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Sustainable development and the water–energy–food nexus: A perspective on livelihoods

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ABSTRACT

The water–energy–food nexus is being promoted as a conceptual tool for achieving sustainable development. Frameworks for implementing nexus thinking, however, have failed to explicitly or adequately incorporate sustainable *livelihoods* perspectives. This is counterintuitive given that livelihoods are key to achieving sustainable development. In this paper we present a critical review of nexus approaches and identify potential linkages with sustainable livelihoods theory and practice, to deepen our understanding of the interrelated dynamics between human populations and the natural environment. Building upon this review, we explore the concept of 'environmental livelihood security' – which encompasses a balance between natural resource supply and human demand on the environment to promote sustainability – and develop an integrated nexus-livelihoods framework for examining the environmental livelihood security of a system. The outcome is an integrated framework with the capacity to measure and monitor environmental livelihood security of whole systems by accounting for the water, energy and food requisites for livelihoods at multiple spatial scales and institutional levels. We anticipate this holistic approach will not only provide a significant contribution to achieving national and regional sustainable development targets, but will also be effective for promoting equity amongst individuals and communities in local and global development agendas.

1. Introduction

Recently there has been renewed interest in the longstanding definitional ambiguities of the term 'sustainable development' and the development of frameworks for its effective application in local and global contexts. This debate has been reignited in anticipation of the post-2015 targets for sustainable development, as set out in the Sustainable Development Goals (SDGs), and the pending expiration of the timeframe for the targets of the Millennium Development Goals (MDGs)[1]. The United Nations is pushing forward a new set of goals and targets for the post-2015 agenda which aims to achieve the long-term sustainable development of human society as a whole[2]. The SDGs commit subscribing countries to new action targets aimed at achieving sustainable water use, energy use and agricultural practices, as well as promoting more inclusive economic development (United Nations, 2014). The water–energy–food nexus has become central to discussions regarding the development and subsequent monitoring of the SDGs. However, while all of the proposed 17 SDGs also resonate with the concept of sustainable livelihoods, the term 'livelihoods' is not mentioned anywhere in current documentation

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[1] www.un.org/millenniumgoals
[2] An outcome of the *Rio + 20 United Nations Conference on Sustainable Development* resulted in the *Future We Want* report (United Nations, 2012).

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(see United Nations, 2014). This is counterintuitive given that, as we argue more fully in this paper, livelihoods are key to achieving sustainable development.

This paper briefly summarises the historical and theoretical development of sustainable livelihoods and nexus approaches, identifying synergies between these two approaches which have resulted in what Biggs et al. (2014) have termed 'Environmental Livelihood Security' (ELS). Based on an extensive review of relevant literature and theoretical paradigms set out by Biggs et al. (2014), ELS was defined as a concept that seeks balance between natural resource supply and human demand on the environment in order to promote sustainability. Accordingly, a robust integrated nexus-livelihoods framework for examining the ELS of a system is necessary for practical application of the concept. In this paper we present such a framework and propose this as a solution for ensuring livelihoods are explicitly accounted for within the water–energy–food nexus. To ensure accurate monitoring of SDG progress and enable sub-national accounting for spatial disparities in meeting SDG targets – a characteristic that the MDGs have been critiqued as deficient in (Black and White, 2004; von Dach et al., 2006) – we present a framework which is adaptable to a range of spatial scales and institutional levels. Finally, we seek to demonstrate how our framework has the potential for many practical cross-sectoral applications which, we argue, will make a constructive contribution to advance the agenda on sustainable development.

2. Sustainable livelihoods approaches

Broadly speaking, approaches to sustainable development have focused on 'top-down' quantitative indicators based on scientific expertise and have a tendency to measure progress at national, regional and global scales. Conversely, sustainable livelihood approaches have tended towards more 'bottom-up' qualitative analyses of data obtained at household, community and local levels. Sustainable livelihood approaches have evolved from shifts in perspectives on poverty, participation and sustainable development (Sen, 1981; Chambers and Conway, 1992) and in 1987, the World Commission on Environment and Development used the term 'sustainable livelihoods' for the first time in discussions on resource ownership, basic needs, and rural livelihood security (WCED, 1987; Conroy and Litvinoff, 1988). The 1992 UN Conference on Environment and Development positioned sustainable livelihoods as a means of linking socioeconomic and environmental concerns (Brocklesby and Fisher, 2003). Both instances were important for moving international concern regarding environmental problems towards a focus on people and their livelihood activities, and placing these concerns within a policy framework for sustainable development (Biggs et al., 2014). In the livelihoods context at the local level, the question of environmental sustainability is focused on whether livelihood activities maintain and enhance, or deplete and degrade, the natural resource base. Livelihood activities may contribute to desertification, deforestation, soil erosion, declining water tables and salinisation (Chambers and Conway, 1992); but conversely they may benefit environmental conservation through climate-compatible activities such as reforestation and agro-biodiversity (Tompkins et al., 2013). At the global level, the question is whether livelihood activities make a net positive or negative contribution to long-term environmental sustainability, and therefore to other livelihoods (Chambers and Conway, 1992).

The Sustainable Livelihoods Approach (SLA) provides a means of linking socioeconomic and environmental concerns (Brocklesby and Fisher, 2003). It can be used as an analytical tool for understanding the factors that influence a community's ability to enhance livelihoods and eradicate poverty (FAO, 2002). Central to the sustainable livelihoods paradigm is recognition that people draw upon a range of assets to realise their livelihood objectives (DfID, 2001; Biggs et al., 2014). These assets are grouped into capitals – financial, natural, human, physical, political and social (refer to Scoones, 1998; Bebbington, 1999; FAO, 2008) – whereby capitals serve as inputs and/or outcomes for livelihoods, with the security of livelihood capitals vulnerable to external factors including environmental and market stresses (Morse et al., 2009). Variously construed as a set of principles, an analytical framework and a development objective (Farrington, 2001; Morse et al., 2009), the sustainable livelihoods approach has the flexibility and capacity to be combined with other paradigms such as the nexus approach discussed below.

Critiques of the SLA were largely summarised by Scoones (2009) who identified four recurrent failings within the approach: (i) an inability to deal with big shifts in the state of global markets and politics; (ii) a lack of focus in linking livelihoods and governance debates to development; (iii) a lack of rigour in accounting for long-term large-scale environmental change; and (iv) a failure to adequately relate agrarian changes with long-term shifts in rural economies (Biggs et al., 2014; Horsley et al., 2015). Additionally, although the SLA recognises in theory that the vulnerability context of livelihood assets includes environmental conditions, applications of the SLA have not generally included sound scientific analysis of short- and long-term climatic and other environmental events affecting livelihood resilience, nor expressed recognition of the dynamics of the water–food–energy nexus and the impacts of these on each of the livelihood capitals. Although some research has addressed elements of these shortcomings[3] current research only implicitly incorporates the fundamental components of achieving sustainable livelihoods from an environmental perspective. We argue that these weaknesses can be adequately compensated for by explicitly combining elements of the SLA framework with elements from the water–energy–food nexus framework to inform a more holistic model.

3. Water–energy–food nexus approaches

'Nexus thinking' was first conceived by the World Economic Forum (2011) to promote the inseparable links between the use of resources to provide basic and universal rights to food, water and energy security. Whilst the World Economic Forum (2011) presented the nexus framework from a securities perspective (water–energy–food security), subsequent versions have taken on various facets with alternative components, such as water resources as a central component (Hoff, 2011), land use–water–energy (Howells et al., 2013) and food as a core component with land–water–energy linkages (Ringler et al., 2013). Nexus thinking is advocated as an advance on current and often sector-specific governance of natural resource use.

Current nexus framings are often focused on macro-level drivers of resource consumption patterns (see Table 1). However, 'larger scale' extraction and consumption of natural resources may lead to depletion of natural capital stocks and increased climate risk without an equitable share of the benefits (Hoff, 2011; Rockström et al., 2009). An example of this exists in north–west India, where intensive agriculture has been driven by government policies to support national food welfare. Unfortunately, these policies have degraded ecosystems without increasing levels of food security (Aggarwal et al., 2004; Pritchard et al., 2013). With regard to the sustainable development goals, Griggs et al. (2013) argues for a more unified environmental and social framework

[3] See for example Turner et al. (2003) who considered human-environment interactions where vulnerability is influenced by the asset base (converse to the SLA); or Donohue and Biggs (2015) who adopt of a multidimensional approach to monitoring livelihoods whereby natural capital is quantitatively assessed.

Table 1
A critical review of the principal nexus frameworks used by governments and multilaterals; identifying the potential linkages and limitations of these frameworks from a 'sustainable livelihoods' perspective.

Nexus framework	Potential linkages to 'sustainable livelihoods'	Limitations from a 'sustainable livelihoods' perspective
The water, energy, food security nexus Stockholm Environment Institute: Hoff (2011)	• Acknowledges inequitable outcomes of benefits gained from natural resource use • Advocates a pro-poor nexus approach to natural resource use reducing the vulnerability of the poorest and safeguarding human rights to food-water-energy security • Recognises the threat of foreign direct investment to the livelihoods of the poor • Awareness of macro-level drivers of vulnerability (e.g. urbanisation, climate change, globalisation) • Acknowledges need for adaptation in current institutions, governance structures and policies • Recognises the need to account for externalities in policy and management to ensure sustainability and equity for all people and ecosystems • Recognises the importance of ecosystem functioning and services to human well-being, and strong links between ecosystems and the livelihoods of poorest	• Recognition of the need for alterations to governance structures and institutions are abstract and focussed on resource use/extraction • Factors mediating access to and utilisation of resources such as societal and cultural structures and norms, which are key determinants of 'security', are given less consideration • Nexus approach to manage complexity and multi-scalar issues, but discussion focuses on macro-drivers and omits complexity at the livelihoods (local – individual) scale (e.g. gendered access to food, agency and choice) • In the section 'Knowledge gaps in the nexus' livelihoods related issues, or dynamics of resource use which may enhance livelihoods, are not considered
The Water-Energy-Food Nexus FAO (2014)	• Situates a nexus approach to natural resource use within the context of social needs and economic development, specifically in the context of reducing poverty, sustainable agriculture and ecosystems and food security • Highlights that taking a nexus approach can engage a range of stakeholders	• Proposed stakeholder dialogue does not explicitly engage poorest and most vulnerable • Outlines monitoring and evaluation of a nexus assessment approach which only addresses outcomes on resource use and productivity as opposed to human wellbeing
Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) Giampietro et al. (2013)	• Allows for context-specific flexibility in constructing multi-level socio-economic structures which can in part, constrain or enable livelihoods	• Modelling focus on distribution, flows and use of resources across various socio-economic sectors does not address other factors which determine the capabilities of the societal sectors to enhance livelihoods or well-being • Does not address factors which determine equitable or inequitable sharing of resources within sectors • Explores the sustainability of resource use at a society-level and within society, but not how sustainable resource use can lead to enhancing livelihoods
Climate, land-use, energy and water strategies (CLEWS) Howells et al. (2013)	• Acknowledges that resource use is linked to development challenges (in introductory section)	• Modelling framework explores feedbacks between resource productivity policy/management decisions in energy, water and land-use sectors under different climate scenarios. Does not address mechanisms for how changes in resource use can enhance livelihoods • Does not explore how changes in resource use can enhance the range of choices people have or how changes in resource use can make livelihoods more resilient to shocks and stresses

with measurable targets. We propose that this can be achieved by incorporating an explicit focus on livelihoods and livelihood dynamics within nexus framings to capture bottom-up approaches and local opportunities for sustainable development.

Nexus framings consider key issues in food, water and energy security through a sustainability lens in order to predict and protect against potential risks of future insecurity. Contrary to framings where the focus is on environmental vulnerability (e.g. Turner et al., 2003), research which enables monitoring of livelihood security from an environmental perspective has yet to evolve. To date, nexus framings and applications of the nexus approach have tended towards technical assessments to enhance productivity, optimise synergies and identify trade-offs across nexus sectors to inform natural resource governance (Howells et al., 2013). However, 'security' is not solely driven by availability of resources but also by access to resources, the capacity to utilise resources as well as dynamics of social power relations and the strength of institutions (Sen, 1999; Ericksen, 2008; Pritchard et al., 2013). Encompassing the more holistic concept of 'livelihoods' within existing nexus framings would integrate the other factors that determine security with the drivers of resource availability. Such an approach would also build upon and complement prior applications of the SLA in the sectors of water (Nicol, 2000), forestry (Warner, 2000), natural resource management (Pound et al., 2003), agriculture (Carswell, 1997), river basin management (Cleaver and Franks, 2005), and fisheries (Allison and Ellis, 2001).

4. Integrating sustainable livelihoods and nexus approaches

There are clear synergies between the SLA and nexus approaches regarding sustainable development. Both consider socio-ecological pressures, governance, the environment (in terms of resource access through natural capital in the SLA) and security (environmental and economic security in the nexus; livelihood security in the SLA) (e.g. World Economic Forum, 2011; Hoff, 2011). To date, the nexus literature has not explicitly identified how water–energy–food securities are interlinked with livelihoods to enhance water–energy–food security at the livelihood level. Table 1 provides a critical review of four main nexus frameworks used by policy-shaping organisations and identifies their commonalities and

oversights with reference to sustainable livelihoods. These examples were selected as many subsequent applications undertaken by policy-makers draw upon these frameworks. For example, the most recent United Nations Water development report (WWAP, 2015) frames nexus issues with water as a central component, drawing upon Hoff (2011) 's framework. While each offers differing sets of precedents, and they vary in their epistemological and sectoral/application contexts, together they highlight common strengths and limitations of the nexus approach more generally. Strengths include indicators to quantify the complexities of dynamic systems while critical limitations include an emphasis on macro-scale aims with inconsistent, and frequently inadequate, attention to the complex variety of resource-user perspectives at local scales.

Although livelihoods are not explicitly accounted for within nexus frameworks, a small but growing body of research has highlighted the value of nexus-based approaches for evaluating the effects of development on livelihoods and for promoting sustainable livelihood practices (e.g. Granit et al., 2012; Bouapao, 2012; Rasul, 2014). Likewise, some applications of the nexus approach have begun to recognise the benefit of participatory approaches, though generally still at macro rather than micro scales. For example, the scenario thinking approach adopted by FAO facilitated a participatory debate about the complex structure of the water–energy–agriculture nexus in Central Asia for national economies dependent on the Aral Sea basin (FAO, 2012, 2014). Regional analyses from a nexus perspective, such as those undertaken by Rasul (2014) for the Hindu Kush Himalayan region and Granit et al. (2012) for the five ex-Soviet Central Asian republics, have underscored the positive effects on livelihoods from stronger regional integration across the water, energy and food sectors, particularly in transboundary basins. In the greater Mekong River region, Bouapao (2012) has taken this theoretical approach further by using primary and secondary data to model the cumulative effect on livelihoods resulting from impending development decisions designed to improve food, water and/or energy security. More than half of the population in the lower Mekong region could experience changes in household food and income from these development decisions, resulting from impacts on fish, crops, vegetables, wetlands and non-timber forest products (Bouapao, 2012). In Myanmar, foreign investment to intensify production from the agricultural and energy sectors may have deleterious effects on rural populations who rely on shared land and water resources but have insecure access (Kattelus et al., 2014). Examples of how sustainable rural livelihoods can be promoted in harmony with the nexus framework come from several sustainable development initiatives in Nicaragua, such as rainwater harvesting systems for smallholders using small-scale water capture and storage systems. These provide potential for increasing the consumption of underutilised but abundant breadfruit for food and flour as well as producing bioenergy from sugarcane bagasse (Gourdji et al., 2014). Gourdji et al. (2014) argue that projects such as these are strategically positioned within the climate–land–energy–water nexus.

'Pre-nexus' literature has also inadvertently explored nexus inter-linkages within the context of sustainable livelihoods. Pathways for reducing environmental footprints have been demonstrated by Khan et al. (2009) through empirical analysis of water-energy trade-offs in broad-acre crop production in the southern Murray Darling basin, Australia, that reduce operation costs and directly benefit farmers. Kemp-Benedict et al. (2009) conceptually noted the association between water availability and productivity (crop-water) in relation to livelihood outcomes for assessing water-related poverty. It is clear that further sustainable solutions regarding natural resource supply to meet human demand could have been more effectively managed using a framework where livelihoods were explicitly considered within the nexus. For example, at a regional level, food and energy crop cultivation (including oil palm) in Southeast Asia has resulted in significant biodiversity loss and peat oxidation, leading to surface subsidence and reversal of peatland systems from carbon sinks to carbon sources creating a large "biofuel carbon debt" (Fargione et al., 2008; Verhoeven and Setter, 2010). Verhoeven and Setter (2010) argue that benefits to local livelihoods would be clearly demonstrable through maintaining healthy ecosystem functions and services whilst optimising local food production. For example, if food and crop production was based on less intensive land use practices, including combinations of local cropping, fish production and grazing, without reclamation and alteration of hydrological processes.

In addressing the nexus-livelihoods research gap we present a framework which inclusively accounts for livelihoods within the water–energy–food nexus. The framework uses the concept of 'environmental livelihood security' to link the nexus and sustainable livelihoods approaches.

5. Environmental livelihood security

Environmental livelihood security (ELS) was first conceptualised by Biggs et al. (2014; p. 1) as "refer[ring] to the challenges of maintaining global food security and universal access to freshwater and energy to sustain livelihoods and promote inclusive economic growth, whilst sustaining key environmental systems functionality, particularly under variable climatic regimes". The term was theorised to address a lack of consideration of 'livelihoods' within nexus frameworks, which is required to ensure water, energy and food securities enable not only sustainable development, but also sustainable livelihoods. The ELS of a system is met when a balance is achieved between human demand on the environment and environmental impacts on humans (Fig. 1). In this way, the theoretical underpinning of ELS draws upon the

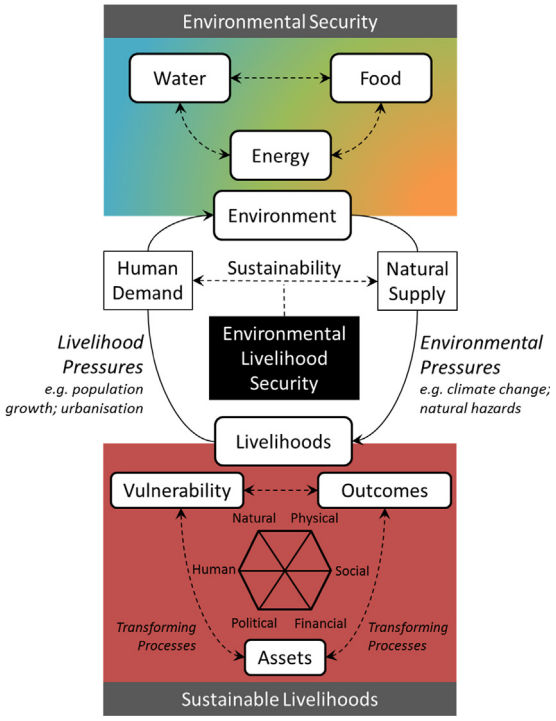

Fig. 1. The conceptual framework for investigating environmental livelihood security (ELS) combines concepts of the water–energy–food–climate nexus with the capitals of the sustainable livelihoods framework to achieve a sustainable balance between natural supply and human demand to ensure 'environmental livelihood security' (*Source*: adapted from Biggs et al., 2014).

concepts of environmental security and human (livelihood) security (Biggs et al., 2014). In addition, the desire to achieve sustainable systems places the concepts of sustainable development and sustainable livelihoods at the centre of ELS. ELS is well-aligned with ongoing discussions about defining a set of unified SDGs and also supports several recommendations of the Rio + 20 meeting such as "[focus on] priority areas for the achievement of sustainable development" and "address and incorporate in a balanced way all three dimensions of sustainable development and their inter-linkages" (United Nations, 2012, p47). This paper advances the conceptual grounding of ELS to develop a framework which can be applied to a system; a system where environment-livelihood interactions are prevalent and the ELS of that system can be determined to identify sustainable solutions for future development.

6. The ELS framework

Integrating sustainable livelihoods with the water–energy–food nexus requires identification of the inter-linkages between these securities, as well as the assets of human populations and the natural environment. An overview of our integrated livelihoods-nexus framework, which illustratively conceptualises ELS is summarised in Fig. 2. The framework depicts the interactions of water–energy–food systems (as illustrated in Fig. 3) with livelihoods. The utility of this framework includes expressly identifying the interaction between components, which previously had only been considered separately under each of the nexus and SLA approaches. For example, our framework implicitly acknowledges the mutually dependent relationship between water and livelihoods: (i) water is needed to support livelihood activities such as fisheries or irrigated agriculture; and (ii) livelihood activities and capitals may contribute to (or deplete) the preservation of water supplies and access [e.g. physical capital (infrastructure) may enable more efficient water extraction and transportation, and financial capital (public or private funds) may assist in implementing more sustainable practices in water use or purchase access to alternative supplies]. Acting upon all internal linkages within this system are external influencing factors, such as

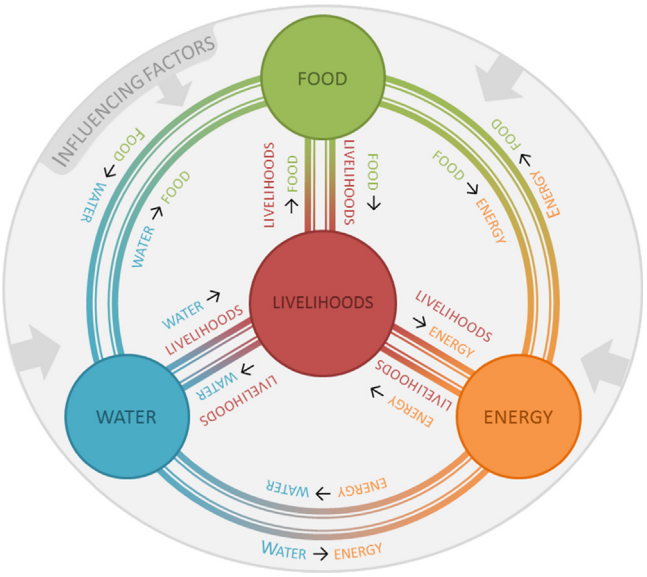

Fig. 2. The notion of *Environmental Livelihood Security* (ELS) conceptualises the links between water, energy, food and livelihoods which need balance to achieve a sustainable system. External influencing factors such as climate change, population growth, and governance can all impact upon attaining ELS.

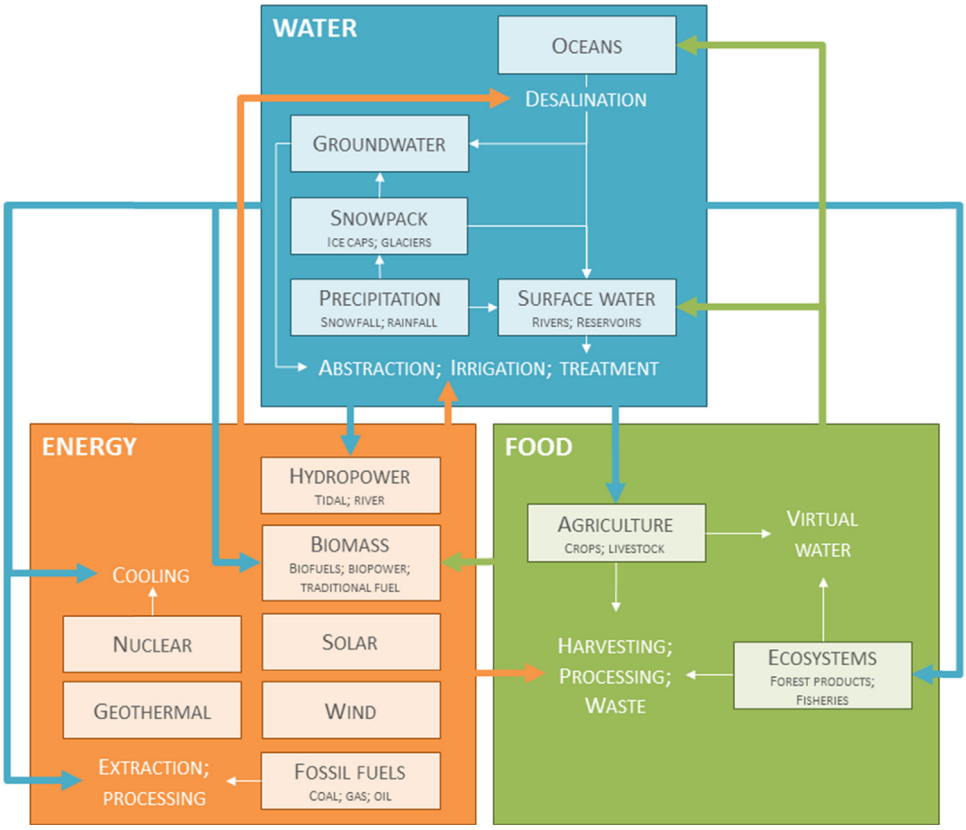

Fig. 3. The environmental nexus system defines the major flows within and between water, energy and food systems.

hazards. To achieve ELS in any particular system, these linkages need to remain balanced and resilient under external pressures/stresses. The ability to assess these components is presented in further detail in Fig. 4, which identifies suggested variables for defining components of the nexus-livelihoods framing (Fig. 2) to inform subsequent indicator derivation for measuring ELS.

To determine the ELS of a system, firstly the system of interest needs to be identified in the context of the water–energy–food nexus (Fig. 3). This will provide an indication of which components of the nexus are applicable and most important to the system. For example, island ecosystems of the Pacific are fragile and unique as a consequence of remoteness, but environmental issues including waste disposal, depletion of natural resources due to economic development and the use of coastal environments for tourism activities, increase the vulnerability of island communities (Briguglio, 1995, 2004, 2014; Briguglio and Galea, 2003; Briguglio et al., 2006; Deacon, 2012). Such contexts highlight important system components and identify the factors that will assist in managing trade-offs within ELS once the system is fully described. Subsequent to defining the system of interest, livelihoods within the system can be taken into account and the full ELS framework (Fig. 4) can be populated by identifying a set of indicators which measure the framework component variables, such as the percentage of population with access to potable water supply (*drinking*); proportion of crops produced for food consumption (*crops*); or amount of energy required to desalinate saltwater (*desalination*).

Identifying indicators for external influencing factors may be more challenging when quantifying impacts upon the system. For example, Pacific islands are particularly vulnerable to cyclones, but they also have to contend with earthquakes, landslides and sea level rise (Deacon, 2012). Increasingly, they face water, energy and food security issues exacerbated by climate change. Therefore external influencing factors that are climatological, meteorological and geophysical in nature are important to identify for island systems in the Pacific (and beyond), and this could potentially be achieved through quantitative hazard exposure assessments (Boruff and Cutter, 2007; Forbes et al., 2013). Other external influencing factors such as future water pricing, geopolitical conflict and international trade may need to be described more qualitatively.

Linkages across systems will need consideration, depending on the level of detail required for assessing ELS, which will be reflective of system scales (e.g. community through to region). Factors such as the export and import of commodities may have scope beyond the system of interest and can be associated with key sustainable development issues such as virtual water trade and reducing carbon footprints. For example, Kad and Weir (2008) state that community-based production of virgin coconut oil in the Pacific Islands has export value and provides a healthier and more viable substitute for costly imported products.

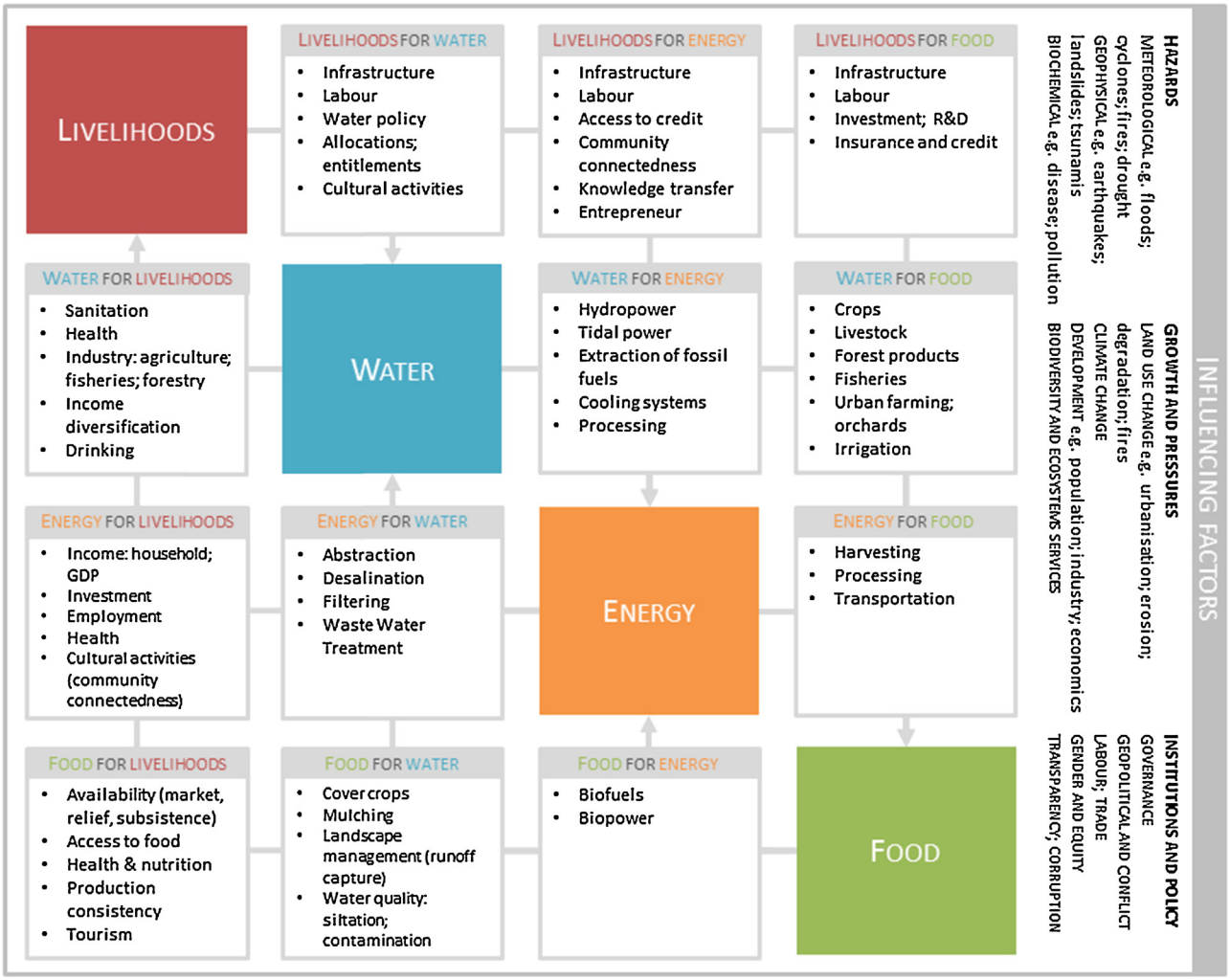

Fig. 4. Examples of fundamental internal (livelihoods–water–energy–food) and external (influencing) factors which need consideration for attaining ELS. Through quantifying such factors the system can be used to promote sustainable development by balancing sustainable activities within livelihoods and the environment.

Once indicators for the framework have been established, the next stage involves identifying appropriate data and methodological requirements to collect information necessary to populate the framework. Identifying indicator-relevant data is largely dependent on the scale of the system being investigated. National census statistics determining the household income derived from energy production may be appropriate for examining at ELS at the national scale; however, if a community-level assessment is required then aggregated statistics may mask local realities and household-level surveys could complement data. Brown et al. (2014) provide an example of conducting household surveys which returned information on harvesting forest timber for firewood and virgin/coconut oil production in the Pacific Islands. Alternative data acquisition techniques may also be required depending on indicators. For example, identifying the aerial extent of land dedicated to crop production can be determined using medium-resolution remotely sensed data (e.g. using a vegetation index) such as Landsat Thematic Mapper imagery for an island-level assessment of ELS, or high resolution Worldview data for a community-level assessment. Many environmental factors can potentially be determined using remote sensing techniques depending on the scale of the system of interest; this raises issues of spatiotemporal resolution which need to be adequately considered to address uncertainty. Application of the framework is designed to be specific enough to apply with ease, yet permit a selection of context-specific indicators for measuring ELS in detail. Flexibility is inherent to allow for a multitude of data acquisition techniques to populate indicators; depending on the context of the application, this could include semi-structured interviews, in-depth narrative interviews, life histories, focus group discussions, ranking exercises, participatory risk mapping, remote sensing techniques, hydrological modelling and scientific hazard maps (this is by no means an exhaustive list). Full engagement with stakeholders will be crucial to identify pressures/stresses from institutions and policy.

Once indicators have been identified to measure the water–energy–food nexus components within the framework, an assessment can be made to quantify all other relevant ELS elements within the system holistically. This will involve assessing the relationship between certain components (e.g. food for livelihoods and livelihoods for food), complex cross-linkages across components (e.g. food for livelihoods versus food for energy), and/or the system as a whole depending on the purpose of the assessment. When ELS has been established for the system of interest, it will then be possible to assess effectiveness of current practices for achieving both environmental and livelihood sustainability. Trade-offs and synergies for climate-compatible development can also be evaluated through scenario analysis exploring complex cross-linkages. For example, in the case of Pacific Islands, viable nexus-livelihoods solutions might be identified such as potential clean energy generation, for example, utilising tidal processes or biofuel production (Cloin, 2007) which directly enhance livelihoods in a sustainable manner. Within the ELS framework, it is possible to identify trade-offs with food and water for livelihoods, to ensure human demand is balanced against natural supply in meeting sustainable development targets.

The framework inherently accounts for system dynamics and, through identifying synergies and trade-offs, encapsulates system feedbacks such as the direction and pace that ELS may transition across spatial and temporal scales. This may assist in the process of identifying whether the ELS of any particular system is in dynamic equilibrium, has multiple-equilibriums (such as impoverished and environmentally degraded components as well as wealthy and environmentally sustainable components) or is linearly increasing or declining in a general sense. While this capacity resonates with systems thinking theory (see Enfors, 2013; Tittonell, 2014), the framework provides a more integrative approach to monitoring and evaluating sustainable development across multiple spatial and temporal scales, while still ensuring that a people-centred livelihoods focus remains at its core. In this way, the approach may contribute to achieving more general targets such as the SDGS in a more holistic and equitable manner, and can also be applied at smaller scales.

7. Contributions of the ELS framework to policy

Insights derived from the ELS framework provide a readily accessible structure for analysis and comprehensive assessment of either new or adjusted policy instruments. As an example, retrospective application of the ELS framework to research conducted in Cambodia by the International Water Management Institute (IWMI) (de Silva, 2014; de Silva et al., 2014; Johnston et al., 2014) provides a suitable point of reference to measure ELS for the Tonle Sap lake system and identify synergies and trade-offs between nexus-livelihoods components. Cambodian government policy seeks to intensify rice production as a national poverty reduction measure, which has profound implications for this unique socio-ecohydrological system. Variables which define the system have already been identified by various studies (Johnston et al., 2013; de Silva, 2014; de Silva et al., 2014; Johnston et al., 2014) and indicators could be derived to measure these variables within the context of the ELS framework. This would highlight implications for the sustainability of fisheries in the context of rice intensification. If this problem had been structured using the ELS framing, a range of policy measures could be investigated to safeguard and enhance fisheries. These could include regulation of pesticide quality, reduction in pesticide use through farmer education and integrated pest management approaches, in-field water management, in-field fish refuges, community refuge ponds (artificial or natural) and reservoir and pond aquaculture. These effectively resonate with the livelihood outcomes as identified within sustainable livelihoods framings (e.g. DfID, 2001). However, through application of the ELS framework the underlying water, energy and food securities can be identified in line with livelihoods and the outcome is more meaningful for ensuring environmental security is attained.

Another example application of the ELS framework would be to exploit synergies in policy formulation when considering alternative adaptation options in response to coastal flooding and erosion. Small Island Developing States (SIDS) are often vulnerable to external economic shocks, natural disaster events and changing climatic conditions (including sea level rise). In developing adaptation and mitigation strategies, the ELS framework could provide a useful tool for selecting policy measures that enhance socioecological resilience of coastal systems exposed to frequent flooding events. For example, a recent United Nations Environment Programme (UNEP) vulnerability assessment in Lami Town, Fiji (Rao et al., 2013) demonstrated that ecosystem-based adaptation strategies involving rehabilitation of mangrove habitats allowed for improved water quality maintenance and food production. Ecosystem restoration was achieved through reestablishment of nursery grounds for subsistence and commercially valuable fish species. Simultaneously, attempts were made to protect basic infrastructure and minimise livelihood disruption regarding access to water and energy supplies. In circumstances such as these examples where livelihood-environment interactions are prominent, a nexus-livelihoods approach could be adopted to investigate system trade-offs and synergies (such as through applying the ELS framework), to provide a stronger evidence base for policy-makers to ensure sustainable use of natural resources to achieve water, energy and food security for livelihoods.

8. Concluding remarks

Poverty eradication is the overarching target of the United Nations (2014) SDGs with an overall commitment to "free humanity from poverty and hunger as a matter of urgency" (United Nations, 2014; p. 1). Sustained poverty eradication is also a central goal of sustainable livelihoods approaches in recognition that sustainable and fulfilling livelihoods are critical to breaking the poverty cycle (FAO, 2002). It therefore seems crucial to consider livelihoods more explicitly when presenting a set of global targets to achieve future sustainable development of society as a whole. Water, energy and food security are key focal elements for reducing poverty by ensuring adequate resources for sustaining and improving livelihoods in equitable ways. Concurrently, the preservation of ecosystems is crucial for sustaining healthy natural environments and ecosystems via provisioning services to directly or indirectly provide foundations for livelihoods (MEA, 2005).

This paper's development of an integrated framework to identify the ELS of a system allows livelihoods to be explicitly encapsulated within nexus thinking. This framework enables conceptual and practical examination of human demand and natural resource supply within a system to ensure socio-ecological resilience and promote sustainable solutions for livelihoods through identifying nexus synergies and trade-offs. The framework presented here can be applied to real-world multi-scale case studies, providing a valuable conceptual mechanism for monitoring sustainable development progress, balancing parallel agendas, informing policy and governance at all levels, aiding climate-compatible development and assisting in progression towards global poverty eradication; thereby contributing, as we have proposed in this paper, to the ultimate aim of securing the environment and livelihoods of both 'developed' and 'developing' communities. In summary, the framework presented has the potential to:

- Assess the environmental livelihood security of a system.
- Consider the linkages between water, energy, food and livelihood securities within a system.
- Identify trade-offs and synergies within the system to better inform decision-making regarding sustainable development.
- Assist in ascertaining the balance between human demand and natural resource supply to achieve sustainability.
- Account for external pressures and stresses acting upon the system.
- Provide a useful tool for monitoring a system's progress towards achieving environmental livelihood security.
- Allow researchers to investigate systems in detail from an applied nexus-livelihoods context.
- Enable policy-makers to use research outputs for more robust decision-making.

Significance statement

The water–energy–food nexus has become central to discussions regarding the development and subsequent monitoring of the sustainable development goals (SDGs) for the post-2015 agenda. Our research presents a novel framework for integrating livelihoods dynamics into the water–energy–food nexus. The framework builds upon the strengths of nexus and livelihood approaches to explore and develop the concept of 'environmental livelihood security': an integrated and holistic approach to measuring and achieving sustainable development outcomes across multi-scale systems to better-inform policy and development agendas. Application of the framework will enable a baseline for monitoring progress in meeting development targets across multiple scales. Further, the framework we propose has the capacity to take the spatial heterogeneity of livelihoods and environmental resources into account, enhancing both the efficiency and equity of development outcomes.

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References

Aggarwal, P.K., Joshi, P.K., Ingram, J.S.I., Gupta, R.K., 2004. Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. Environ. Sci. Policy 7, 487–498.
Allison, E., Ellis, F., 2001. The livelihoods approach and management of small-scale fisheries. Mar. Policy 25, 377–388.
Bebbington, A., 1999. Capital and capabilities: a framework for analysing peasant viability, rural livelihoods and poverty. World Dev. 27, 2021–2044.
Biggs, E.M., Boruff, B., Bruce, E., Duncan, J.M.A., Duce, S., Haworth, B.J., Horsley, J., Curnow, J., Neef, A., McNeill, K., Pauli, N., Van Ogtrop, F., Imanari, Y., 2014. Environmental Livelihood Security in South-East Asia and Oceania: a nexus-livelihoods approach for spatially assessing change. In: IWMI-CGIAR White PaperInternational Water Management Institute, Colombo, Sri Lanka, Online at: ⟨http://www.iwmi.cgiar.org/publications/other-publication-types/environmental-livelihood-security-south-east-asia-oceania/⟩ (accessed October 2014).
Black, R., White, H., 2004. Targeting Development: Critical Perspectives on the Millennium Development Goals. Routledge, London.
Boruff, B.J., Cutter, S.L., 2007. The environmental vulnerability of Caribbean island nations. Geog. Rev. 97, 24–45.
Bouapao, L., 2012. Livelihoods and migration. In: Smajgl, A., Ward, J. (Eds.), The Water–Food–Energy Nexus in the Mekong Region. Springer, New York, NY, Chapter 5.
Briguglio, L., 1995. Small-Island Developing States and their Economic Vulnerabilities. World Dev. 23, 1615–1632.
Briguglio, L., 2004. Economic vulnerability and resilience: concepts and measurements. In: Briguglio, L., Kisanga, E.J. (Eds.), Vulnerability and Resilience of Small States. Commonwealth Secretariat and the University of Malta, Malta, pp. 43–53.
Briguglio, L., 2014. A Vulnerability and Resilience Framework for Small States. Report prepared for the Commonwealth Secretariat.
Briguglio, L., Galea, W., 2003. Updating and augmenting the economic vulnerability index. In: Occasional Reports on Islands and Small States, No. 2004/4. Islands and Small States, Institute of the University of Malta, Malta.
Briguglio, L., Cordina, G., Farrugia, N., Vella, S., 2006. Conceptualising and measuring economic resilience. In: Briguglio, L., Cordina, G., Kisanga, E.E. (Eds.), Building the Economic Resilience of Small States. Islands and Small States Institute in collaboration with the Commonwealth Secretariat, Malta, pp. 265–288.
Brocklesby, M., Fisher, E., 2003. Community development in sustainable livelihoods approaches—an introduction. Community Dev. J. 38, 185–198.
Brown, P., Daigneault, A., Gawith, D., Aalbersberg, W., Comley, J., Fong, P., Morgan, F., 2014. Evaluating Ecosystem-Based Adaptation for Disaster Risk Reduction in Fiji. Landcare Research, New Zealand Online at ⟨http://www.landcareresearch.co.nz/__data/assets/pdf_file/0004/77341/Fiji_disaster_risk_reduction.pdf⟩ (accessed October 2014).
Carswell, G., 1997. Agricultural intensification and rural sustainable livelihoods. Institute of Development Studies, Brighton IDS Working Paper 64.
Chambers, R., Conway, G.R., 1992. Sustainable rural livelihoods: Practical concepts for the 21st century. In: IDS Discussion Paper No. 296. Institute of Development Studies, Brighton.
Cleaver, F., Franks, T., 2005. How institutions elude design: river basin management and sustainable livelihoods. Alternative Water Forum, Bradford Centre for International Development, Bradford.
Cloin, J., 2007. Coconut oil as a fuel in the Pacific Islands. Nat. Resour. Forum 31, 119–127.
Conroy, C., Litvinoff, M. (Eds.), 1988. The Greening of Aid: Sustainable Livelihoods in Practice. Earthscan, London.
Deacon, C., 2012. Sustainable Livelihoods in the Pacific Islands: The Case of Levuka, Fiji. Oxford Brookes University, Oxford Thesis submitted for MA Degree in Development and Emergency Practice.
de Silva, S., 2014. Institutional profiles from the Tonle Sap Lake region: findings from informant interviews. In: Program Report: AAS-2014-44CGIAR Research Program on Aquatic Agricultural Systems, Penang, Malaysia.
de Silva, S., Johnston, R., Senaratna Sellamuttu, S., 2014. Agriculture, irrigation and poverty reduction in Cambodia: policy narratives and ground realities

compared. In: Working Paper: AAS-2014-13CGIAR Research Program on Aquatic Agricultural Systems, Penang, Malaysia.
DfID (Department for International Development), 2001. Sustainable Livelihoods Guidance Sheets. Department for International Development, London.
Donohue, C., Biggs, E.M., 2015. Monitoring socio-environmental change for sustainable development: developing a multidimensional livelihoods index (MLI). Appl. Geogr. 62, 391–403.
Enfors, E., 2013. Social–ecological traps and transformations in dryland agro-ecosystems: using water system innovations to change the trajectory of development. Global Environ. Change 23, 51–60.
Ericksen, P.J., 2008. Conceptualizing food systems for global environmental change research. Global Environ. Change 18, 234–245.
FAO, 2002. Analytical Framework: Sustainable Livelihoods. Food and Agriculture Organisation of the United Nations Accessed at ⟨http://fao.org/docrep/007/j2602e02.htm⟩ (accessed 17 March 2014).
FAO, 2008. The Livelihood Assessment Tool-Kit: Analysing and Responding to the Impact of Disasters on the Livelihoods of People. Food and Agriculture Organisation of the United Nations, Rome.
FAO, 2012. Mutually Acceptable Mechanism on Integrated Use of Water Resources in Central Asia: Application of the Scenario Approach. Food and Agriculture Organization of the United Nations, Rome.
FAO, 2014. The Water–Energy–Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture. Food and Agriculture Organisation of the United Nations, Rome.
Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P., 2008. Land clearing and the biofuel carbon debt. Science 319, 1235–1238.
Farrington, J., 2001. Sustainable livelihoods, rights and the new architecture of aid. In: Natural Resource Perspectives 69Overseas Development Institute, London.
Forbes, D.L., James, T.S., Sutherland, M., Nichols, S.E., 2013. Physical basis of coastal adaptation on tropical small islands. Sustainability Sci. 8, 327–344.
Giampietro, M., Aspinall, R.J., Bukkens, S.G.F., Cadillo Benalcazar, J., Diaz-Maurin, F., Flammini, A., Gomiero, T., Kovacic, Z., Madrid, C., Ramos-Martín, J., Serrano-Tovar, T., 2013. An innovative accounting framework for the Food–Energy–Water Nexus—application of the MuSIASEM approach to three case studies. In: Environment and Natural Resources Working Paper No. 56. Food and Agriculture Organisation of the United Nations, Rome.
Gourdji, S., Craig, M., Shirley, R., Ponce de Leon Barido, D., Campos, E., Giraldo, M., Lopez, M., Pereira de Lucena, A.F., Luger, M., Kammen, D.M., 2014. Sustainable development opportunities at the climate, land, energy and water nexus in Nicaragua. In: Center for Latin American Studies, Working Paper No. 33. University of California, Berkeley, CA.
Granit, J., Jägerskog, A., Lindström, A., Björkland, G., Bullock, A., Löfgren, R., de Gooijer, G., Pettigrew, S., 2012. Regional options for addressing the water, energy and food nexus in Central Asia and the Aral Sea Basin. Int. J. Water Resour. Dev. 28, 419–432.
Griggs, D., Stafford-Smith, M., Gaffney, O., Rockstrom, J., Ohman, M.C., Shyamsundar, P., Steffan, W., Glaser, G., Kanie, N., Noble, I., 2013. Sustainable development goals for people and planet. Nature 495, 305–307.
Hoff, H., 2011. Understanding the Nexus: Background Paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.
Horsley, J., Prout, S., Tonts, M., Ali, S.H., 2015. Sustainable livelihoods and indicators for regional development in mining economies. Extr. Ind. Soc. 2, 368–380.
Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, R., Gielen, D., Rogner, H., Fischer, G., van Velthuizen, H., Wiberg, D., Young, C., Roehrl, A., Mueller, A., Steduto, P., Ramma, I., 2013. Integrated analysis of climate change, land-use, energy and water strategies. Nat. Clim. Change 3, 621–626.
Johnston, R., de Silva, S., Try, T., 2014. 2014 Investing in water management to improve productivity of rice-based farming systems in Cambodia. In: Robins, L. (Ed.), A Policy Dialogue on Rice Futures: Rice-Based Farming Systems Research in the Mekong Region, ACIAR Proceedings No 142. Australian Centre for International Agricultural Research, Canberra, Proceedings of a dialogue held in Phnom Penh, 7–9 May 2014, Cambodia.
Johnston, R., Roberts, M., Try, T., de Silva, S., 2013. Groundwater for Irrigation in Cambodia, Issue Brief #3 from the Investing in Water Management to Improve Productivity of Rice-based Farming Systems in Cambodia Project, June 2013. IWMI-ACIAR, Colombo, Sri Lanka.
Kad, S., Weir, T., 2008. Virgin coconut oil as a tool for sustainable development in outer islands. Pac. Econ. Bull. 23, 50–62.
Kattelus, M., Mizanur Rahaman, M., Varis, O., 2014. Myanmar under reform: emerging pressures on water, energy and food security. Nat. Resour. Forum 38, 85–98.
Kemp-Benedict, E., Bharwani, S., de la Rosa, E., Krittasudthacheewa, C., Matin, N., 2009. Assessing Water-related Poverty Using the Sustainable Livelihoods Framework. Stockholm Environment Institute, Stockholm.
Khan, S., Khan, M.A., Hanjra, M.A., Mu, J., 2009. Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy 34, 141–149.
MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-Being. World Resources Institute, Washington, DC.
Morse, S., McNamara, N., Acholo, M., 2009. Sustainable livelihood approach: a critical analysis of theory and practice. In: Geographical Paper No. 189. University of Reading, Reading.
Nicol, A., 2000. Adopting a sustainable livelihoods approach to water projects: implications for policy and practice. In: ODI Working Paper 133Overseas Development Institute, London.
Pound, B., Snapp, S., McDougall, C., Braun, A. (Eds.), 2003. Managing natural resources for sustainable livelihoods: uniting science and participation. Routledge, London.
Pritchard, B., Rammohan, A., Sekher, M., Parasuramn, S., Choithani, C., 2013. Feeding India: Livelihoods, Entitlements and Capabilities. Routledge, London.
Rasul, G., 2014. Food, water and energy security in South Asia: a nexus perspective from the Hindu Kush Himalayan region. Environ. Sci. Policy 39, 35–48.
Ringler, C., Bhaduri, A., Lawford, R., 2013. The nexus across water, energy, land and food (WELF): potential for improved resource use efficiency? Curr. Opin. Environ. Sustainability 5, 617–624.
Rao, N.S., Carruthers, T.J.B., Anderson, P., Sivo, L., Saxby, T., Durbin, T., Jungblut, V., Hills, T., Chape, S., 2013. In: An economic analysis of ecosystem-based adaptation and engineering options for climate change adaptation in Lami Town, Republic of the Fiji Islands. A technical report by the Secretariat of the Pacific Regional Environment Programme, Apia, Samoa.
Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. a OR b?. Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. 14, 32.
Scoones, I., 1998. Sustainable Rural Livelihoods: A Framework for Analysis. Working Paper 72. Institute for Development Studies, Brighton, UK.
Scoones, I., 2009. Livelihoods perspectives and rural development. J. Peasant Stud. 36, 171–296.
Sen, A.K., 1981. Poverty and Famine: An Essay on Entitlement and Deprivation. Oxford University Press, Oxford.
Sen, A.K., 1999. Development as Freedom. Oxford Paperbacks, Oxford.
Tittonell, P., 2014. Livelihood strategies, resilience and transformability in Africa. Agric. Syst. 126, 3–14.
Tompkins, E.L., Mensah, A., King, L., Long, T.K., Lawson, E.T., Hutton, C.W., Hoang, V.A., Gordon, C., Fish, M., Dyer, J., Bood, N., 2013. An investigation of the evidence of benefits from climate compatible development. In: Sustainability Research Institute Paper, 44Sustainability Research Institute, London.
Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A., 2003. A framework for vulnerability analysis in sustainability science. Proc. Natl. Acad. Sci. U.S.A. (PNAS) 100, 8074–8079.
United Nations, 2012. The future we want. In: Resolution 66/288. Rio + 20 United Nations Conference on Sustainable Development. UN General Assembly, Rio de Janeiro, Brazil.
United Nations, 2014. Introduction and Proposed Goals and Targets on Sustainable Development for the Post 2015 Development Agenda. United Nations Online at ⟨http://sustainabledevelopment.un.org/content/documents/4528zerodraft12OWG.pdf⟩ (accessed September 2014).
Verhoeven, J.T.A., Setter, T.L., 2010. Agricultural use of wetlands: opportunities and limitations. Ann. Bot. 105, 155–163.
von Dach, S.W., Ott, C., Klaey, A., Stillhardt, B., 2006. Will international pursuit of the millennium development goals alleviate poverty in mountains? MT. Res. Dev. 26, 4–8.
Warner, K., 2000. Forestry and sustainable livelihoods. Unasylva 51, 3–12.
WCED, 1987. Our Common Future. World Commission on Environment and Development, Oxford.
World Economic Forum (WEF), 2011. Water Security: The Water–Food–Energy–Climate Nexus. World Economic Forum, Washington DC.
WWAP (United Nations World Water Assessment Programme), 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. UNESCO, Paris.