quantum global
research lab

Managing the Energy-food-water-Nexus in Developing Countries: Case Studies of Transition Governance

J.J. Wakeford, S.M Lagrange, C. Kelly

QGRL WORKING PAPER
No. 2016/01

April 2016

Managing the Energy-food-water Nexus in Developing Countries: Case Studies of Transition Governance

Jeremy J. Wakeford,[1] Sasha Mentz Lagrange[2] and Candice Kelly[2]

April 2016

Abstract

Energy, food and water security have traditionally been examined by researchers and addressed by policymakers in isolation of one another. However, an emerging literature is examining the numerous interdependencies, linkages and spill-overs that exist among complex energy, food and water systems. These interconnections, referred to hereafter as a 'nexus', imply that the governance of these systems should be conducted in an integrated manner that seeks to minimise trade-offs and maximise synergies. This paper aims to contribute to this growing nexus literature, as well as the related field studying the governance of transitions, by investigating the strategies and policies that are required to manage nexus risks and vulnerabilities in different developing country contexts. A case study approach is followed, in which Malawi, South Africa and Cuba are taken as representatives of (largely) agrarian, industrial and 'sustainable' socioecological regimes, respectively. In each case, an analysis is conducted of the key aspects of the nexus, including challenges and risks, as well as of relevant policy frameworks and interventions that have been introduced in these countries. The paper finds that nexus challenges manifest differently in the various socioecological regimes. In the Malawian case, a key vulnerability is the low productivity of the agrarian food regime. The government is trying to address this through a fertiliser subsidy scheme, but this raises new risks for long-term soil and water quality. South Africa's major challenges lie in the dependency of food systems on (largely imported) oil, and the vulnerability of its scarce water resources to pollution from fossil fuel-based industrial activities and agriculture. The Cuban case shows that the adoption of agroecological farming practices can help to achieve substantial reductions in energy use by the food system, while boosting the average level of food supply per capita. The paper concludes that despite exhibiting major differences in their status quo challenges, all three case studies point to the need for transitions to more sustainable 'green economies' in order to mitigate growing risks in the energy-food-water security nexus. It is further suggested that countries like Malawi have an opportunity to leapfrog the fossil-fuelled industrial stage of development and transition more directly from an agrarian to a sustainable regime.

Keywords: energy-food-water nexus; sustainability transitions; food security; transition governance.

[1] Macroeconomist, Quantum Global Research Lab, Zug, Switzerland. Email: Jeremy.Wakeford@quantumglobal.ch (corresponding author).
[2] Research Associate, Sustainability Institute, Stellenbosch, South Africa.
Views expressed in this paper are attributable to the authors and not necessarily to their institutions.

1 Introduction

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 at adequate quality levels. Globally, some 1.3 billion people lack access to electricity, over 780 million people lack reliable access to safe drinking-water and sanitation (World Bank 2013), and it is estimated that 805 million people experience chronic undernourishment (Food and Agriculture Organization [FAO] 2014).

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. By 2050, the demand for energy is expected to increase by 80%, food by 60% (OECD-FAO 2014) and water by 55% (International Renewable Energy Agency [IRENA] 2015). However, 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; Godfray et al. 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 and security (Intergovernmental Panel on Climate Change [IPCC] 2014).

Energy, food and water security have traditionally been examined by researchers and addressed by policymakers in isolation of one another. However, an emerging literature is examining the numerous interdependencies, linkages and spill-overs that exist among complex energy, food and water systems (see, for example: FAO 2011; Hof 2011; World Economic Forum [WEF] 2011; Rodriguez, Delgado, DeLaquil & Sohns 2013; World Bank 2013; Searchinger et al. 2014; IRENA 2015). These interconnections, referred to as a ‘nexus’, imply that the governance of these three critical systems should be conducted in an integrated manner that seeks to minimise trade-offs and maximise synergies. This paper aims to contribute to this growing nexus-related literature as well as the related literature on the governance of sustainability transitions, by investigating the strategies and policies that are required to manage and mitigate nexus risks and vulnerabilities in developing countries. In addition, it explores the question of how much context matters, in the sense that different policy responses may be required in countries exhibiting varying stages of development or different socioecological regimes.

After a brief outline of conceptual issues in section 2, a case study approach is followed, in which Malawi, South Africa and Cuba are examined as representatives of (largely) agrarian, industrial and ‘sustainable’ socioecological regimes, respectively. Section 3 presents an analysis of the key aspects of the nexus in each case, including the major challenges and vulnerabilities. Section 4 assesses the strengths and weaknesses of relevant policy interventions that have been introduced in these three countries and makes additional recommendations for policies designed to improve resilience and sustainability. The final section draws conclusions and points to areas requiring further research.

2 Conceptual framework

This section describes two theoretical frameworks that underpin the case study analyses. The first part defines what is meant by the energy-food-water nexus by specifying the lifecycle elements of the three systems and mapping the main interactions among them. It also identifies the major generic drivers that influence the nexus. The second part briefly outlines the three socioecological regimes that informed the choice of case study countries.

2.1 The energy-food-water nexus

Energy, food and water systems lie at the interface between social and ecological systems. Coupled social-ecological systems are 'complex' in that they are composed of many, non-homogeneous components that interact along multiple pathways (Cilliers 2008). These interactions can be dynamic and non-linear, and they encompass positive and negative feedback loops, thresholds and tipping points. Crucially, these interactions give rise to the emergent properties of the system; the properties are not contained within the individual components themselves (Cilliers 2008). This principle is recognised in this nexus research via the focus on the interactions among the energy, food and water systems, each of which is a complex system in its own right. In this paper, energy, food and water systems are understood and analysed in terms of their entire value chains or life cycles, including production, processing, storage, distribution, consumption and waste disposal stages, and their supporting infrastructures. Table 1 summarises the main elements for each of these stages across the three systems.

Table 1: Main elements in energy, food and water system life cycles

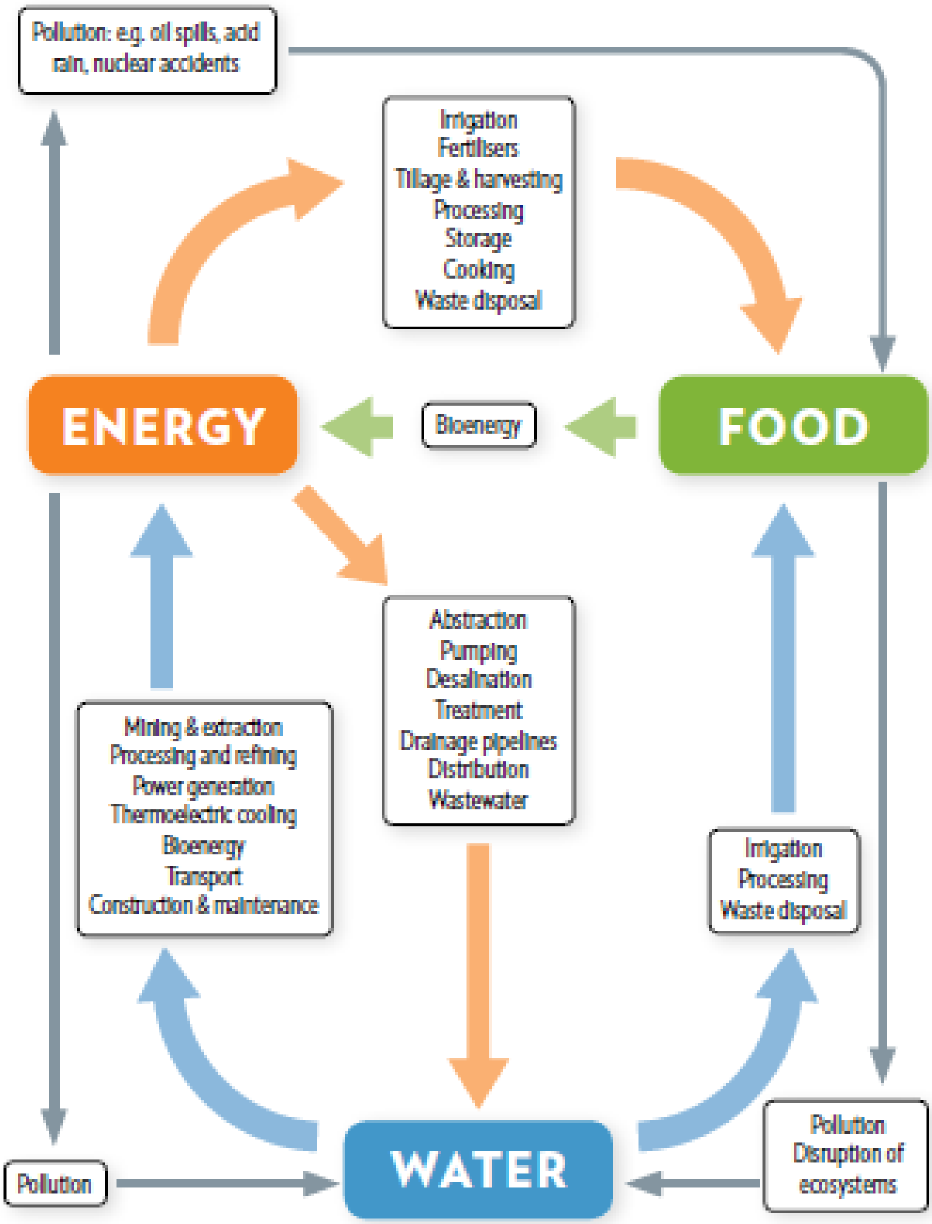
Life cycle stage:	Energy system	Food system	Water system
Primary resources	• Biomass • Fossil fuels, uranium • Wind, solar, hydro, geothermal	• Soils, nutrients (Nitrogen, Phosphorous and Potassium (N, P, K), lime), manure, water, energy	• Precipitation, rivers, lakes, aquifers
Production	• Extraction of primary fuels and minerals • Machinery, drilling rigs, etc.	• Pesticides • 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 • Power generation	• Food processing and manufacturing	• Treatment, purification • Desalination
Distribution	• Oil and gas pipelines • Electricity transmission	• Roads, railways, ports • Shops, markets	• Pipelines, pumps, reticulation systems
Consumption	• Energy access • Pricing structures • Health implications of energy sources	• Calorific intake, nutritional content, dietary patterns, cultural preferences, nutrition and health	• Water access • Pricing structures • Health implications of water quality
Waste	• Mining waste • Greenhouse gas emissions from fossil-fuel combustion • Spent uranium fuel	• Nutrient flows, on-farm agri-waste, food waste • Eroded soils, siltation • Embodied water • Embodied energy • Greenhouse gases	• Water-borne sewage systems • Treatment of waste water

The interdependencies that characterise the nexus occur at all of these life cycle stages. The major interdependencies are as follows (see Figure 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 used at many stages of the water system value chain, including: extraction from lakes, rivers and aquifers; desalination; water treatment and purification; construction of dams, reservoirs and pipelines; bulk conveyance and distribution to end-consumers; 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.
- Energy industries, agricultural production and food processing may negatively affect water quality via various forms of pollution and interference with ecosystem services that are critical for the hydrological cycle.

The nexus operates at different spatial scales, including globally, regionally, nationally and locally. The global perspective is important given the increasing international integration of energy and food markets. While water is not in itself a globally traded commodity, it is increasingly traded in its 'virtual' form, embedded in food – both raw and processed – and manufactured goods. An important concept for understanding nexus interactions (and resulting risks) is that of 'societal teleconnections', defined as "human-created linkages that link activities, trends, and disruptions across large distances, such that locations spatially separated from the locus of an event can experience a variety of impacts from it nevertheless" (Moser & Hart 2015:13). Put more simply, impacts and vulnerabilities do not only result from local causes; they can come about due to long-distance relationships, such as the embeddedness of individual countries within the world trading system. Examples of societal teleconnections operating on a global scale that are of particular relevance to the nexus include: (1) international trade; (2) energy systems; (3) food systems; (4) geopolitical alliances; and (5) financial systems.

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

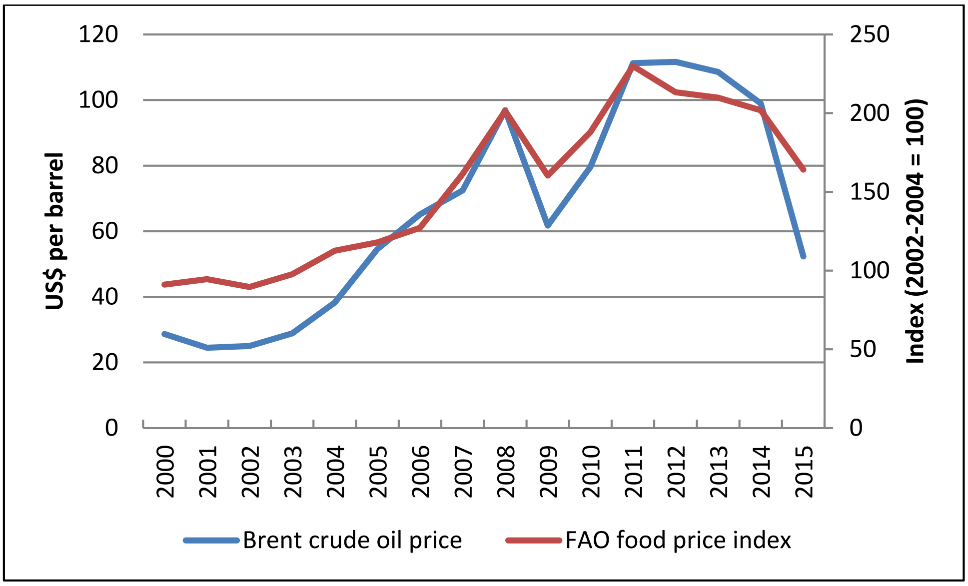


Source: Adapted from IRENA (2015, fig. 1.1, p.24)

There are several systemic drivers operating at a global level (and in some cases on a national and local level) that affect all components of the nexus. 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 depletion and increasing scarcity of resources (e.g. of fossil fuels, arable land and fresh water supplies) and environmental degradation (including pollution and greenhouse gas emissions). 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 (WEF 2011; IPCC 2014).

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-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, including on-farm production and distribution (see Figure 2). Thus food and energy security – both critically affected by international prices – are inextricably linked. 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 may be counteracted by the rebound effect (Berkhout, Muskens & Velthuijsen 2000).

Figure 2: International crude oil and food prices



Source: EIA (2016) and FAO (2016a)

2.2 Socioecological regimes

Since 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 is based 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 fundamental ways in which energy and materials are used to satisfy collective human needs and wants. Three established and one emerging socio-metabolic regimes have been identified in the literature (Sieferle 2001; Fisher-Kowalski & Haberl 2007). In this paper, a case study country is selected to represent each of three regimes, as follows (the earlier, *hunter-gatherer* regime is not considered).

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 a new 'sustainable' or '*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 (Fischer-Kowalski & Haberl 2007). Cuba is used as a case study to illustrate aspects of this regime, particularly with reference to the agroecological component of the country's food system.

3 Case studies of nexus linkages and vulnerabilities

This section presents the three case studies of the nexus in different developing country contexts. In each case, an overview is provided of key elements and linkages in the energy-food-water nexus, and the major nexus-related risks and vulnerabilities are highlighted. Section 3.4 provides a comparative assessment.

3.1 The nexus in an agrarian regime: Malawi

Malawi is a small, landlocked country in East Africa with about 17 million inhabitants. The following statistics regarding the dominance of agriculture in both economic activity and employment, coupled with extensive reliance on biomass energy, demonstrate the largely agrarian nature of Malawi's socioecological regime. More than 77% of households depended on (mostly subsistence) agriculture for their livelihoods in 2013 (FAO 2016c). Farming generally takes place on fragmented, small parcels of customary land (Gamula, Hui & Peng 2013) and the agricultural sector is the main source of economic growth and exports, representing about 37% of gross domestic product and 83% of foreign exchange earnings (AfDB 2013). Malawi's population is predominantly rural, with only 15% living in urban areas (NSO 2012). The country is heavily reliant on biomass energy, with almost 90% of the population using wood or charcoal as a primary source of energy (Gamula et al. 2013). Only 10% of the population is connected to the electricity grid, with huge disparities between urban (37%) and rural areas (2%) (World Bank 2016). The country's overwhelming reliance on traditional biomass fuels is arguably both a cause (since it limits the productivity and diversity of economic activities) and a result (indicating limited effective demand) of Malawi's extremely low per capita gross national income, which stood at $790 in purchasing power parity terms in 2014 (World Bank 2016). This low-income status, coupled with the very high poverty rate – some 72% of the population lived in extreme poverty in 2012 (World Bank 2016) – illustrates the enormous limitations of the agrarian regime.

Given its largely agrarian economy, Malawi provides a useful example of how the nexus manifests in a predominantly rural, underdeveloped context. Subsistence farming in Malawi has traditionally relied very little on external energy inputs; most of the energy required in the food system is for used for cooking. The use of petroleum fuels for transporting produce to agricultural markets is negligible in the subsistence and small-scale farming sector.[3] Malawi's main source of energy – fuel wood – clearly depends on adequate rainfall. The same is true for the production of bioethanol from sugarcane, which contributes 3% of the national liquid fuel supply (Gamula et al. 2013). The country's limited power generation capacity (286 megawatts) is almost entirely dependent on adequate water flows for the hydroelectric power stations on the Shire and Wovwe rivers (Kumambala & Ervine 2009). Water infrastructure is generally poorly developed, especially in the rural areas, and modern irrigation systems are underdeveloped. The agricultural sector accounts for about 86% of water withdrawal in Malawi, but mostly in the form of green water, i.e. water from rainfall and groundwater sources that does not rely on infrastructure (FAO 2016c). While the rainfed nature of agriculture means that dependence on energy supplies for irrigation is limited, this constrains crop yields.

Although nexus interdependencies are somewhat limited in the agrarian regime owing to the lack of modern infrastructure and production and distribution processes, there are several major nexus-related vulnerabilities. First, the low productivity of the largely subsistence agricultural sector, together with large post-harvest food losses due to a lack of adequate storage facilities, results in a high level of food insecurity. Many households are barely able to produce enough for their own consumption, let alone a marketable surplus to generate income and alleviate extreme poverty. An estimated 23% of the population were undernourished between 2010 and 2012 (FAO 2016b). Food security is also jeopardised by the direct dependence for much of agricultural production on rainfall and the lack of irrigation infrastructure.

Second, the over-reliance on traditional biomass fuels has adverse impacts on health (through indoor air pollution) and the environment, including deforestation, soil erosion, siltation and the resulting interference with water supplies and hydropower generation (Kambewa & Chiwaula 2010). The extremely limited access to modern energy sources hinders the expansion of economic activity and retards human development. Third, a lack of access to improved water and sanitation are also significant challenges, and the latter also contributes to water pollution through faecal contamination (Government of Malawi 2011).

Fourth, increasingly erratic rainfall patterns, linked to climate change, pose a threat to water security, food production and hydropower generation (Wood & Moriniere 2013). The overreliance on singular sources of food (maize) and energy (biomass) both make the country more vulnerable to climate change (e.g. droughts and flooding), while aggravating its effects, as the dual pressure on woodlands has led to deforestation in several parts of the country (Kumambala & Ervine 2009). Apart from climate change, the other major drivers affecting the nexus in Malawi are population expansion (the United Nations Population Division (UNPD 2012) projects a population of 26 million by 2030) and economic growth, which are putting increasing strain on limited food, water and energy supplies.

---

[3] Malawi also has a small, more modernised commercial farming sector that produces mainly export crops such as tobacco; however, the focus here is on the traditional farming sector.

3.2 The nexus in an industrial regime: South Africa

South Africa is classified by the World Bank as an upper-middle income country, with a per capita gross national income (in purchasing power parity terms) of $12 700 in 2014 (World Bank 2016). Given its relatively sophisticated industrial systems, South Africa provides a useful example of a largely industrial socioecological 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 67% of primary energy and powers 90% of electricity, while oil contributes about 16% of total energy supply and 98% of transport energy (IEA 2016). About 95% of agricultural output originates from industrialised commercial farming and less than 5% of employed people work in the agriculture sector (World Bank 2016). The economy is dominated by services (68% of gross value added) and industry (29.5%), while agriculture contributes just 2.5% (World Bank 2016).

Given this industrialised economic structure, it is not surprising that the energy-food-water nexus interconnections are more complex than those in Malawi's agrarian regime. The food system in South Africa is highly dependent on fossil fuel energy at every stage of the value chain (Wakeford & Swilling 2015), as specified in section 2.1. Food production is also clearly critically dependent on water inputs – primarily at the primary production stage, but also to a lesser extent for food processing (Baleta & Pegram 2014). Water is needed at various stages of the energy system life cycle, including coal and uranium mining, oil refining and production of synthetic liquid fuels from coal and gas, and cooling in coal-fired power stations. Hydropower has a relatively small water footprint as it contributes less than 2% of South Africa's power generation capacity (IEA 2016). While production of biofuels is currently very limited, the industry is being promoted by various government policies (notably blending regulations), and expansion of biofuel production could have significant impacts on water demand if it is irrigated (Brent 2014). The direct use of food products for bioenergy production is very limited, both because the biofuel industry is at a nascent stage and because the government has prohibited the use of maize (the main food staple) as a feedstock for ethanol production owing to food security concerns. Finally, most households and industry get their water from municipal water systems, and energy inputs are needed at all stages of the water supply-use cycle, including abstraction, treatment, distribution to consumers, and waste-water reticulation and treatment.

South Africa's relatively sophisticated industrialised systems have supported reasonably high levels of national and household energy, food and water security compared to other developing countries – except in some poverty-stricken rural areas and urban informal settlements. Nonetheless, the nexus exhibits a considerable degree of vulnerability that arises from resource dependence and environmental degradation. Although South Africa is able to meet its national food requirements through domestic production and imports, the food system's dependence on energy inputs renders it vulnerable to increased prices and interruptions to supplies of both liquid fuels and electricity (Wakeford & Swilling 2014). Energy price shocks quickly get transmitted to food prices, which threatens food security for poorer households (Mason-Jones et al. 2014). 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. The depletion of fossil fuel resources – especially domestic coal and global oil reserves – could pose a threat to South Africa's industrial regime in the longer term (Hartnady 2010; Wakeford 2013).

Despite the numerous challenges within the energy and food systems, their dependence on increasingly scarce and degraded water resources could be the biggest nexus risk in the medium to long term. Ironically, 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 major coal fields, arable land and key river systems (von Bormann & Gulati 2014). Water and soil quality are at risk from acidification (resulting from coal mining and nutrient leaching), pollution from mines, industry and agricultural pesticides, and eutrophication from intensive use of chemical fertilisers (FAO 2005; GCIS 2012; Oberholster & Botha 2014). Should exploration and production of shale gas proceed in the vast Karoo Basin, this will require large amounts of water for drilling, well completion and hydraulic fracturing in one of the most arid and water-stressed regions of the country (Fig & Scholvin 2015). Furthermore, efforts to mitigate climate change by introducing carbon capture and storage could raise the water intensity of coal-fired power stations by between 46 and 90%, depending on the type of plant technology used (von Bormann & Gulati 2014).

These risks highlight the dilemma of the industrial regime, namely that increased energy supplies – and resulting economic sophistication – come at the expense of greater pollution costs. As an arid country, South Africa faces difficult trade-offs in terms of the allocation of water among competing sectors and the protection of water resource quality in the face of development demands.

3.3 The nexus in an agro-ecological regime: Cuba

Until 1989, 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 phase called the 'Special Period in Peacetime' (Suárez, Beatón, Faxas Escalona & Pérez Montero 2012). 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 (Endres & Endres 2009). The energy and food systems underwent major 'revolutions' (Altieri et al. 2012; Guevara-Stone 2008; Koont 2004), such that Cuba provides an example of an emerging agro-ecological socioeconomic regime.[4]

In the energy domain, Cuba has achieved significant efficiencies, with its total energy consumption falling by 52% between 1990 and 2012 (FAO 2016b). The government has set a goal of producing 24% of its electricity from renewable sources by 2030 (EIA 2015). Renewables have formed the backbone of new decentralised energy systems, affording greater energy security in the event of major weather events such as hurricanes (Piercy et al. 2010). Some electricity and bioethanol energy is generated from sugar bagasse and sugarcane, respectively (SYC 2009). There has not been quantified research conducted on the water requirements of sugarcane in Cuba, but sugarcane is known to be one of the world's thirstiest

[4] Less information is available about Cuba's water system and the changes it has undergone, and therefore this section focuses mainly on the energy-food system.

crops (WWF 2015). Otherwise, the direct reliance of the energy sector on water is minimal, as hydropower accounts for less than 1% of the country's electricity mix (IEA 2016).

The need to grow food using much less oil (implying less use of mechanisation) and synthetic chemical inputs (fertilisers and pesticides) sparked major changes in Cuba's agricultural system in the early 1990s. A new agricultural paradigm emerged, based on a shift in farming practices from conventional to agroecological, together with changes in land management – notably including the rise of urban agriculture (Piercy et al. 2010). About three million hectares of land are farmed using agroecological practices (Altieri et al. 2012). The energy consumed by Cuba's agricultural sector[5] followed a marked declining trend between 1990 and 2012, with a 68% reduction in overall energy use over the period (IEA 2016). Farmers returned to animal traction to replace tractors they could no longer run on diesel (Pfeiffer 2006), and the country as a whole used 72% less agricultural chemicals in 2007 than in 1988 (Rosset et al. 2011). The decrease in synthetic inputs was accompanied by an increase in the production of vegetables produced by small farmers, with an average annual growth of 4.2% in per capita food production from 1996 to 2005 (Rosset et al. 2011). Thus the agroecological model has boosted energy efficiency and conservation and also demonstrated its viability in terms of certain types of food production, with yields of numerous agricultural products outperforming those of the industrial model (Rosset et al. 2011).

Another benefit of agroecological systems is that they tend to be more water-wise than industrial agricultural systems. Agroecological farming ensures that water run-off is minimised and soil evapotranspiration is prevented through practices such as deep mulching (covering the ground with thick layers of biomass), canopy control through agroforestry, green manuring and optimising water usage by all tree and plant species. Furthermore, carbon levels and microbiological life is higher in organic soils, thus ensuring greater water absorption (Altieri et al. 2012).

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. 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. Developments in agroecological practices have also played a critical role in reducing over-cultivation of land, thus reducing stress on soils, and reducing the use of fertilisers and pesticides, thereby protecting watercourses from nutrient leaching and chemical contamination (Rosset et al. 2011). Thus far, however, agroecological farming has important limitations in terms of cereal, dairy and meat production.

It must be noted, however, that the entire country does not conform to the agroecological model. Cuba's overall energy system is still heavily reliant on oil and, to a much lesser extent, natural gas. Cuba's own oil and gas reserves are depleting and it is heavily dependent on imported oil, mostly subsidised crude from Venezuela (EIA 2015). Oil comprises on average 35% of total imports, and food accounts for 15% (IFAD 2015). Furthermore, there is evidence that Cuba's agricultural sector is becoming dualistic, with the (re)emergence of an

[5] This refers to direct energy consumption (e.g. fuel and electricity), rather than the energy embodied in inputs such as fertilisers, pipes, etc.

industrial/biotechnological facet, as testified by the expansion of maize and soya monocrops and the advent of genetically modified crops (Altieri & Funes-Monzote 2012). Cuba relies on the commercial production of certain cash crops to finance imports of some of its food requirements. These 'protected' areas for large-scale, industrial-style agricultural production represent less than 10% of the cultivated land, but they are increasing in scale (Altieri & Funes-Monzote 2012). 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.

3.4 Comparative assessment

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, and partly because the economies are mixed in terms of traditional/agrarian, industrial and 'ecological' components. Nevertheless, they provide a more nuanced and detailed illustration of how the nexus dynamics play out in different developing country contexts.

The three countries rely primarily on different types or mixes of energy resources – traditional biomass (Malawi), fossil fuels (South Africa) and a drive towards using renewable energy in Cuba. Traditional biomass is limiting in the range and extent of economic activities it supports, and carries high costs for human health and the environment. Fossil fuels like coal and oil have underpinned industrialisation in South Africa as elsewhere, but a high price is also paid in terms of pollution impacts. The Cuban case shows how difficult and slow a transition away from fossil fuels can be.

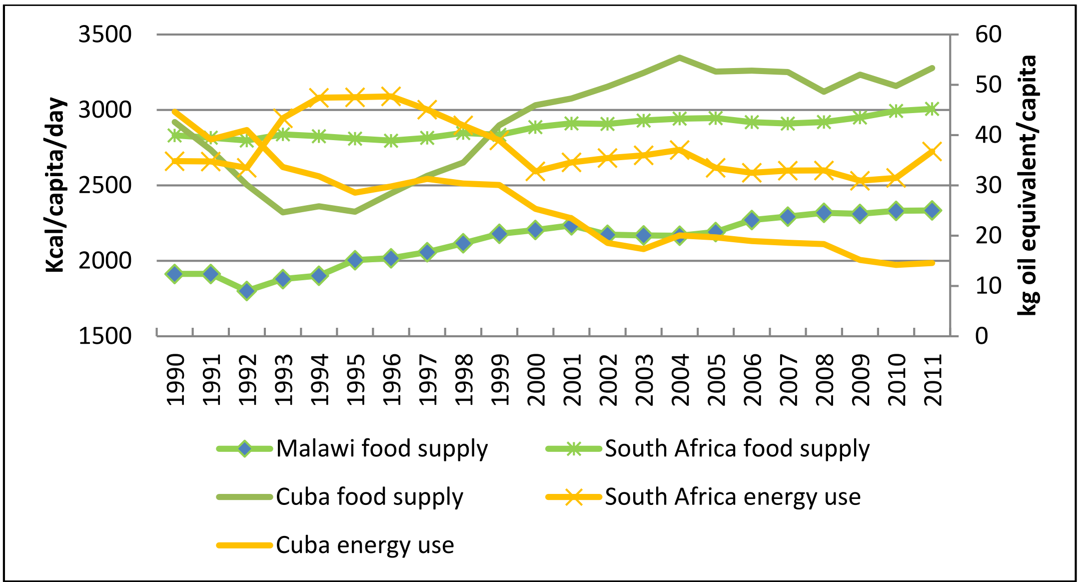
The various farming styles in each country are also illustrative of different challenges facing their food systems. Malawi has a majority subsistence, small-scale farming sector characterised by low productivity, and nearly a quarter of the population is undernourished. South Africa's predominantly industrial farming regime provides adequate amounts of food nationally – but only for those that can afford it. This industrial agriculture regime is also highly dependent on fossil fuel inputs and contributes greatly to soil degradation and water pollution. Cuba's agroecological farming methods have boosted the quantity and nutritional quality of food, while significantly decreasing the amount of energy used in the agriculture sector.

The food-energy nexus differences between Malawi, South Africa and Cuba are nicely illustrated in Figure 3, 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.[6] 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 under the government's farm input subsidy programme (discussed in more detail in section 4.1). 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

[6] Data on energy consumption in agriculture are not available for Malawi.

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 appear to show that through low-energy agroecological farming, Cuba has found a much more energy-efficient way of meeting its citizens' dietary requirements compared to South Africa; however, Cuba's increase in food supply has been met partly by growing imports.[7]

Figure 3: Per capita energy use in agriculture and food supplies in Malawi, South Africa and Cuba



Source: FAO (2016b), IEA (2016)

4 Governance of the nexus: policy recommendations for resilience and sustainability

This section considers possible strategies, policies and measures governments in developing nations (with support from multilateral agencies, donors and non-governmental organisations) could adopt in order to mitigate nexus-related risks to energy, food and water security and to make energy-food-water systems more resilient and sustainable. It begins with some generic recommendations that are broadly applicable to all developing countries, and then discusses more targeted policies that respond to the specific vulnerabilities identified for each of the three case study countries.

4.1 Generic recommendations

4.1.1 Transitioning to sustainability

The recommendations are informed by a set of overarching policy goals that rest on the three pillars of sustainable development: social inclusiveness, economic productivity and environmental sustainability. The first goal is to improve food, water and energy security for people living in developing countries, especially for those in the poorest segments. This requires

[7] For example, cereal imports grew from 1.37 million tonnes (mt) in 1996 to 2.1 mt in 2011 (FAO 2016b).

improving access to basic services that underpin a decent quality of life, healthy societies and productive economies. The second goal of enhancing economic productivity goes further than the conventional notion of economic efficiency because it recognises the limited extent of natural resources and therefore the necessity of raising the productivity of resource use (UNEP 2011; UNEP 2014). This begins with waste reduction, but also includes the use of innovative technologies that allow more value to be created from fewer material inputs, and unavoidable waste to be used as a resource in closed-loop production and consumption systems. The third goal involves improving environmental sustainability by protecting and restoring ecosystems and biodiversity levels, and reducing environmental impacts including pollution and greenhouse gas emissions. This feeds back into social and economic goals by ensuring a continued stream of ecosystem services, which underpin all socioeconomic systems (BMU 2012).

The concept of transitioning to 'green economies' has gained increasing traction in global development discourses in recent years as it offers a way in which to operationalise sustainable development objectives. UNEP (2010:5) defines a green economy as one that "results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities." Alternatively, "a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive" (UNEP 2011:16). A key green economy principle is the need to decouple economic growth from resource use and environmental impacts (Fischer-Kowalski & Swilling 2011). In the context of the nexus, the more specific aim would be to decouple energy and water consumption from economic growth and particularly from an increase in food production.

4.1.2 Strengthening institutions, governance and policy coherence

Well-functioning institutions, effective governance systems and integrated policy frameworks are prerequisites for the design of effective policies and the implementation of viable 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 discussed above. The following recommendations 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.

The complexity of nexus issues and the many trade-offs involved in nexus policy choices implies a need to build strong institutions with effective capacity. Capacity-building programmes should promote multi- and transdisciplinary approaches and foster the adoption of a coherent nexus approach that is underpinned by science as a basis for sound policymaking (BMU 2012). 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 (IRENA 2015). Investment is needed to collect standardised and consistent datasets to operationalise such nexus assessment tools (Stockholm Environment Institute 2014).

Responding to – and in some instances preventing – nexus challenges means that a silo approach to policymaking within governments must be transcended. There needs to be improved 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 (BMU 2012). 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.

Effective management of nexus challenges also 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). International and regional cooperation is vital to overcoming potential or actual intercountry rivalries and tensions over access to critical transboundary resources such as water (BMU 2012; UN-Water 2014). 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 (Bailey et al. 2015).

Enhancing food, energy and water security requires governments to 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 (BMU 2012).

4.2 Improving access to basics in Malawi

In light of the vulnerabilities identified in section 3.1, nexus policy interventions in Malawi should aim primarily at: expanding and modernising access to energy; significantly increasing the productivity, diversity and sustainability of the agricultural sector to enhance food security; and improving access to safe water, especially in the context of increasing climate variability. Meeting these multiple objectives will require management of certain potential trade-offs.

4.2.1 Modernising access to energy

The main priorities for improving energy security in Malawi are to define sustainable solutions to modernise the use of biomass to improve efficiencies and reduce ecological degradation, and to expand access to electricity through investment in power generation and distribution infrastructure.

The 2009 Biomass Energy Strategy stands out as an attempt to take a proactive approach towards managing and developing the biomass energy sector, but it has not (yet) achieved the large-scale shift required to genuinely transform the biomass energy sector (Gamula et al. 2013). There are, however, several initiatives that have been undertaken by the government of Malawi that illustrate its attempts to respond to the energy/biomass crisis. The National Improved Cookstoves Task Force, launched in 2013, has the goal of getting 2 million households to adopt the stoves by 2020 (Nielsen et al. forthcoming). The use of improved cooking stoves enables improved combustion and energy efficiency, which brings socioeconomic benefits, health benefits (by reducing particulate emissions), and a reduced impact on forest ecosystems. There have also been attempts to promote biogas digesters, with the construction of a number of units as pilot projects for rural communities, but local acceptance was found to be limited (Gamula et al. 2013). The production of bagasse from sugarcane and rice hulls has steadily increased over the past decade and further expansion can provide feedstock for cogeneration plants. Malawi has a competitive advantage in terms of its technical expertise and experience in the production of liquid biofuels, especially ethanol from sugarcane, which it could further capitalise on. However, there is a need for studies that examine the lifecycle impact of expanded ethanol or sugarcane production on energy, food and water security in Malawi. Promoting sustainable forestry management principles can help to prevent forest degradation and deforestation, while enabling communities to benefit from the many services offered by forest ecosystems, be it in the form of wood or non-timber forest products (Shackleton & Shackleton 2004). A key challenge in driving the recommended modernisation of biomass usage in Malawi is the fact that mandates relating to the biomass sector fall under different government departments. Another obstacle is weak institutional capacity, which hinders policy implementation.

Public investment is required for energy-smart infrastructure, characterised by decentralised small grids relying on renewable energy sources such as solar, particularly to provide electricity in rural areas. Malawi has large untapped energy generation potential from renewable energy sources – with solar, hydro and geothermal showing high potential and wind and biomass showing medium potential (IRENA 2012). Engaging with the private sector (e.g. through public-private partnerships or independent power producer programmes) to develop these sources as opposed to importing fuel to power diesel generators would be a far better use of resources. By introducing measures that support the deployment of renewable energy technologies in rural areas, the government can help improve access to energy for agricultural communities.

4.2.2 Boosting agricultural productivity

In an effort to transcend some of the limitations of the agrarian regime, Malawi's government has in recent years introduced a Farm Input Subsidy Programme (FISP) – mainly involving subsidised fertilisers – in order to boost crop yields. The programme aims both to improve food security and to boost foreign exchange reserves through increased agricultural exports. While this programme appears to have raised yields, in particular of maize (Pauw & Thurlow 2014), 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, amplified by exchange rate weakness. In addition, the detrimental effects of excessive fertiliser use on water resources (in particular, eutrophication) can negatively affect electricity generation by stimulating plant growth that reduces water flows to the country's main hydropower facility (Liabunya 2004).

The FISP could be reformed in various ways in order to take nexus issues into consideration and improve sustainability. Efficiency could be raised through precise application of fertilisers, which aims to improve the accuracy and timing of applications (FAO 2011) and can contribute to lower greenhouse gas emissions per unit of output and possibly avoid excess nitrates being discharged into aquifers and surface waters. Wood and Moriniere (2013) recommend the expansion of the FISP in ways that promote and support climate-resilient crops and crop mixes for each climate zone identified in the country, thus supporting increased crop diversification and intensification. They further recommend linking FISP subsidies to increases in investments in conservation agriculture practices and sustainable natural resource management, as a means to mitigate the ill-effects associated with the use of fertilisers, insecticides, and herbicides (Wood & Moriniere 2013). More broadly, the adoption of low-input, high-diversity agricultural systems such as agroecology could increase food production, alleviate pressure on woodlands and improve water quality and flow (Altieri et al. 2012). Agroecology includes the practice of agroforestry, in which trees are incorporated into annual food crop systems, by planting trees interspersed among crops. Farmers' knowledge of how to make organic manure from crop residues and green leaves is inadequate (Holden & Lunduka 2012) and should be an important focus area of the Ministry of Agricultural and Food Security's extension services. Increased use of nitrogen-fixing crops and agroforestry trees could also reduce the need to import inorganic nitrogen fertilisers and improve soil quality. The government could also promote integrated food-energy systems, in which food and energy are produced concomitantly on farms to achieve sustainable crop intensification (FAO 2011).

Although the percentage of Malawians living in urban areas is currently low (15%), the urban share of the population is projected to expand to 30% by 2050 (UNDESA 2014). Thus urban and peri-urban agriculture holds potential to contribute to food security and livelihood diversification. Allowing livestock production in urban areas with adequate measures to compost animal manure could offer significant opportunities in nutrient recycling and production of energy (biogas), thus contributing to improved waste management, food security and employment creation (Swedish University of Agricultural Science 2014).

4.2.3 Expanding access to safe water

Addressing the water dimension of the nexus in Malawi's agrarian regime entails focusing on expanded access to domestic water, improving wastewater management, and moving towards smart agricultural water management. Government efforts should begin with the sustainable implementation of integrated water resource management principles for Malawi's main water bodies, incorporating unregulated small-scale users (Wood & Moriniere 2013). Forest degradation, and the resulting impact on water resources, can be contained through schemes such as tree planting programmes, Reduced Emissions from Deforestation and Degradation and payments for ecosystem services. Water quality can also be preserved by developing waste management schemes and improved sanitation infrastructure in urban areas. Large-scale promotion of rainwater harvesting is a potential measure not only to increase water for consumption in a sustainable manner, but also to recharge groundwater aquifers. In rural areas, especially those that are not adjacent to Lake Malawi, water access could be improved through the use of solar PV pumps (IRENA 2015). Malawi could also consider the development of multipurpose water resource projects that support hydropower, irrigation and water supply. However, such projects require careful economic viability and environmental impact assessments, taking all aspects of the nexus into consideration.

The Green Belt Initiative, introduced by the government in 2009, is a prime example of a nexus intervention aiming at higher agricultural output of food and cash crops with the goals of increasing macro- and micro-level food security and decreasing poverty (Nielsen et al. forthcoming). Through the initiative, the government has set the target of expanding irrigation usage to small-scale farmers and commercial farmers to one million hectares, mainly by using the country's three biggest lakes and perennial river resources (Chinsinga, Chasukwa & Pashane Zuka 2012). Irrigation efficiency can be improved through techniques such as precision irrigation, low-head drip irrigation, and wastewater recycling and fertigation (using liquid fertilisers) (FAO 2011).

The main obstacles to the achievement of this agenda are likely to be a lack of institutional capacity, finance and household purchasing power. Malawi will therefore need the continued support of the international community. The government should strive to promote labour-intensive solutions and invest in knowledge-building and skills development for the long term.

4.3 Greening South Africa's economy

The main policy priorities to mitigate key nexus risks in South Africa's industrial regime are as follows: (1) to reduce the risks and externality costs of heavy reliance on fossil fuels and address power-supply constraints by boosting energy efficiency and investing in cleaner energy technologies; (2) to improve the resilience of the food system to energy-related shocks by reducing energy intensity along the food value chain; and (3) to address growing water scarcity (exacerbated by climate change) with a combination of supply-side and demand management policies and measures, and to halt and reverse declining water quality through improved regulations and incentives.

4.3.1 Improving energy efficiency and expanding renewables

The starting point for improving energy security should be a concerted effort to manage energy demand through incentives and regulations designed to enhance energy efficiency and conservation. The introduction of a carbon tax, which has been mooted by the National Treasury of South Africa, would incentivise energy users to increase efficiency and minimise waste of all fossil fuel-derived energy carriers. Power demand management has been implemented in South Africa largely through necessity to address the country's electricity crisis. This has involved an agreement with energy-intensive industrial users to cut consumption when reserve margins are low, periodic 'load shedding' across the country, and a more than doubling of average electricity tariffs. The government's ambitious solar water heating programme has fallen far short of expectations with 400 000 systems having been installed by the end of 2014, instead of the targeted 1 million (Steyn 2015). Some efficiency standards have been introduced, but these could be augmented.

Dependence on oil imports and the consequent vulnerability to oil price shocks can in principle be reduced through demand management - principally improved transport energy efficiency – and by developing indigenous energy resources (Wakeford & Swilling 2014b). All four potential domestic substitutes for imported oil – new crude oil discoveries, coal-to-liquid fuels, gas-to-liquid fuels and biofuels – are potentially problematic from an environmental point of view, either in terms of pollution risks and greenhouse gas emissions, or in terms of excessive water usage. Thus a more sustainable alternative is to reduce the demand for liquid fuels through a comprehensive suite of policies and technologies that encourage greater fuel efficiency (including eco-driving, improved traffic management and more fuel efficient vehicle designs) and a gradual switch to electrified transportation, with an emphasis on mass public transit and freight rail (Wakeford 2013; Wakeford & Swilling 2014b).

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 (IRENA 2015). The Department of Energy's (DoE) (2011) Integrated Resource Plan for Electricity aims to double the national power generation capacity to over 80GW by 2030, with 42% of the new capacity slated to come from renewables and 23% from nuclear power. The DoE's Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) has proved to be a successful model, galvanising foreign and domestic investments totalling over $14 billion as of 2015 (Nassiep 2015). Over six gigawatts of renewable capacity (largely wind and solar PV) has been commissioned, with project timelines much shorter than for conventional power plants (Walwyn & Brent 2015). Furthermore, the average cost of renewable energy has been falling steadily.

4.3.2 Reducing energy and water intensity in the food system

To boost the resilience of the food system, a range of measures should be introduced to reduce energy intensity and improve water productivity. At the production stage, methods such as conservation agriculture and agroecological farming techniques offer energy and water saving opportunities. Conservation agriculture, which involves minimal soil tillage, has been shown to reduce the need for diesel fuel by 40% in maize production across four climatic zones in South Africa (Blignaut et al. 2015). Agroecology, defined as "the science of applying ecological concepts and principles to the design and management of sustainable food systems" (Wezel & Soldat 2009:13), can improve the resource-efficiency of agriculture, reduce its negative environmental impacts and enhance food security (IAASTD 2009; De Schutter 2010; Foresight 2011; Lampkin et al. 2015). Policy and institutional support could be provided through agricultural extension services; training and skill acquisition programmes for emerging farmers; increased funding for research; and the strengthening of networks involving scientists, farmers, civil society organisations and government departments (Wakeford & Swilling 2014a). Another way in which fossil fuel use in the agriculture sector can be reduced is to use renewable energy for water pumping to replace some of the quarter million pumps running on diesel and coal-fired electricity (IRENA 2015).

Energy efficiency in the distribution of food to consumers can be enhanced through logistical improvements and a (partial) relocalisation of agriculture to reduce distances between producers and consumers, for example by promoting urban and peri-urban agriculture (Wakeford & Swilling 2014a). Government can help to establish localised agricultural markets and promote farmers' markets by, for example, making public spaces available in urban areas and rural towns.

Agricultural water productivity improvements can result from various technical solutions and innovations, supported by a range of policy tools. Efficient sprinkler delivery systems have been shown to generate savings of 30% relative to conventional technologies (Weizsäcker et al. 2009). Other efficient technologies include knowledge-based precision irrigation (UN-Water 2014), drip irrigation (IRENA 2015), irrigation scheduling, landscaping, crop engineering, on-farm canal lining (2030 Water Resources Group 2009), deficit irrigation and 'smart' irrigation scheduling (UNEP forthcoming), no-tillage practices, mulching and hydroponics (UNEP 2014). Low-tech, improved farming practices based on agroecological practices and in-field water harvesting can play a role in limiting irrigation needs and reducing the risk of crop failure (Auerbach 2005). Market mechanisms can play a useful role in terms of incentivising efficient use of water (Baleta & Pegram 2014). These tools include appropriate water pricing, tradable water rights, increase imports of water-intensive foodstuffs, and allocating water use licences among farmers according to the productivity of water use.

The extensive loss of food along the food supply chain in South Africa, which also implies losses of embedded energy and water, can be tackled in various ways (Notten et al. 2014). For example, government can provide information and training through agricultural extension agencies on innovations to reduce losses during harvesting, handling and storage of agricultural produce; food processors can be encouraged to adopt technologies that prolong product life; and retailers can be encouraged to give discounts on nearly expired produce and provide information to consumers on good food storage practices. To the extent that some food waste is unavoidable, it can be used as a resource if the right regulatory frameworks and incentives are put in place (Notten et al. 2014), such as energy generation in anaerobic digesters, composting, and using food waste as animal feed.

4.3.3 Managing water quality and demand

Water security can be enhanced through expanding supply and managing demand. According to the 2030 Water Resources Group (2009), the largest potential sources of expanded (blue) water supply in South Africa are new dams, enlarged dams, groundwater and artificial recharge, and gravity transfers. Smaller potential sources, which are typically more expensive, include rainwater harvesting (agricultural and domestic), pumped transfers, and desalination. Perhaps even more important than expanding supplies, water policy must urgently address the serious decline in water quality that is occurring in many parts of the country. This will require better enforcement of the National Water Act (no. 36 of 1998) (von Bormann & Gulati 2014), which includes regulations governing the use of water and emissions of pollutants. In particular, the regulations governing the environmental management of mining waste and mine sites need to be strengthened and enforced so as to reduce mining pollution and acid mine drainage. There is an urgent need for upgrades and extensions of wastewater and sewage treatment facilities in many municipalities across the country, as these pose unacceptable risks to water quality. Protecting ecological infrastructure such as wetlands is a cost-effective way of ensuring greater water quality and quantity (Oberholster & Botha 2014:12).

On the demand side, there is considerable scope for efficiency improvements in the water system. The industry sector presents the largest scope for water savings, through techniques such as paste-thickening and water-recycling in mining, dry-cooling and pulverised beds in power generation, leak reduction, reuse of condensates, and pressure management (2030 Water Resources Group 2009). In the municipal and domestic sector, measures to improve water efficiency that would also bring net cost savings include municipal water pressure management, leak repair, low-flow showerheads, aerated faucets, and dual-flush toilets. Appropriate water pricing that reflects true costs has long been lacking in South Africa and could help to incentivise the foregoing technical solutions. Energy requirements of the water system can be reduced through the adoption of efficient pumps with variable-speed drives, gravity-fed distributions systems, minimising leaks and maintaining dams, and the installation of micro-hydro technologies in water pipes (Water in the West 2013).

Although South Africa has taken important steps towards integrated planning that addresses various aspects of the energy-food-water nexus, there are still some notable gaps and areas that require improvement. In general, the National Development Plan does not specifically address the nexus and how it can be aligned with developmental planning and policies (von Bormann 2014). Although South African government departments have devised integrated energy plans and integrated water plans, and there is some alignment between these, they do not adequately account for the intricate connections in the energy-water nexus and the risks involved in their interdependence (Gulati 2014).

Most concerning, however, is the disjuncture between plans for the expansion of agriculture through irrigation contained in the National Development Plan and Industrial Policy Action Plan, and the reality of water resource constraints (Goga & Pegram 2014). Thus there is a need for greater coordination and integration of planning across the water, energy and agriculture/food sectors, especially to ensure proper management of water resources and quality.

4.4 Lessons from Cuba's energy and agroecological transitions

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 in countries that shift away from fossil fuel dependence.

4.4.1 Energy efficiency

Valuable lessons can be learned from the way Cuba tackled its energy challenges during the country's 'Special Period'. This essentially entailed regulatory measures and incentives to limit demand and improve efficiency, together with a variety of interventions aimed at bolstering domestic energy production.

Cuba's energy revolution was enabled by a wide range of transforming institutional structures. In the early 1990s, The Technical Department of Energy, which fell under the auspices of the Ministry of Economy and Planning, was responsible for planning the country's energy infrastructure and reportedly had access to renowned renewable energy and energy efficiency expertise (Cherni & Hill 2009). Other important institutions that were established to enact and implement new energy policies included: the National Energy Commission, a sub-ministry for renewable energies attached to the Ministry of Basic Industry; the National Group for Renewable Energy Sources, Energy Efficiency and Cogeneration; and the Financial Fund for Energy Efficiency, an inter-ministerial commission headed by the president of the Central Bank (Alberto 2008; IAEA 2008). The 1993 National Energy Sources Development Programme focused on encouraging government entities to use renewable energy sources to satisfy growing demand, achieve higher efficiency in the use of bagasse and other crop residues, and to increase the use of domestically produced crude oil and associated gas in electricity generation as a substitute for imported fuel oil. This led to government officials and members of the Cuban scientific community mobilising to expand domestic energy supply to key infrastructural nodes such as schools, hospitals, clinics and community centres, especially in the poorest, most isolated communities (Barclay 2003). The Cuban Electricity Conservation Programme, the Energy Conservation Programme of the Ministry of Education and the 2006 Energy Revolution Programme underpinned the transition of the country towards a new energy paradigm and rested on the integration of technical, educational, social and economic measures (Alberto 2008).

The energy revolution entailed various measures to promote energy demand-side management programmes and improve energy supply. First, substantial public investments were made to rehabilitate and decentralise the national electricity grid, with an emphasis on renewable energy (Cherni & Hill 2009). Subsidies were provided for renewable energy infrastructure such as wind energy for water pumping and electricity generation, and solar thermal energy for water heating (Alberto 2008). As an illustration of what has been termed integrated food-energy systems (FAO 2011), Cuba has introduced biogas digesters, which are used to capture methane gas from animal manure (especially on pig farms) for use as a cooking gas. Second, a national programme was initiated to phase out inefficient appliances and lighting (Alberto 2008; Piercy et al. 2010). Third, a new stepped electricity tariff structure was introduced, which encouraged people to limit their power consumption (Alberto 2008). Education and awareness programmes have also been a cornerstone of Cuba's improved energy demand-side management (Alberto 2008). Fourth, the government supported increased exploration, production and use of domestic fossil fuels to meet energy needs, including the use of previously flared natural gas for power generation (IAEA 2008). Fifth, diverse measures were taken to mitigate the impact of the oil crisis on transportation, including the manufacture and importation of large numbers of bicycles and the use of large buses (Piercy et al. 2010). Finally, Cuba's spatial planning policy was reconfigured to reshape the functioning of the economy through relocalisation, for example by decentralising the locations of key services such as education and health (Piercy et al. 2010).

Despite all the achievements of the energy revolution, Cuba's energy system is still largely reliant on oil, mostly imported from Venezuela, and further efforts are needed to tap the country's renewable energy potential, especially wind and solar energy.

4.4.2 The agroecological farming revolution

The Cuban government initially responded to the country's crippling food scarcity during the Special Period with a system of food ration cards and schemes targeting the vulnerable, which helped to keep food within physical and economic reach of its entire population (Pfeiffer 2006). The state also began reorganising the agricultural sector, converting large state farms into smaller, private cooperative farms geared towards productivity (Koont 2004; Pfeiffer 2006). The government enacted major land reforms in 1993 and introduced incentives for working in the agricultural sector, which played a significant part in the rejuvenation of the peasant class and the re-emergence of traditional farming knowledge. A quarter of the population still lives in rural areas (FAO 2016b), partly as a result of measures that the government put in place to curb a rural-urban migration and encourage the uptake of farming (Cherni & Hill 2009). In urban agriculture, the agricultural working sector became among the top earning professions, contributing to the revaluing of agriculture and related professions in Cuban society (Wright 2008). New institutions were created to support Cuba's food revolution, notably the formation of a ministerial department devoted to urban agriculture, entrusted with securing land-use rights for urban gardeners, making extension officers available to community gardeners, as well seed shops to supply seeds, and the provision of tools and bio-products (Piercy et al. 2010). The Crop Protection Institute is a pivotal institution that supports organic farming in the country.

The widespread adoption of agroecological practices, in both urban and rural contexts, has been the core engine of the Cuban food revolution. The state played a critical role in facilitating this shift of the agricultural production model by applying agroecological research results at scale to offset the shortage of synthetic chemical inputs. The Ministry of Agriculture spearheaded a programme to convert the sector to low-input, self-reliant practices (Gonzalez 2003). Farmers embraced agroecological practices, allowing them to make the best out of all types of terrains and soil structures. These practices included intercropping, crop rotation, deep mulching, the use of insect traps and medicinal plants, companion planting, production and use of organic fertilisers and pesticides, vermiculture and composting (Koont 2004; Piercy et al. 2010; Rosset et al. 2011; Altieri et al. 2012). Cuba has relied on an efficient social dynamic for a widespread adoption of agroecological practices, the c*ampesino – a –campesino* (CAC) or farmer-to-farmer movement. Through the CAC, a farmer who has discovered a solution shares it with other farmers. This grew into a nationwide movement in Cuba in the 2000s and resulted in 65% of the country's food being produced on only 25% of the land (Rosset et al. 2011).

Since the Special Period, the promotion of urban agriculture in Cuba has helped to alleviate pressure on the hinterland to feed the country and has reduced reliance on energy-intensive transportation and refrigeration, as the produce were made locally available at urban markets (Gonzalez 2003). This was complemented by the promotion of a *parcelas (*popular gardens) system, through which land is granted to private individuals on a rent-free basis, as long as it is kept productive (Koont 2004). Importantly, this land has been made available by the government cost-free, thus enabling all actors of society, from industrial groups to hospitals, schools and pensioners, to make use of every piece of idle land to grow food for self-provisioning (Gonzalez 2003).

Notwithstanding the impressive gains made in Cuba's food sector, especially horticulture, the country still relies heavily on imported grains and meat products. Cuba is striving to minimise its dependence on cereal imports by increasing the domestic production of maize and soya. However, this presents trade-offs as these crops tend to have significant energy demands, including for irrigation. Cuba has also resorted to developing niche markets for food export products (such as coffee, citrus fruit, honey and shellfish) to generate foreign currency to enable imports of other vital foodstuffs (Koont 2004).

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, Cuba arguably serves as an example of a country where the government undertook a 'purposive transition' (Smith, Sterling and Berkhout 2005) in the agriculture and energy sectors. 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.

5 Conclusions

While is it increasingly acknowledged that energy, food and water security are becoming increasingly important and threatened in a world characterised by growing populations and economies, resource depletion and climate change, this paper has argued that complex energy, food and water systems are inextricably linked and need to be understood and governed as integrated systems. Management of the energy-food-water nexus is emerging as a critical issue facing developing countries in particular.

Through case study analysis, the paper has shown that nexus-related vulnerabilities manifest differently in a variety of contexts, such as different socioecological regimes (agrarian, industrial and ecological). In the Malawian case, the key vulnerabilities are the low productivity of the agrarian food regime and the limitations of a largely traditional biomass-based energy system. South Africa's major challenges lie in the dependency of food systems on (largely imported) oil, and the vulnerability of its scarce water resources to pollution from fossil fuel-based industrial activities and agriculture. The Cuban case shows that the adoption of agroecological farming practices can help to achieve substantial reductions in energy use by the food system, while boosting the average level of food supply per capita.

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.

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.

The analysis of policy options in the three case studies showed that a broad array of policy tools and technical solutions are available to mitigate the risks inherent in the energy-food-water nexus, but that the appropriate measures differ somewhat according to the country's socioecological regime. The main priority for countries with a largely agrarian regime, such as Malawi, 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 and pollution risks. Policies to promote decentralised renewable energy systems, small-scale sustainable agriculture and agroforestry, and local water solutions could improve rural welfare and also help to slow down the pace of urbanisation and therefore alleviate the growing pressure on limited urban infrastructure and services.

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 thereby limit the impact of resource depletion, and reduce the negative impacts of fossil fuel use on the environment (notably soils and water 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 some clues as to what is possible in terms of a shift to a more sustainable food-energy system when it is directed as a purposive transition by a strong state with an effective bureaucracy and engaged citizenry. Questions remain, however, as to whether the Cuban experience can be replicated in market-based economies, especially those with weak state institutions. Furthermore, Cuba's ongoing reliance on oil and the re-emergence of industrial farming for key grain crops shows that it still has a long way to go to achieve sustainability.

In sum, despite exhibiting major differences in their status quo challenges, all three case studies point to the need for transitions to more sustainable 'green economies' in order to mitigate growing risks in the energy-food-water security nexus.

References

2030 Water Resources Group. 2009. Charting our Water Future: Economic Frameworks to Inform Decision Making. Munich: 2030 Water Resources Group.

African Development Bank [AfdB]. 2013. *Malawi Country Strategy paper*. [Online] Available at: http://www.afdb.org/en/countries/southern-africa/malawi/malawi-economic-outlook/. Accessed: 25 March 2015.

Alberto, A. 2008. Distributed generation in Cuba. Cogeneration and Onsite Power Production 61. [Online] Available at: www.cubanismo.net/teksten_nl/sociaal/distri_generation.pdf Accessed: 15 August 2015.

Altieri, M.A., Funes-Monzote, F.R. & Petersen, P. 2012. 'Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty'. *Agronomy for Sustainable Development* 32:1–13.

Altieri, M. A. & Funes-Monzote, F.R. 2012. *The Paradox of Cuban Agriculture*. [Online] Available at: http://monthlyreview.org/2012/01/01/the-paradox-of-cuban-agriculture/. Accessed: 28 April 2015.

Auerbach, R. (Ed.) 2005. *Rainwater harvesting, organic farming and landcare: a vision for uprooting rural poverty in South Africa.* Durban: Rainman Landcare Foundation.

Bailey, R., Benton, T.G., Challinor, A., Elliot, J., Gustafson, D., Hiller, B., Jones, A., Jahn, M., Kent, C., Lewis, K., Meacham, T., Rivington, M., Robson, D., Tiffin, R. & Weubles, D.J. 2015. *Extreme weather and resilience of the global food system*. Final Project Report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience, The Global Food Security Programme, UK.

Baleta, H. & Pegram, G. 2014. *Water as an input in the food value chain. Understanding the Food Energy Water Nexus.* South Africa: World Wildlife Fund-South Africa.

Barclay, E. 2003. *The período especial forces Cuba to look inwards.* [Online] Available: http://www.globalexchange.org/countries/americas/cuba/936.html. Accessed 18 April 2015.

Berkhout, P.H.G., Muskens, J.C. & Velthuijsen, J. 2000. Defining the Rebound Effect. *Energy Policy*, 28(6-7), 425-432.

Blignaut, J., Knot, J., Smith, H., Nkambule, N., Crookes, D., Saki, A., Drimie, S., Midgley, S., de Wit, M., von Loeper, W. & Strauss, J. 2015. *Promoting and advancing the uptake of sustainable, regenerative, conservation agricultural practices in South Africa with a specific focus on dryland maize and extensive beef production*. Pretoria: ASSET Research.

BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). 2012. Bonn2011 Conference: The Water, Energy and Food Security Nexus – Solutions for a Green Economy: Policy Recommendations. 13 February 2012. [Online] Available at: http://www.water-energy-food.org/documents/bonn2011_policyrecommendations.pdf Accessed: 10 July 2015.

Brent, A. 2014. *The agricultural sector as a biofuels producer in South Africa. Understanding the Food Energy Water Nexus.* South Africa: WWF-South Africa.

Cherni, J.A. & Hill, Y. 2009. Energy and policy providing for sustainable rural livelihoods in remote locations – The case of Cuba. *Geoforum* 40: 645-654.

Chinsinga, B., Chasukwa, M. & Pashane Zuka, S. 2013. The Political Economy of Land Grabs in Malawi: Investigating the Contribution of Limphasa Sugar Corporation to Rural Development. *Journal of Agricultural and Environmental Ethics* 26:1065-1084.

Cilliers, P. 2008. Complexity Theory as a General Framework for Sustainability Science, in Burns, M. & Weaver, A. (Eds.). *Exploring Sustainability Science: A Southern African Perspective.* Stellenbosch: African Sun Media. pp. 39-57.

De Schutter, Olivier. 2010. Report submitted by the Special Rapporteur on the right to food, to the United Nations Human Rights Council, A/HRC/16/49.

Energy Information Administration [EIA]. 2016. Europe Brent crude oil spot price. [Online] Available at: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=rbrte&f=a Accessed: 21 January 2016.

EIA. 2015. *Country analysis note for Cuba*. [Online] Available: http://www.eia.gov/countries/country-data.cfm?fips=CU. Accessed: 18 April 2015.

Endres, A. B. & Endres, J. M. 2009. Homeland security planning: what victory gardens and Fidel Castro can teach us in preparing for food crises in the United States. *Food and Drug Law Journal* 64(2):405–440.

FAO. 2005. *Fertilizer use by Crop in South Africa*. Rome: United Nations Food and Agriculture Organisation.

FAO. 2011. *'Energy-smart' food for people and climate*. Issue Paper. Rome: United Nations Food and Agriculture Organisation.

FAO. 2014. *The State of Food Insecurity in the World 2014*. Rome: Food and Agriculture Organisation of the United Nations.

FAO. 2016a. FAO Food Price Index. Rome: Food and Agriculture Organisation of the United Nations. [Online] Available at: http://www.fao.org/worldfoodsituation/foodpricesindex/en/ Accessed: 21 January 2016.

FAO. 2016b. FAOSTAT database. [Online] Available at: http://faostat3.fao.org/home/E.

FAO. 2016c. AQUASTAT database. [Online] Available at: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

Fig, D. & Scholvin, S. 2015. Fracking the Karoo: The Barriers to Shale Gas Extraction in South Africa Based on Experiences from Europe and the US. In Scholvin, S. (Ed.) *A New Scramble for Africa? The Rush for Energy Resources in Sub-Saharan Africa*. Farnham, UK: Ashgate.

Fischer-Kowalski, M. 1998. Society's Metabolism: The Intellectual History of Materials Flow Analysis, Part I, 1860-1970. *Journal of Industrial Ecology* 2(1):61-78.

Fischer-Kowalski, M. & Haberl, H. (eds.). 2007. *Socioecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use.* Cheltenham, U.K.: Edward Elgar.

Fischer-Kowalski, M. & Swilling, M. 2011. *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth.* Paris: United Nations Environment Programme.

Foresight. 2011. *The future of food and farming.* Final Report. [Online] Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/288329/11-546-future-of-food-and-farming-report.pdf

Gamula, G. E. T., Hui, L. & Peng, W. 2013. An Overview of the Energy Sector in Malawi. *Energy and Power Engineering* 5:8-17.

Godfray, C., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S. and Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science* (327):812-818.

Goga, S. & Pegram, G. 2014. *A review of integrated planning in South Africa. Understanding the Food Energy Water Nexus.* South Africa: World Wildlife Fund-South Africa.

Gonzalez, C.G. 2003. Seasons of resistance: sustainable agriculture and food security in Cuba. Environmental Law and Sustainable Development in 21st Century Cuba. *Tulane Environmental Law Journal* 16:685-732.

Government Communication and Information System [GCIS]. 2012. *South Africa Yearbook 2011/12.* Pretoria: Government Communication and Information System.

Government of Malawi. 2011. The Second National Communication of the Republic of Malawi to the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCC). [Online] Available at: http://unfccc.int/resource/docs/natc/mwinc2.pdf. Accessed: 26 March 2015.

Guevara-Stone, L. 2008. Viva La Revolución Energética. *Alternatives Journal* 34(6) 22-24.

Gulati, M. 2014. *Understanding the Food Energy Water Nexus: Through the energy and water lens*. South Africa: World Wildlife Fund-South Africa.

Hartnady, C. 2010. South Africa's Diminishing Coal Reserves. *South African Journal of Science* 106(9/10):1-5.

Hoff, H. 2011. *Understanding the Nexus*. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. Stockholm: Stockholm Environment Institute.

Holden, S. & Lunduka, R. 2012. Do fertilizer subsidies crowd out organic manures? The case of Malawi. *Agricultural Economics* 43:303–314.

International Assessment of Agricultural Knowledge, Science and Technology for Development [IAASTD]. 2009. *Agriculture at a Crossroads: Summary for Decision Makers of the Global Report*. Johannesburg: IASSTD.

International Energy Agency [IEA]. n.d. *What is Energy Security? International Energy Agency*. [Online] Available at: http://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/.

IEA. 2016. *Statistics and Balances. International Energy Agency*. [Online] Available at: http://www.iea.org/stats/index.asp.

IRENA. 2012b. *Cuba energy profile* [Online] Available: http://www.irena.org. Accessed: 30 March 2015.
IFAD. 2015. *Rural poverty in Cuba*. [Online] Available at: http://www.ruralpovertyportal.org/country/home/tags/cuba. Accessed: 6 April 2015.

Intergovernmental Panel on Climate Change [IPCC]. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

IRENA. 2015. Renewable energy in the water, energy & food nexus. Abu Dhabi: International Renewable Energy Association.

Kambewa, P. & Chiwaula, L. 2010. *Biomass energy use in Malawi*. Paper prepared for the International Institute for Environment and Development (IIED). Available at: http://pubs.iied.org/pdfs/G03075.pdf. Accessed 22 January 2016.

Koont, S. 2004. Food security in Cuba. *Monthly Review* 55 (8).

Kumambala, P. G. & Ervine, A. 2009. Site selection for combine hydro, irrigation and water supply in Malawi: Assessment of water resource availability. *Desalination* 248:537–545.

Lampkin, N.H., Pearce, B.D., Leake, A.R., Creissen, H., Gerrard, C.L., Girling, R., Lloyd, S., Padel, S., Smith, J., Smith, L.G., Vieweger, A. & Wolfe, M.S. 2015. *The role of agroecology in sustainable intensification*. [Online] Available at: http://www.snh.gov.uk/docs/A1652615.pdf/. Accessed: 20 August 2015.

Liabunya, W.W. 2004. Malawi Aquatic Weeds Management at Hydro Power Plants, ESCOM Ltd. Blantyre: Generation Business Unit.

Mason-Jones, K., Notten, P. & Rambaran, N. 2014. *Energy as an input in the food value chain. Understanding the Food Energy Water Nexus*. South Africa: World Wildlife Fund-South Africa.

Moser, S.C. & Hart, J.A.F. 2015. The long arm of climate change: societal teleconnections and the future of climate change impacts studies. *Climatic Change* 129:13–26.

Nassiep, K. 2015. SA's renewable energy plan a global success story. Business Day. [Online]. Available at: http://www.bdlive.co.za/opinion/2015/10/07/sas-renewable-energy-plan-a-global-success-story Accessed: 2 February 2016.

National Statistical Office [NSO]. 2012. *Integrated Household Survey 2010-2011 – Household Socio-Economic Characteristics Report.* Zomba: National Statistical Office.

Nielsen, T., Schünemann, F., McNulty, E., Zeller, M.Nkonya, E., Kato, E., Meyer, S. , Zhu, T. & Anderson. W. Forthcoming. The food-energy-water security nexus: Definitions, policies, and methods in an application to Malawi and Mozambique. IFPRI & FAO.

Notten, P., Bole-Rentel, T. & Rambaran, N. 2014. *Developing an understanding of the energy and water implications of wasted food and waste disposal. Understanding the Food Energy Water Nexus.* South Africa: World Wildlife Fund-South Africa.

Oberholster, P. & Botha, A-M. 2014. *The importance of water quality to the food industry in South Africa. Understanding the Food Energy Water Nexus.* South Africa: World Wildlife Fund-South Africa.

OECD-FAO. 2014. *OEC- FAO Agricultural Outlook 2014-2023*. Paris: OECD Publishing.

Pauw, K. & Thurlow, J. 2014. *Malawi Strategy Support Program- Malawi's farm input subsidy program- where do we go from here?* Washington D.C.: International Food Policy Research Institute.

Pfeiffer, D.A. 2006. *Eating Fossil Fuels.* Gabriola Island, Canada: New Society Publishers.

Piercy, E., Granger, R. & Goodier, C. 2010. Planning for peak oil: learning from Cuba's 'special period'. Proceedings of the Institution of Civil Engineers. *Urban Design and Planning* (163): 169-176.

Rodriguez, D.J., Delgado, A., DeLaquil, P. & Sohns, A. 2013. *Thirsty Energy*. Water Paper no. 78923. Washington, D.C.: World Bank.

Rosset, P.M., Machín-Sosa, B., Roque-Jaime, A.M., Avila-Lozano, D.R. 2011. The Campesino-to-Campesino agroecology movement of ANAP in Cuba. *Journal of Peasant Studies* 38:161–191.

Searchinger, T., Hason, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A. & Heimlich, R. 2014. Creating a sustainable food future. *World Resources Report 2013-14: Interim Findings*. Washington: World Resources Institute.

Shackleton, C. & Shackleton, S. 2004. The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. *South African Journal of Science* 100.

Sieferle, R.P. 2001. *The Subterranean Forest. Energy Systems and the Industrial Revolution.* Cambridge: The White Horse Press.

Smith, A., Stirling, A., & Berkhout, F. 2005. The governance of sustainable socio-technical transitions. *Research Policy* 34:1491–1510.

Sorrell, S., Speirs, J., Bentley, R., Brandt, A. & Miller, R. 2010. Global Oil Depletion: A Review of the Evidence. *Energy Policy,* 38(9), 5290-5295.

Statistical Yearbook of Cuba. 2009. 1st ed. Havana, Cuba: Edited by the National Office of Statistics; 2010. ISBN: 959-7119-19-6.

Stockholm Environment Institute. 2014. *Managing environmental systems: the water-food-energy nexus. Research Synthesis Brief.* [Online]. Available at: http://www.sei-international.org/mediamanager/documents/Publications/Air-land-water-resources/SEI-RSB-2014-Water-energy-food-nexus-LR.pdf. Accessed: 22 August 2015.

Swedish University of Agricultural Science. 2014. Urban and Peri-urban Agriculture for Food Security in Low-income Countries: Challenges and knowledge Gaps. [Online] Available: http://www.slu.se/slu-gobal. Accessed: 10 July 2015.

Suárez, J. A., Beatón, P. A., Faxas Escalona, R. & Pérez Montero, O. 2012. Energy, environment and development in Cuba. *Renewable and Sustainable Energy Reviews* 16: 2724–2731.

UNDESA. 2014. *World Urbanization Prospects: The 2014 Revision*. [Online] Available at: http://esa.un.org/unpd/wup/. Accessed: 10 July 2015.

United Nations Environment Programme [UNEP]. 2010. Green Economy Developing Countries Success Stories. Geneva: UNEP.

UNEP. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*. Paris: UNEP.

UNEP. 2014. *Assessing Global Land Use: Balancing Consumption with Sustainable Supply.* A Report of the Working Group on Land and Soils of the International Resource Panel. Paris: United Nations Environment Programme.

UNEP. (forthcoming). Decoupling Economic Growth from Water Uses and Water Pollution. Report of the International Resource Panel. Paris: UNEP.

United Nations Population Division [UNPD]. 2013. *World Population Prospects: The 2012 Revision*. New York: United Nations.

UN-Water. 2013. *Water Security and the Global Water Agenda*. Analytical Brief. New York: UN-Water.

UN-Water. 2014. *United Nations World Water Development Report 2014*. New York: UN-Water.

Von Bormann, T. 2014. Understanding the Food Energy Water Nexus: Through the water and food lens. South Africa: World Wildlife Fund-South Africa.

Von Bormann, T. & Gulati, M. 2014. The food energy water nexus: Understanding South Africa's most urgent sustainability challenge. World Wildlife Fund-South Africa.

Wakeford, J.J. 2013. *Preparing for peak oil in South Africa: An integrated case study*. New York: Springer.

Wakeford, J.J. & Swilling, M. 2014a. Implications of increasing world oil scarcity for national food security in South Africa. *Agrekon: Agricultural Economics Research, Policy and Practice in Southern Africa* 53(4):68-91.

Wakeford, J.J. & Swilling, M. 2014b. Peak oil as a stimulus for a green economy transition in South Africa: Alternative liquid fuel and transport options. *International Journal of African Renaissance Studies* 9(2):133-153.

Wakeford, J.J., Kelly, C. and Lagrange Mentz, S. 2015. Mitigating Risks and Vulnerabilities in the Energy-Food-Water Nexus in Developing Countries. Research report prepared for the United Kingdom Department for International Development, December 2015. Sustainability Institute, South Africa. Available at: http://r4d.dfid.gov.uk/Project/61478/Default.aspx

Walwyn, D.R. & Brent, A.C. 2015. Renewable energy gathers steam in South Africa. Renewable and Sustainable Energy Reviews 41:390-401.

Water in the West. 2013. Water-Energy Nexus: A Literature Review. Stanford University. Available at: http://waterinthewest.stanford.edu/sites/default/files/Water-Energy_Lit_Review.pdf Accessed: 15 August 2015.

Weizsäcker, E.U.V., Hargroves, K., Smith, M., Desha, C. & Stasinopoulos, P. 2009. *Factor 5: Transforming the Global Economy through 80% Improvements in Resource Productivity*. London: Earthscan.

Wezel, A. And Soldat, V. 2009. A quantitative and qualitative historical analysis of the scientific discipline of agroecology. *International Journal of Agricultural Sustainability* 7(1):3–18.

Wood. L. & Moriniere, L. 2013. Malawi climate change vulnerability assessment. Prepared for the U.S. Agency for International Development. [Online] Available at: http://www.eldis.org/go/home&id=66263&type=Document#.VRzlkWb8M3g. Accessed: 22 January 2016.

World Bank. 2013. *Thirsty Energy: Securing Energy in a Water-Constrained World*. [Online] Available at: http://www.worldbank.org/en/topic/sustainabledevelopment/brief/water-energy-nexus. Accessed: 5 March 2015.

World Bank. 2016. *World Development Indicators*. [Online] Available at: http://databank.worldbank.org/ddp/home.do. Accessed: 21 January 2016.

World Economic Forum [WEF]. 2011. *Water security: the water-food-energy-climate nexus: the World Economic Forum water initiative*. Washington: Island Press.

WWF. 2015. *Overview of the sugarcane sector.* [Online] Available at: https://www.worldwildlife.org/industries/sugarcane. Accessed: 5 May 2015.