ Green subsidies (price support measures, tax incentives, direct grants and loan support)<br>■ Environmental taxes (e.g. carbon tax; tax on waste)<br>■ Charges and levies (e.g. stepped block tariffs for water and power)<br>■ Feed-in tariffs for renewable energy<br>■ Eliminate harmful/distorting subsidies<br>■ Payments for ecosystem services<br>■ Tradable water rights and water markets |
| REGULATORY MECHANISMS | ■ Efficiency standards (e.g. for appliances, equipment and vehicles)<br>■ Bans on inefficient/obsolete technologies (e.g. incandescent lamps)<br>■ Green building codes (e.g. minimum energy performance standards)<br>■ Environmental impact assessments<br>■ Establishment of nature reserves and protected areas<br>■ Bans on polluting activities<br>■ Emission standards (e.g. industries, vehicles)<br>■ Maximum effluent concentrations<br>■ Requirements for treatment of water before discharge<br>■ Certification (e.g. organic farms)<br>■ Waste disposal and recycling regulations |
| EDUCATION AND AWARENESS | ■ Public awareness campaigns (e.g. radio and television)<br>■ School education programmes and curricula<br>■ Tertiary education programmes<br>■ Eco-labelling<br>■ Publication of water and energy footprints |

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**Solar photovoltaic farm, IPP Greefspan, Douglas, South Africa**

### 3.1.3 Technical measures to improve energy, food and water security

Within a nexus context, **energy security** can be enhanced by:

- Expanding access to modern sources of energy, especially in low-income countries and among the poor more generally.
- Building resilience to external energy shocks, for instance by developing indigenous energy sources.
- Improving energy efficiency and reducing waste all along the energy supply and use chain.
- Reducing the dependence of energy systems on water.
- Carefully managing bioenergy in order to avoid potential competition with food production.
- Reducing environmental impacts of energy systems, especially on water quality.

The resilience of **food systems** to nexus risks can be boosted by:

- Improving agricultural productivity sustainably.
- Reducing the energy intensity of agricultural production, for example through agroecological farming practices.
- Improving the energy efficiency and sustainability of food processing, distribution and storage.
- Raising water productivity in agriculture and food production.
- Managing demand and encouraging more energy-efficient diets.
- Reducing food waste throughout the food system.

Within the context of the nexus, **water security** can be enhanced by:

- Adopting integrated water resource management practices in rural and urban areas that aim to decouple water use from economic growth.
- Expanding access to safe water by investing in water supply infrastructure.
- Increasing the efficiency of water systems throughout the water value chain, including abstraction, conveyance, treatment, distribution and wastewater treatment.
- Managing water demand and enhance water consumption efficiencies in agriculture, industry and residential sectors.
- Reducing the reliance of water systems on energy in general and fossil fuels in particular.
- Improving the resilience of water systems to climate-related shocks and boosting water security through trade in virtual water.
- Minimising wastage of water and using wastewater as a resource.
- Safeguarding water quality by reducing pollution and restoring ecological infrastructure such as wetlands.

A wide range of specific technical measures can be adopted to mitigate nexus-related risks and improve energy, food and water security in developing countries (see the summary in Table 3-2). It is important to bear in mind, however, that the term ‘developing country’ spans a wide spectrum of nations with diverse characteristics. The applicability of these measures will therefore depend on regional, national and local contexts, such as a country’s level of development, geographic and climatic conditions, availability of different energy resources, suitability of agricultural crop and livestock mixes, and so on.

**Table 3-2: Summary of technical mitigation measures for energy, food and water systems**

| STAGE OF LIFECYCLE | ENERGY SYSTEM | FOOD SYSTEM | WATER SYSTEM |
|---|---|---|---|
| PRODUCTION | ■ Combined heat and power plants<br>■ Renewable energy generation<br>■ Supercritical coal power stations<br>■ Production of bioenergy | ■ Sustainable intensification<br>■ Conservation agriculture<br>■ Agroecological farming<br>■ Integrated nutrient management<br>■ Plant breeding<br>■ Integrated pest management and natural pesticides<br>■ Intercropping and crop rotation<br>■ Tillage reduction<br>■ Soil rehabilitation (mulching, composting) | ■ Sustainable groundwater management<br>■ Rainwater harvesting<br>■ Desalination<br>■ Preservation and rehabilitation of wetlands and aquatic ecosystems<br>■ Prevention of soil erosion and deforestation |
| TRANSMISSION/ CONVEYANCE | ■ High-voltage direct-current power lines | ■ Urban agriculture | ■ Gravity-fed systems<br>■ Repair and maintenance<br>■ Minimising leaks<br>■ Pumps with variable speed drives<br>■ Conduit hydroelectricity |
| STORAGE | ■ Improved batteries<br>■ Pumped storage | ■ Use renewable energy to help preserve and store food | ■ Maintenance of dams |
| PROCESSING | | ■ Improved maintenance of processing plants<br>■ Optimising combustion efficiency<br>■ Using high-efficiency motors | ■ Technical energy efficiency measures<br>■ Ecological infrastructure |
| DISTRIBUTION | ■ Decentralised mini-grids<br>■ Smart grids<br>■ Off-grid energy systems | ■ Improved logistics<br>■ Road and rail infrastructure<br>■ Relocalising food production and consumption systems<br>■ Developing urban and peri-urban agriculture<br>■ Local food markets | ■ Gravity-fed systems<br>■ Efficient pumps<br>■ Minimising leaks<br>■ Software for control systems<br>■ Micro-hydro technologies in pipes |
| CONSUMPTION | ■ High density compact cities<br>■ Efficient building design<br>■ Efficient appliances and cookstoves<br>■ Solar water heating<br>■ Efficient lighting<br>■ Eco-driving<br>■ Traffic management systems<br>■ Efficient vehicle designs<br>■ Electric and hybrid vehicles<br>■ Transport modal shifts to public transit and freight rail | ■ Encourage dietary shifts to foods requiring less water and energy inputs<br>■ Pre-emptively manage increased meat demand | ■ Sprinklers, precise irrigation, drip irrigation, deficit irrigation, 'smart' irrigation scheduling<br>■ Mulching, reduced tillage, drought-resistant crops<br>■ Various water efficiency technologies for industry<br>■ Low-flow showerheads, dual-flush toilets, efficient washing machines<br>■ Solar water heaters, geothermal heating |
| WASTE | | ■ Reduce post-harvest losses by building storage and refrigeration facilities and improving packaging<br>■ Improve distribution, e.g. improved road and transport infrastructure | ■ Gravity-assisted reticulation in wastewater conveyance<br>■ Efficient pumps |

## 3.2 Lessons from the Case Studies

In order to gain greater insight into the kinds of policies and technical measures that are applicable to different kinds of developing countries, this report investigated the experience of three case study countries. Table 3-3 presents a summary of the main policy recommendations for Malawi, South Africa and Cuba, which represent predominant aspects of the agrarian, industrial and emerging agro-ecological socio-ecological regimes. The key lessons emerging from these countries are as follows.

**To address nexus vulnerabilities, the main priority for countries with a largely agrarian regime is to expand access to food, energy and water among their populations, while limiting negative impacts on ecosystems.** The still limited reliance on fossil fuels in countries like Malawi can be viewed as an opportunity to leapfrog towards a more sustainable socioecological regime, without following the conventional fossil fuel-based pathway of industrial development that exposes economies to volatile international fuel prices. Such an economy could be powered increasingly by decentralised, small-grid or off-grid renewable energy systems using local energy resources. Governments should promote small-scale sustainable agriculture and agroforestry, which seek to increase food production based on knowledge-intensive systems and possibly in conjunction with bioenergy production to stimulate rural economies. Local water supply options such as rainwater harvesting and solar pumps could help to improve water access in rural areas and reduce the need for long-distance water transfers to urban areas. If policies to support these outcomes are successful, they could help to slow down the pace of urbanisation and therefore alleviate the growing pressure on urban infrastructure and services. The main obstacles to the achievement of this agenda are likely to be lack of institutional capacity, finance and household purchasing power. LICs will therefore need the support of the international community. Governments should strive to promote labour-intensive solutions and invest in knowledge-building and skills development for the long term.

**In countries (such as South Africa) with largely industrial regimes that rely heavily on fossil fuels, the key nexus security challenges are to limit the vulnerability to international energy price volatility, reduce energy and resource intensity, and reduce the negative impacts of fossil fuel use on the environment (notably soils and water resources).** The starting point should be a concerted effort to manage energy demand through incentives and regulations designed to enhance energy efficiency and conservation. On the supply side, increasing the renewable energy share of the energy mix can bring multiple benefits, including expanded energy access, and reduced pollution, carbon emissions and water consumption. To boost the resilience of the food system, a range of measures should be introduced to reduce energy intensity in agricultural production and food distribution. A programme of support for small-scale agroecological farming holds the potential to meet several goals including improving household-level food security, reducing reliance on fossil fuel inputs, and creating sustainable rural livelihood opportunities. In the water sector, governments should implement regulations and incentives to reduce environmental impacts of industrial activities (including industrial agriculture and extensive use of fossil fuels for power generation) to halt and reverse the degradation of freshwater resources. A potential obstacle to such measures aimed at 'greening' industrial systems is the lock-in to fossil fuel-based infrastructure systems that deliver energy services, food and water, and supporting socio-political regimes with dominant interests heavily invested in the status quo. However, falling prices of renewable energy, and investor appetite for renewable energy investments, are beginning to demonstrate that an alternative, more sustainable path is viable.

**Cuba provides an example of a country that adopted radical measures in its energy and food sectors in order to deal with a sudden and drastic limitation on oil imports, on which the country had relied heavily for energy and agricultural production. As such, it exhibits certain characteristics of an 'ecological' regime that might emerge to replace the industrial regime as more countries shift away from fossil fuel dependence.** Cuba's 'energy revolution' was enabled by a wide range of transforming institutional structures and policies, which included: energy targets; energy demand side management programmes including regulations on energy efficiency and phasing out inefficient appliances; public investments for the rehabilitation and decentralisation of the national electricity grid; energy-efficient transportation options such as bicycles and large buses; and spatial planning to promote localisation of economic activities. The government responded to the country's crippling food scarcity by reorganising the agricultural sector, converting large state farms into smaller cooperative farms geared towards productivity. The widespread adoption of agroecological practices has been the core engine of the Cuban food revolution. The government also promoted urban agriculture, partly through making land available and establishing local markets. In addition, food schemes were introduced to support vulnerable households. However, Cuba's success in reconfiguring its energy and food systems rested on a context-specific socio-political system (state socialism supported by a strong bureaucracy) and hence its experience with sweeping policy changes might be difficult to achieve (or less desirable) in other contexts. Nonetheless, another important lesson to be drawn from Cuba is that the country invested heavily in educating its people, which helped to shift behaviours and facilitated the adoption of new technologies and practices.

**Despite exhibiting major differences in their status quo challenges, all three case studies seem to be pointing in the direction of more sustainable 'green economies' as a way of mitigating risks in the energy-food-water security nexus.**

**Table 3-3: Comparison of key policy recommendations from the case studies**

| | MALAWI | SOUTH AFRICA | CUBA |
|---|---|---|---|
| GOALS | ■ Expand and modernise access to energy<br>■ Increase the productivity and diversity of the agricultural sector<br>■ Improve access to safe water | ■ Reduce the risks of fossil fuel reliance by boosting energy efficiency<br>■ Reduce energy intensity along the food value chain<br>■ Improve water security by managing demand and protecting quality | ■ Limit dependency on fuel and food imports<br>■ Consolidate agroecological farming practices<br>■ Strengthen water security in the face of climate change risks |
| ENERGY SECURITY | ■ Modernise access to biomass, with improved cookstoves, biogas digesters, biofuel production and sustainable forestry<br>■ Expand electricity access through investment in infrastructure, including decentralised renewables and mini-grids<br>■ Establish adequate oil storage facilities | ■ Introduce fuel conservation and efficiency measures to reduce oil import dependence<br>■ Increase power generation capacity with renewable energy sources<br>■ Reduce the water dependence of energy systems (e.g. expand solar and wind power)<br>■ Promote energy conservation and efficiency measures | ■ Maintain guidelines for energy targets and energy efficiency regulations<br>■ Further expand renewable energy<br>■ Diversify sources of oil imports<br>■ Increase cogeneration of heat and power<br>■ Adopt best practices in the built environment and hospitality industry to maximise efficiencies |
| FOOD SECURITY | ■ Adopt low-input, high-diversity agricultural systems and integrated food-energy systems<br>■ Promote crop and export diversification<br>■ Reform the FISP, e.g. linking it to conservation agriculture and precise application of fertilisers<br>■ Promote urban and peri-urban agriculture<br>■ Expand irrigation and improve its efficiency | ■ Use income support, competition policy, and support for small-scale farmers to boost food security<br>■ Reduce fossil energy use in agriculture through conservation agriculture, agroecology and solar pumps<br>■ Improve the efficiency of food distribution through localisation<br>■ Improve water productivity<br>■ Reduce food waste | ■ Consolidate agroecological farming<br>■ Continue urban agriculture<br>■ Expand irrigation networks<br>■ Assess costs and benefits of staple crop production (especially sugar) |
| WATER SECURITY | ■ Limit deforestation<br>■ Apply integrated water resource management<br>■ Develop urban waste management<br>■ Promote rainwater harvesting<br>■ Use solar PV pumps<br>■ Invest in multipurpose water resources projects | ■ Enhance water supply with dams, groundwater, transfers and rainwater harvesting<br>■ Protect water quality with regulations and by restoring ecological infrastructure<br>■ Manage water demand and improve water productivity in agriculture, industry and residential sectors<br>■ Reduce reliance of the water system on energy | ■ Restore ecological infrastructure and soil quality<br>■ Harvest rainwater<br>■ Expand infrastructure for water transfers |

## 3.3 Conclusions

By drawing on a growing international literature and three case studies, this report has showed that a broad array of policy measures and technical solutions are available to address the risks inherent in energy-food-water nexus. These interventions will form a critical part of societal transitions toward greater resilience and sustainability in the face of global and local environmental, resource and population pressures.

Enhancing food, energy and water security requires an integrated nexus approach that takes into account the linkages and interdependencies among food, energy and water systems and seeks to minimise the risks arising from these interconnections while also building resilience to external and internal shocks. This must begin with efforts to build well-functioning institutions, effective governance systems and integrated policy frameworks, as these are prerequisites for the design of effective policies and the implementation of viable technical solutions to tackle nexus risks and vulnerabilities. Both vertical and horizontal coordination within governments is essential to ensure better policy coherence and effectiveness, while cooperation must be sought with stakeholders from all sectors of society to ensure sustainable and equitable governance of resources.

Countries must devise strategies to build resilience to teleconnection impacts arising from their embeddedness in global trading systems and should engage in multilateral forums to improve international policy coordination in managing the nexus.

Individual nexus interventions will be much more coherent and effective if they are designed and implemented within an overarching paradigm aimed at a transition to 'inclusive green economies'. This involves expanding access to food, water and energy services while transforming economic systems to be more resource efficient, less carbon intensive, and less damaging to the environment. In short, economic growth must be decoupled from resource use and environmental impacts, for example through increased resource productivity, a reduction of waste, and the adoption of closed loop production systems.

A nexus approach includes two key principles. First, policy interventions should aim to identify win-win solutions that harness synergies and maximise co-benefits across the energy-food-water nexus. By way of example, certain renewable energy technologies present opportunities for synergistic solutions that widen energy access, reduce reliance on polluting fossil fuels, and limit the need for water in energy generation. Second, policymakers must deal with unavoidable trade-offs by assembling relevant scientific information and involving stakeholders in consultative processes to inform policy decisions.

There can be significant spatial differences in appropriate nexus mitigation strategies and policy interventions. In rural areas, the key issue is optimising land use to provide a range of services. This involves, *inter alia*, management of ecosystems to provide a sustainable stream of services, choices of whether to use land to produce food or biofuels, taking steps to minimise harmful impacts of agriculture such as soil erosion and salinization, and preventing the pollution of water resources. In urban areas, by contrast, the emphasis is on creating resource-efficient, low-carbon cities. This is partly about how to configure infrastructure systems to be as efficient as possible, such as integrated planning of infrastructure for energy, water and wastewater access.

Management of the energy-food-water nexus is emerging is one of the largest and most pressing challenges facing humanity this century. It is hoped that the overview of key nexus issues, drivers, risks and mitigation options provided in this report can lay the foundation for more specific and detailed research and policy formulation in the developing world. Perhaps the greatest scope for further nexus research lies at the **country level**, because the nexus can play out very differently in different contexts, depending on factors such as resource endowments, climate and topography, and level of development, etc. There is also a need for **regional studies** that explore possibilities for inter-country cooperation in responding to nexus challenges that are especially acute in some parts of the world. At a **global scale**, processes need to be developed for dealing with nexus issues within multilateral forums, to handle issues such as land and virtual water grabs, agricultural trade policies that exacerbate food price crises, and other societal teleconnections.

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