

Research article

Energising the WEF nexus to enhance sustainable development at local level

Julia Terrapon-Pfaff*, Willington Ortiz, Carmen Dienst, Marie-Christine Gröne

Wuppertal Institute for Climate, Environment and Energy, Döppersberg 19, 42103 Wuppertal, Germany



ARTICLE INFO

Keywords:

WEF nexus
Water-energy-food nexus
Sustainable energy
Local level
System thinking
Sustainable development
Developing countries

ABSTRACT

The water-energy-food (WEF) nexus is increasingly recognised as a conceptual framework able to support the efficient implementation of the Sustainable Development Goals (SDGs). Despite growing attention paid to the WEF nexus, the role that renewable energies can play in addressing trade-offs and realising synergies has received limited attention. Until now, the focus of WEF nexus discussions and applications has mainly been on national or global levels, macro-level drivers, material flows and large infrastructure developments. This overlooks the fact that major nexus challenges are faced at local level. Aiming to address these knowledge gaps, the authors conduct a systematic analysis of the linkages between small-scale energy projects in developing countries and the food and water aspects of development. The analysis is based on empirical data from continuous process and impact evaluations complemented by secondary data and relevant literature. The study provides initial insights into how to identify interconnections and the potential benefits of integrating the nexus pillars into local level projects in the global south. The study identifies the complex links which exist between sustainable energy projects and the food and water sectors and highlights that these needs are currently not systematically integrated into project design or project evaluation. A more systematic approach, integrating the water and food pillars into energy planning at local level in the global south, is recommended to avoid trade-offs and enhance the development outcomes and impacts of energy projects.

1. Introduction

Access to clean water, modern energy services and sufficient food supply is fundamental for reducing poverty and moving towards more sustainable development. Due to their uneven geographical distribution, the natural resources needed to provide these services are often scarce and factors such as climate change put additional pressure on regional and local availability. But resource availability is only one aspect; even more critical is resource accessibility and affordability for all sections of the population.

In addition to these challenges, the demand for water, energy and food is expected to further increase due to drivers such as population growth, economic development, urbanisation and changing consumer habits – all of which will pose serious challenges in many developing countries and emerging economies. To meet the needs of those people with limited access to these three resources and rising demand in rapidly developing regions it is necessary to address water, energy and food issues jointly, because choices and actions in any of these domains can significantly affect the others (positively as well as negatively) (Halstead et al., 2014). Limited access to energy and water can, for example, reduce food security, while water is needed for energy generation and energy is needed to extract, distribute and treat water.

These types of complex interdependencies, trade-offs and synergies are commonly described as the water-energy-food nexus (WEF nexus). In the WEF nexus, water, energy and food are not treated as separate systems but as subsystems of the nexus.

The WEF nexus concept is increasingly recognised as a conceptual framework by international organisations, academics, policy analysts and other stakeholders (Endo et al., 2017). Organisations such as the International Renewable Energy Agency (IRENA, 2015) and the Food and Agriculture Organization of the United Nations (Flammini et al., 2014) have recently published reports addressing the WEF nexus. Likewise, the European Commission (EC, 2015) conducted a foresight study on the WEF nexus to identify emerging research and innovation opportunities for the EU in the context of climate change. Also the volume of scientific publications on the WEF nexus has increased significantly in recent years (Albrecht et al., 2018), but so far the focus of discussions and applications of the concept has been on global or national levels, macro-level drivers, material flows and large infrastructure developments. This overlooks the fact that major nexus challenges are faced by communities, households, institutions and small businesses at local level. Furthermore, knowledge and analysis of the role that renewable energies can play in the nexus context are limited and often detached from the mainstream nexus discussions (IRENA, 2015).

* Corresponding author. Wuppertal Institute for Climate, Environment and Energy Division, Future Energy and Mobility Structures, Doeppersberg 19, 42103 Wuppertal Germany.
E-mail address: julia.terrapon-pfaff@wupperinst.org (J. Terrapon-Pfaff).

Although it is accepted that the water, energy and food systems are interlinked, to the authors' knowledge no comprehensive studies have systematically assessed the local links between access to sustainable energy and food and water issues at a meta level. Consequently, this paper provides a first systematic evaluation of the WEF nexus links from an energy perspective, with the aim of supporting the creation of better strategies to meet local development challenges in developing countries and emerging economies. This paper also advances a systematic four-step nexus assessment approach to operationalise the WEF nexus concept and analyse it in practice.

Specifically, this paper aims to enhance the understanding of the impact that decentralised and off-grid energy systems can have on the water and food dimension of the nexus by conducting a systematic analysis of the linkages between small-scale energy projects in developing countries supported under the “WISONS of sustainability” initiative¹ and the food and water aspects of development. The specific objectives of the paper are: (a) to highlight the need to integrate local level nexus applications and research into the mainstream WEF nexus discussion by reviewing the WEF nexus state-of-the-art in section 2; (b) to identify approaches to operationalise the mainly theoretical WEF nexus concepts, resulting in the proposal of a systematic four-step nexus assessment approach in section 3; and (c) to overcome the lack of evidence-based knowledge on the WEF nexus at local level by mapping the linkages between small-scale renewable energy applications and food and water aspects of development in section 4 to gain insights into if and how applying the WEF concept could improve energy development interventions at local level.

2. WEF nexus – state-of-the-art and beyond

2.1. WEF nexus and sustainable development

Since 2008, the WEF nexus has become a buzzword in the international development community's sustainable development discourse (Srivastava and Mehta, 2014). As Allouche et al. (2015) state, it is hard to disagree with the notion that by acknowledging the links between the three sectors (so far treated separately by most development interventions), synergies can be created and trade-offs avoided, resulting in the acceleration of sustainable development. Despite the growing attention the WEF nexus has received from international organisations, development agencies, academics, policy analysts and other stakeholders, the so-called “silo mentality” still prevails and food, energy and water challenges continue to be addressed mostly within sectorial boundaries – particularly in terms of projects, investment and policy decisions (Bhattacharyya et al., 2015). Even the existing academic and practitioner literature on the implications of the energy-water-food nexus is often fragmented (Glassman et al., 2011).

Furthermore, when dealing with the WEF nexus and associated literature, it is important to be aware of the dominant narrative under which the nexus debate was initially framed. After the financial, energy and food crises in 2007 and 2008, the WEF nexus emerged as a security concept in light of resource scarcity. Allouche et al. (2014) note that the WEF nexus emerged from global security concerns about natural resources, leading to a scarcity narrative which frames the WEF nexus as a technical and management challenge. Srivastava and Mehta (2014) similarly state that the nexus has been labelled mainly as a security concern. Likewise, Biggs et al. (2015) point out that the nexus was

initially framed from a security perspective to predict and protect against potential future risks to resource availability, thereby neglecting the fact that security is not the only important variable. Leese and Meisch (2015) also argue that constructing the nexus as a security problem obscures the fact that the roots of resource crises lie in unequal distribution.

This framing of the WEF nexus as a resource scarcity and security concern originated from the fact that the concept was for the first time actively promoted by the World Economic Forum in 2011, where the debate was initially driven by private sector actors with the aim of preventing resource scarcity negatively affecting economic growth (Allouche et al., 2015). In the same year, the nexus conference in Bonn put the WEF nexus on the sustainable development agenda, focusing not on economic security but on human security (Hoff, 2011). Framing sustainability as a security issue instead of as a matter of distributional justice (Leese and Meisch, 2015) can result in a shift of focus from the needs of the poor towards issues of national and international stability. Consequently, this approach favours large-scale solutions (Allouche et al., 2015) and allows measures that would otherwise be unacceptable (Srivastava and Mehta, 2014).

In light of resource scarcity playing a central role in the nexus discussions, the focus of WEF research has been on global and national scales, macro-level drivers, resource and material flows, technical assessments and large infrastructure developments. According to Biggs et al. (2015), the debate has mainly focused on technical assessments. Stevens and Gallagher (2015) highlight the fact that the national or supra-national scales predominantly feature while smaller, more localised scales are missing in most WEF nexus discussions. Similarly, Prasad et al. (2012) highlight the focus on large infrastructure planning, while Villamayor-Tomas et al. (2015) state that material flow analysis and modelling are the prevailing frameworks within the WEF nexus. In their review of methods applied in the WEF context, Albrecht et al. (2018) highlight that over three quarters of the published nexus literature focuses on quantitative aspects, resulting in a need to better integrate the social, institutional and political contexts.

Missing, however, is a focus on the major nexus challenges faced by the poor at local, community and household levels. The WEF nexus is crucial for households and communities –especially in rural areas (Leck et al., 2015) – but this livelihood level has not been part of the nexus research (Biggs et al., 2015). Accordingly, the European Commission's WEF nexus report (EC, 2015) recommends for future work to focus on “... local level, applying local solutions and decentralised approaches ...” as well as on “... inclusion of social aspects”. And there is also a need for analyses that address the WEF nexus not only from a technical angle, but also from a social science angle (Leck et al., 2015) and for a stronger focus on the role that institutional stakeholders and actors play in the WEF nexus (Villamayor-Tomas et al., 2015).

Directing WEF nexus research efforts towards these aspects is important. Globally, 1 billion people lack access to safe drinking water (OECD, 2016) and 1.1 billion people still have no access to modern energy services (SE4All, 2016). At the same time, these people (who often lack access to both water and sustainable energy services) frequently depend primarily on agriculture for their livelihoods (Stevens and Gallagher, 2015; Brandi et al., 2014). Accordingly, the WEF nexus is increasingly recognised as a conceptual framework for sustainable development (Biggs et al., 2015). Applying the WEF concept is expected to make the implementation of the Sustainable Development Goals (SDGs) more efficient and robust (Brandi et al., 2014; Yumkella and Yillia, 2015) and should reduce the risk of actions targeted at one SDG undermining the accomplishment of another (Weitz et al., 2014a). Despite these expectations, the poor have, to date, been neither the beneficiaries nor the targets of the WEF nexus (Srivastava and Mehta, 2014). Notwithstanding this criticism regarding security framing and the tendency of the main body of WEF nexus research to focus on the macro analysis of resource flows, the concept has huge potential to make a valuable contribution to enhancing development at local level

¹ “WISONS of sustainability” (www.wisions.net) is an initiative by the Wuppertal Institute supported by the Swiss-based foundation ProEvolution. Since 2004, WISONS has supported the implementation of small-scale sustainable energy projects in developing countries. Several projects are selected and supported every year based on a set of sustainability criteria (technical viability, economic feasibility, local and global environmental benefits, replicability and marketability, potential for poverty reduction, social equity and gender issues, local involvement and employment potential, sound implementation strategy and dissemination concept).

(Allouche et al., 2015); particularly as water, energy and food have generally not been conceptually separated by local communities, farmers and fishermen, in contrast to the approach taken by many government entities, institutions, experts and academics (Middleton et al., 2015). The WEF nexus is in a sense a rediscovery for experts who previously worked mainly within their disciplinary boundaries (Leck et al., 2015). Srivastava and Mehta (2014) rightly ask what impact the WEF nexus discussion in the international development arena will ultimately have on the realities of everyday life at local level.

2.2. Small-scale energy projects and the WEF nexus

To date water is at the centre of most WEF nexus concepts and research (Hoff, 2011). Accordingly, although water security is in many ways closely linked to energy security, water has been prioritised in the mainstream nexus discussions (Allouche et al., 2015). Yet, knowledge of the role renewable energies can play in the nexus context is limited and often detached from the mainstream nexus discussions (IRENA, 2015). At the same time, significant investment is being made in the renewable energy sector in many developing countries and emerging economies, making this a crucial time for ensuring that the most efficient and effective pathways for the water, energy and food sectors are chosen. The role of decentralised and off-grid systems must also be considered, as it is anticipated that such systems will have to meet 60% of the electricity demand of those people who currently have no access to electricity (IEA, 2010). Accordingly, Yumkella and Yillia (2015) argue that energy should be at the centre of the WEF nexus.

Focusing on the need to localise the WEF nexus, it is important to better understand the connection between access to sustainable energy (defined as clean, reliable, affordable and accessible energy from renewable sources) and food and water aspects of development. Although it is widely accepted that access to sustainable energy services can contribute to reducing poverty, energy is not the only component necessary for fostering holistic social and economic development. Consequently, energy development projects that solely provide access to sustainable energy services often fail to address all the needs of the beneficiaries and perform below their optimum (Stevens and Gallagher, 2015). It can be argued that applying a more integrated approach and taking other needs into account, such as providing mechanical power for processing or electricity for powering irrigation, could contribute to more sustainable development. In this way, the WEF nexus concept could potentially help to improve energy development interventions at local level.

Research into the role of the WEF nexus for sustainable energy access projects at local level is limited. Exceptions are the work of Stevens and Gallagher (2015), who review micro-hydro country case studies in Nepal, Peru and Zimbabwe with regard to WEF nexus aspects, and Guta et al. (2017), who analyse five decentralised energy case studies from a WEF nexus perspective. These case study analyses provide valuable insights into the WEF nexus connection of sustainable energy projects, but a more systematic approach using a larger study sample and analysing the links between access to sustainable energy and food and water issues is lacking. More systematic WEF nexus evaluations could help to develop better strategies for meeting local development challenges in developing countries and emerging economies.

2.3. WEF nexus concepts and approaches

Various conceptual frameworks relating to the WEF nexus have been developed by different authors and organisations. The first being the WEF nexus framework of the World Economic Forum (2011), which frames the WEF nexus as a major global risk for economic and social development while framework developed by Hoff (2011) for the Nexus conference in Bonn is centred around the availability of water resources – taking into account global trends and potential fields of action. The eco-system-based framework from IISD (2013) followed, which

considers the access and availability dimensions of water, energy and food and embeds the WEF nexus in the natural, built, institutional and governance systems. The FAO published a resource-focused framework in 2014, which concentrated on the links between the human and natural systems for fostering sustainable development. Since then, several other frameworks have been published, including the one from IRENA (2015), which focuses on the implications of energy policies on the nexus dimensions and Biggs et al. (2015), who call for the integration of livelihood dynamics into the WEF nexus to enhance water, energy and food security at local livelihood level.

However, very few authors have addressed the question of how to translate these WEF nexus concepts, which are mainly theoretical, into practical nexus assessment approaches. Even fewer practical applications of nexus assessments exist. Albrecht et al. (2018) state that despite the promising conceptual approach, to date the use of the WEF nexus as an analytical tool to systematically evaluate water, energy and food interlinkages has been limited. Srivastava and Mehta (2014) see challenges in translating the global level WEF debate into local practice. In their study on the role of the WEF nexus as a research, policy and project agenda. Middleton et al. (2015) found in their research on the role of the WEF nexus as a research, policy and project agenda that the nexus has yet to be integrated into policies and practice. Endo et al. (2015), who analysed methods applied in the WEF nexus context, call for case study assessments focusing on place-based interactions between the water energy and food subsystems to support decision-making processes. Likewise, Leck et al. (2015) call for the practical application of the WEF nexus to case studies.

Hence, the question remains: how best to put the existing nexus frameworks, which are mainly theoretical, into operation? (Srivastava and Mehta, 2014). To answer this question, research-based evidence on the WEF nexus (going beyond quantitative input-output analysis) is required to support the further development of a comprehensive WEF nexus analysis approach (Leck et al., 2015).

One of the few studies focusing on how to analyse the WEF nexus in practice is the Flammini et al. (2014) study, which developed a detailed stepwise nexus assessment approach combining qualitative assessment and quantitative indicator methods with stakeholder dialogue options. While this approach is valuable, it focuses on country level and is only partly applicable to small-scale applications. Another recommendation on how to conduct nexus assessments comes from Alcamo (2015), who recommends a system approach to nexus problems: map the nexus system, quantify the linkages with the help of models or scenarios, identify the critical linkages in the system and, based on these analyses, identify policy options. To explore the interactions between water, food and energy within the SDGs, Weitz et al. (2014a) propose three approaches: (1) screen for interactions among proposed targets; (2) explore the nature of interactions between targets (interdependent/posing conditions and constraints/reinforcing); and (3) identify linking targets at the nexus of different sectors. These approaches provide valuable insights but are not entirely suitable for analysing the WEF nexus in relation to small-scale energy development projects, as they either focus on national level (Flammini et al., 2014), on policy development (Alcamo, 2015) or on the high-level objectives of the SDGs (Weitz et al., 2014b). For the analysis conducted in this paper, we adapted the existing approaches to make them applicable to local case studies as well as to the meta-analysis of case studies. The four-step nexus assessment approach developed is presented in the following section.

3. Methodology: operationalising the nexus

3.1. Nexus assessment approach

To analyse the role the WEF nexus plays at local level, an approach needs to be suitable for small geographical units or even individual or household-level activities. Such an approach also needs to focus on practical implementations and deal with qualitative and often

incomplete data availability. Despite none of the previously described approaches proposed in the literature being wholly suitable for the envisaged purpose, four essential general steps for conducting a WEF nexus assessment can be identified. Ideally, these steps should be participative and should integrate different stakeholders:

(Step 1) Qualitative mapping of the links between the water, food and energy subsystems

To understand the complex interlinkages between the energy, water and food/ agriculture subsystems at local level in developing countries, the bilateral, circular and dynamic links between the different system elements need to be systematically mapped. The mapping of the causal relationships should ideally also illustrate the influence different elements have on each other, so the system map can be understood as an influence model. This mapping should be based on qualitative analysis of non-measurable information, for example from project reports, scientific literature, expert or stakeholder assessments or field studies. It is important to note that a system map is always a simplification of a complex system as complexity cannot be fully mapped. Accordingly, there are various ways to map the system, making different system maps for the same system theoretically possible.

(Step 2) Quantification of WEF nexus links

To better understand the relevance, scale and/or scope of the links in the analysed WEF nexus context, quantitative evidence on the different links should be gathered wherever possible. Data availability at local level is often limited. Consequently, quantification in this context (in contrast to the perspective of [Chang et al. \(2016\)](#)) should not be understood as an attempt to model complex input-output flows, but rather as a means of gathering information to support the identification of the most critical links.

(Step 3) Identification of critical links

Based on the results of the qualitative and quantitative assessments, critical links in the analysed WEF nexus system should be identified. Critical links are links that a) influence the behaviour of other elements of the system; b) are strong in terms of scope or scale; and/or c) are of strategic importance because they can be influenced by actions and decisions. According to [Alcamo \(2015\)](#), identifying these critical links helps to determine which parts of the system should be studied in more detail. Knowledge of critical links can also help to identify the most important intersections between the water, energy and food subsystems.

(Step 4) Leverage of results

Analysing WEF nexus subsystems should not simply be a research exercise. The results of WEF nexus assessments should be applied in practice to generate synergies and avoid trade-offs between the water, energy and food/agricultural aspects of development. The results should be disseminated and applied to e.g. improve project designs, support decision-making and provide policy recommendations.

Following these steps, this paper attempts to systematically analyse sustainable energy projects and their relationship to food and water aspects of development.

3.2. Methods and materials

3.2.1. Study sample

The analysis is based on the results of a detailed process evaluation of 103 projects and a two-cycle impact evaluation of over 50 of these sustainable energy projects. The evaluations are complemented by secondary data (e.g. project documentation and information collected during field visits) and a review of the relevant literature. The projects evaluated used different renewable energy sources applying various renewable energy technologies, such as solar photovoltaic, solar thermal, biogas digesters, biomass combustion and gasification, small

wind turbines and micro-hydro power plants, as well as incorporating efficiency measures. All the applications were small-scale (defined in our study as ≤ 100 kW capacity) and were intended to meet the energy needs of individuals, communities or small businesses. The projects were implemented in over 20 different developing countries in Asia, Sub-Saharan Africa and Latin America.

3.2.2. Analytical approach

Firstly, a nexus matrix table was developed to systematically map the WEF links between the energy, water and food systems at local level in developing countries. The WEF nexus matrix for sustainable energy projects (Step 1) is a helpful tool to better understand the bilateral linkages between any two of the three subsystems examined. However, within a complex system – such as the WEF nexus – not all links can be described as linear relationships between two sectors. Interrelationships are often circular and dynamic and can occur simultaneously or successively within and between subsystems. Therefore, the information collected and presented in the nexus matrix table must be expanded and transferred using a system thinking approach ([Arnold and Wade, 2015](#)).

Applying a system approach allows for the integration of water, food and energy aspects in an analytical manner by mapping key elements of the subsystems and visualising their interdependencies ([Pittock et al., 2016](#)). This holistic system mapping exercise (Step 2) allows for the WEF nexus to be viewed as one system. It visualises how different elements can potentially influence each other and increases the understanding of the whole system.

The system mapping in the presented case starts from the sustainable energy supply, visualising the inter and circular connections in the analysed subsystems – not only between any two of the three sectors but also between all three sectors. The connections are defined as having an increasing or decreasing influence on the relevant variables. An increase or decrease does not necessarily equate to a positive or negative effect. For example, a decrease in water supply is a negative effect, while a decrease in conventional fuel use is a positive effect. As in the nexus matrix table, the links represent potential links that can be project, site or technology specific. Watershed protection activities, for example, have only been integrated into a small number of hydro power projects in the sample, but if implemented more widely these types of activities could be of benefit to various types of projects, not only to ensure water flow for energy generation but also for agricultural activities or household use.

Following the mapping of the WEF nexus, the results of the process evaluation were assessed with regards to quantitative evidence (Step 2) of the most direct linkages of the energy projects to the water and food/agricultural subsystems. In the third step, the critical links are highlighted, based on the findings from the evaluation of the project sample (Step 3).

4. Results

4.1. Mapping the WEF linkages of small-scale energy projects

The starting point of the analysis is the provision of sustainable energy, including both new and improved access to energy from sustainable sources, through the implementation of small-scale energy development projects. To generate energy, renewable sources such as water, solar radiation, wind or biomass are used as input variables. While solar radiation and wind – depending on the geographical and weather conditions – are available in almost unlimited quantities, using water or biomass as energy sources can directly affect the water or agricultural and food subsystems. These effects can be either positive or negative in terms of the availability of these resources for other purposes or impacts on the environment. For example, if biomass is used to generate energy this biomass cannot be used for e.g. fodder, fertiliser, fibre or fuel purposes, which could lead to usage conflicts or result in negative environmental effects. Conversely, using biomass waste that

Table 1

WEF nexus matrix for sustainable energy projects in developing countries.

	Small-scale sustainable energy access	Local water supply	Local food and agricultural system
Energy	<ul style="list-style-type: none"> ● Energy used for lighting or other electrical appliances (TV, mobile phone, machinery etc.) ● Reduced usage of unsustainable fuel sources (e.g. kerosene, diesel) 	<ul style="list-style-type: none"> ● Water used for energy generation (micro-hydro, biogas) ● Water used for energy can alter water flows, which can result in environmental impacts e.g. risk to fish population ● Water used for energy can reduce water availability for other uses, such as irrigation 	<ul style="list-style-type: none"> ● Feedstock for bioenergy generation (agricultural and food waste, energy crops)
Water supply	<ul style="list-style-type: none"> ● Energy used for clean drinking water (to filter or boil drinking water) ● Increased water availability (water pumping) ● Energy used for irrigation ● Energy efficient irrigation technologies can save energy 	<ul style="list-style-type: none"> ● Watershed protection to sustain and enhance watershed functions (energy generation can benefit from sustained water flows) ● Efficient irrigation technologies can save water 	<ul style="list-style-type: none"> ● Use of biomass waste for energy can reduce water pollution ● Incorrect handling of biogas effluents can pollute water sources
Food/Agriculture	<ul style="list-style-type: none"> ● Food preservation (solar drying, milk chilling) ● Agricultural processing (mechanical and electrical energy for milling, grinding etc.) ● Food processing (biogas cooking, solar cookers, improved cook stoves) ● Increased harvest (night-time fishing, use of biogas sludge as fertiliser) ● Reduced pressure on the environmental system due to reduced fuel wood use 	<ul style="list-style-type: none"> ● Improved irrigation can increase agricultural production ● Sustainable agricultural practices can reduce water pollution and water use 	<ul style="list-style-type: none"> ● Sustainable agricultural practices supported under the framework of sustainable energy projects

was previously polluting the environment or endangering human health can potentially have beneficial effects.

The water and agricultural subsystems are not simply supply systems for the generation of energy; the energy generated can be used as an input in both subsystems – for example, to provide clean drinking water or preserve, process or prepare agricultural and food products. These potential linear connections between the water, energy and food subsystems are presented in Table 1. Not all the relationships described are relevant for each project site, technology or country; the table intends to present possible connections between sustainable energy projects and the water and food subsystems that should be considered when planning and implementing energy projects.

Based on the identified bilateral relationships between the water, food and energy subsystems presented in the nexus matrix (Table 1), in a next step the circular links and dynamic relationships within and between the subsystems are mapped to better represent the complex system of the WEF nexus in small-scale energy projects in the global south.

The causal relationships mapped in the influence model (Fig. 1) show the different variables which can be both drivers and effects in the complex WEF nexus system. It can be observed that the use of energy in the agriculture and food system has mainly reinforcing tendencies which are mostly positive, resulting in higher agricultural production and processing or increased food preservation and improved food preparation. This ultimately contributes to increased food security. While these links exist (and are observable in different projects in the evaluation sample), generally a single project only achieves some of these effects. As our impact evaluation shows, some of these links, such as energy for productive activities (e.g. for agricultural processing), do not usually establish themselves automatically. They have to be fostered by accompanying project activities. The same holds true for energy as an input variable for the water system. The energy generated can be used to provide clean drinking water or to power irrigation pumps, increasing the availability of drinking water and the amount of irrigated land. The analysis shows that the success of activities requiring technological inputs or behavioural change depends on these aims being incorporated at the project planning stage. In addition, the amount of energy needed for these activities must be included in the calculation of the energy demand to be met by the small-scale system – otherwise the plan is generally to use the energy for consumptive uses. Such uses are

often equally or more important to the beneficiaries as productive uses as they can directly improve the standard of living. Examples include the provision of lighting or energy for communication and information technologies, such as TVs or mobile phones.

In terms of negative impacts on overall resource availability, the analysis shows that the energy projects using biomass or water as energy sources generally had no negative effects on overall resource availability. However, in theory the risk of direct or indirect negative effects on variables in the water or agricultural and food subsystems exists (as shown by the system mapping). These potentially serious consequences need to be considered when planning and implementing a small-scale energy project.

4.2. Quantifying the WEF nexus links

Following the systematic mapping of the WEF nexus links, the next step of the nexus assessment (Step 2) is to look at these links in more quantitative terms. This involved analysing the relevant direct links between sustainable energy supply and the water and food subsystems in the process evaluation sample of 103 projects. This analysis showed that almost half of the projects (47%) focused mainly on providing energy for the food or water subsystems (Fig. 2), with energy for food being the second most common energy need addressed in the project sample (39%). This analysis shows that water and food aspects of development play an important role in local energy development interventions.

With regard to the types of links to the food and energy subsystems, Fig. 3 shows that about half of the projects providing energy for food support agriculture and food processing activities, with close to 40% providing energy for food preparation. Following the system map, these activities should, in theory, directly or indirectly improve food supply and contribute to improving food security. However, it is difficult to empirically prove these subsequent impacts and further research to systematically integrate WEF nexus links into the evaluation design is required.

The projects addressing the energy need for water mainly focus on providing energy for irrigation (87%), with a small share supporting urban water use in the form of water pumping. The use of energy for irrigation is, furthermore, directly linked to the agricultural and food system. This demonstrates that providing sustainable energy at local

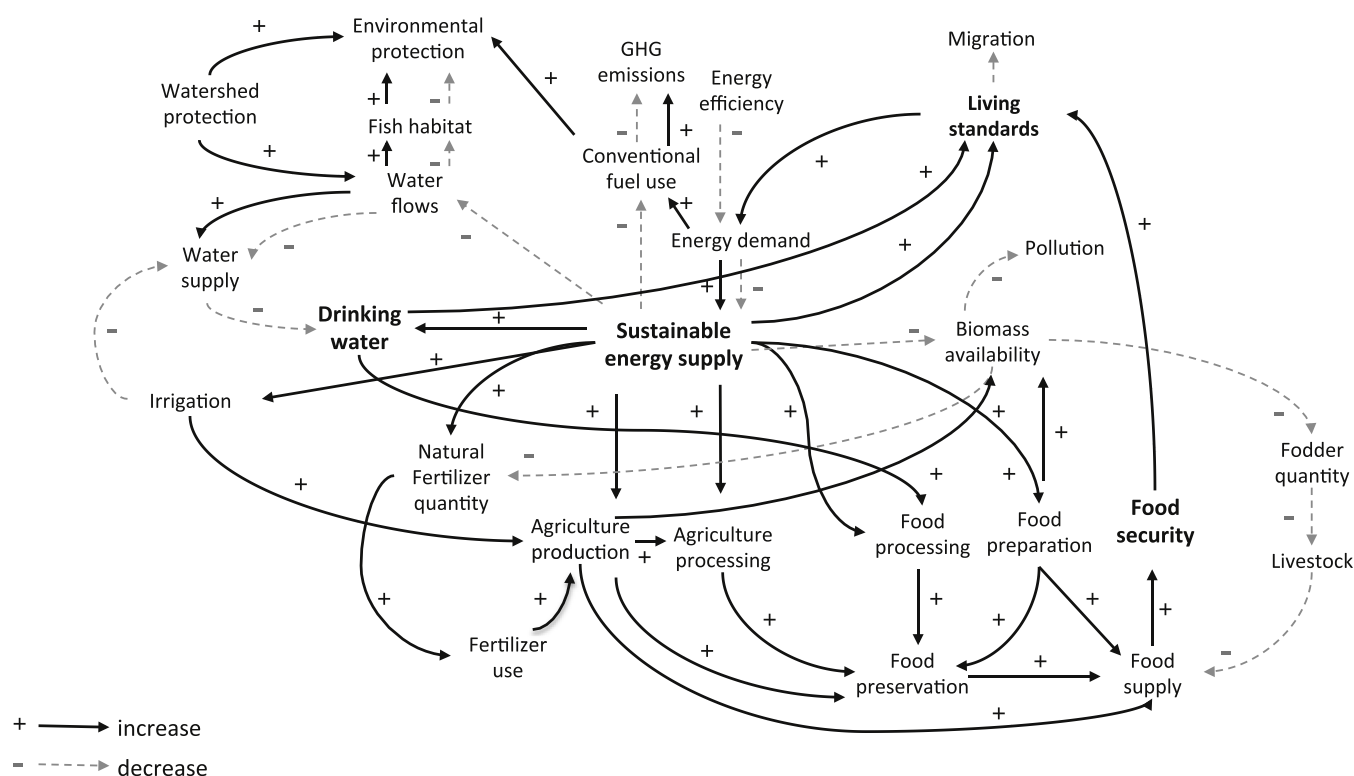


Fig. 1. Map illustrating how sustainable energy supply, water and food influence each other at local level in developing countries.

level in developing countries is often strongly linked not only to one but to both the other subsectors.

4.3. Identifying critical WEF links within small-scale energy projects

Based on the system mapping of the three nexus pillars and the analysis of the direct links between the energy projects and water, food or agricultural applications, the evaluation results were used to identify critical links (Step 3).

Considering the projects that provided “energy for food”, critical links were identified in relation to energy for both food preparation and food or agricultural processing. The use of energy devices (such as improved solar thermal cookers and cook stoves to prepare food) and the use of biogas for cooking are directly connected to the food pillar but do not necessarily have a direct influence on supply levels and food security. This impact only occurs if, prior to the implementation of the sustainable energy technology, the availability of fuel wood or other conventional energy sources was limited; for example, if a household was unable to collect or afford the quantity of fuel wood needed to prepare food. Using a cooking device that runs on renewable energy could, in such cases, improve the situation if it can provide sufficient

energy for food preparation. From another angle, food preparation habits can have a direct influence on the successful adoption of the energy device implemented. The evaluation results showed that if the energy technology does not meet the needs of traditional cooking habits, it is unlikely to be used by the beneficiaries. For example, a solar cooker might make food preparation take longer and make cooking impossible after sunset, which could hinder its adoption. In summary, energy projects focusing on cooking devices must take traditional food preparation methods into consideration otherwise the projects have a high risk of failure.

The evaluation results also showed that energy projects focusing on providing sustainable energy for agricultural or food processing can often directly contribute to an increase in food availability. For example, the implementation of solar dryers increased food availability by enabling farmers to preserve some of the fruit and vegetables they produced. Prior to the introduction of the technology, parts of the harvest were wasted because it was impossible to use all the produce while it was still fresh. In another project, biogas was used to generate electricity for milk chilling, allowing the evening milk to be stored until the following morning when it was collected by the processing company. These examples show that access to sustainable energy

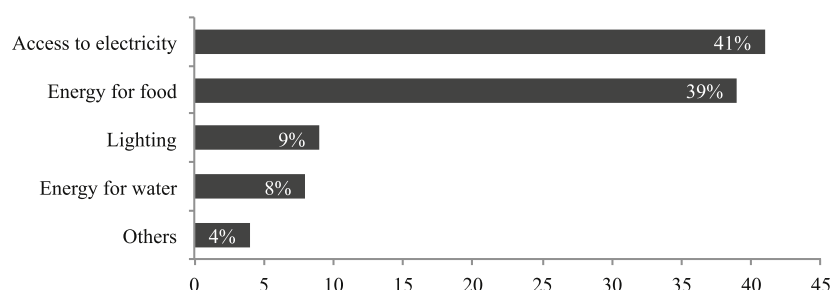


Fig. 2. Share of energy needs addressed in evaluation sample of 103 projects (%).

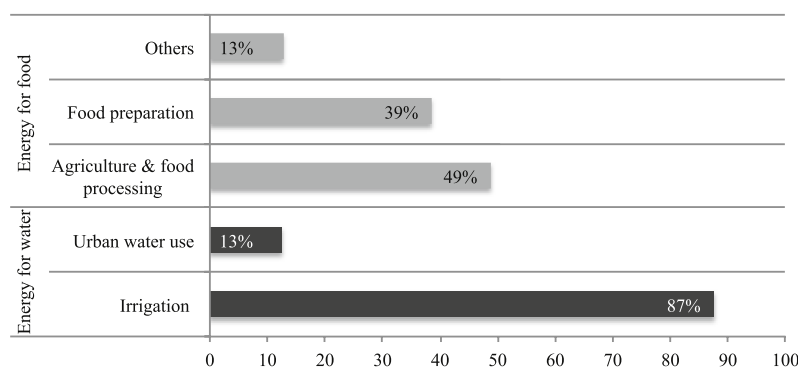


Fig. 3. Share of “energy for food” and “energy for water” applications in the evaluation sample of 103 projects (%).

technologies can be critical in increasing the availability of agricultural products and improving food supply. However, as previously mentioned, the implementation of these productive activities needs to be integrated into the energy system planning stage as energy access alone does not usually foster productive activities.

Regarding the projects that focused on “energy for water” (which mainly concentrated on providing energy for irrigation), the evaluation results showed different critical links depending on the project focus. The results support the assumption that using energy to supply water for irrigation can contribute to improved harvests or to the cultivation of crops (such as vegetables) that were not previously viable. In several cases, the improvement and diversification of the harvest was reported to enhance food supply. Compared to the other technologies, the evaluation results showed that several irrigation projects resulted in increased income generation. This was due to higher levels of agricultural productivity and the establishment of alternative income-generating opportunities, such as a tree nursery or vegetable production for local and regional markets. In cases where irrigation was already in place, the introduction of more efficient equipment succeeded in reducing water use, which had a positive impact on water availability. To achieve these water savings, the technology must be efficient and when a new technology is introduced to a region, the local people must be trained to ensure the correct use of the equipment. In addition to the positive effects of energy access on water uses such as irrigation, it was also identified that using the surplus energy from underutilised micro-hydro power plants for irrigation purposes could improve the usage rate and, consequently, the feasibility of the energy system. Despite these mainly positive effects reported in the evaluation, one of the energy for water projects led to unintended negative effects on the environment. In this project, farmers chose to use diesel to fuel their new irrigation pumps, instead of oil from wild *Jatropha* seeds.

As these descriptions of critical links between small-scale sustainable energy projects and food and water aspects show, there is no single critical link. Many different links can be critical for achieving positive results and avoiding negative results. This complexity underlines the importance of taking the WEF nexus linkages into consideration when planning development interventions at local level. Neglecting these aspects increases the risk of failure or unintended unsustainable developments.

5. Discussion

The research presented shows that complex links exist between sustainable energy projects in the global south and the food and water sectors. The energy needs addressed are often directly connected to food or agricultural activities or are connected indirectly by providing energy for water use in agriculture. These findings underline the fact that the WEF nexus is more than a conceptual framework when it comes to sustainable development at local level. Water, food and energy are generally not separate needs; together they represent the core

challenges faced by households, communities, institutions and small businesses at local level in developing countries.

Despite the fact that energy and water needs are addressed by the small-scale energy development projects analysed, currently these needs are not systematically integrated into project design or project evaluation. A more systematic approach to integrating water and food links in energy planning at local level could help to avoid trade-offs, as well as helping to enhance the development potential. One of the barriers identified to the application of a more holistic WEF nexus approach is the type of funding available, which may only provide loans, subsidies or grants for one of the three nexus pillars. Another barrier is the challenge of putting holistic approaches into practice. This requires expertise in the different fields, making the project implementation more complex. As well as this increased complexity, practical issues such as skill shortages within local practitioner organisations in the field of energy development can also prevent the more systematic integration of water and food aspects into energy projects.

With regards to the methodological challenges of operationalising the WEF nexus at local level, the mapping of the WEF system revealed links between the three subsystems. However, it should be noted that mapping such a complex system is always a simplification and other system maps are possible (Pittcock et al., 2016). In this case, the mapping was based on the systematic review of a sample of 103 projects. As such, it provides a good basis for further discussions and can support a more systematic decision-making process in terms of energy development projects and water and food aspects of development. Regarding quantification, it is clear that direct connections can be assessed but, to learn more about the cascading links and effects, more detailed evaluations integrating WEF nexus aspects into the research design are required.

Furthermore, to verify and understand the links between the water, food and energy subsystems, it is crucial to address the same research needs and challenges as for the evaluation of development projects in general and small-scale energy projects in particular. This involves overcoming the problems of establishing causality between the variables, because the more complex the system the more difficult it is to determine what the drivers and effects are. Even more important than quantifying the links (which only answers the question of “what” happened), is to understand “why” and “how” links are established. It will only be possible to enhance sustainable development by applying a WEF nexus approach when the underlying causes connecting sustainable energy with the water and food subsystems are understood.

6. Conclusion

This paper analysed the linkages between small-scale energy projects in developing countries and the food and water aspects of development. The initial analysis of existing literature showed that the water-energy-food (WEF) nexus is widely discussed as a framework in the sustainable development debate. Despite this, limited attention has

been given to the local level where communities, households, institutions and small businesses face the fundamental challenges of simultaneously meeting their water, energy and food needs.

Furthermore, although a number of conceptual WEF nexus frameworks have been developed, limited information exists about how to best apply these frameworks in practice. This paper suggests a four-step nexus assessment approach to operationalise the WEF nexus for the local level: (1) qualitatively map the WEF nexus links; (2) quantify the links; (3) identify critical links; and (4) leverage the results to improve project design and implementation. This systematic approach was applied to an empirical data set from continuous process and impact evaluations of small-scale energy projects in developing countries.

The results of the analysis show that complex links exist between sustainable energy projects and the food and water sectors. The energy needs addressed are often directly connected to food or agricultural activities or are connected indirectly by providing energy for water use in agriculture. A more systematic approach integrating the water and food pillars in energy planning at local level in the global south should be advocated to avoid trade-offs and enhance the development potential of energy projects.

Acknowledgement

We acknowledge financial support by Wuppertal Institute for Climate, Environment and Energy within the funding programme ‘Open Access Publishing’.

References

- Albrecht, T.R., Crootof, A., Scott, C.A., 2018. The Water-Energy-Food Nexus : a systematic review of methods for nexus assessment. *Environ. Res. Lett.* 13, 043002. <https://doi.org/10.1088/1748-9326/aaa9c6>.
- Alcamo, J., 2015. Systems thinking for advancing a nexus approach to water, soil and waste. 1–14 (2) United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).
- Allouche, J., Middleton, C., Gyawali, D., 2015. Technical veil, hidden politics: interrogating the power linkages behind the nexus. *Water Altern.* (WaA) 8, 610–626.
- Allouche, J., Middleton, C., Gyawali, D., 2014. Nexus Nirvana or Nexus Nullity? A Dynamic Approach to Security and Sustainability in the Water-energy-food Nexus. STEPS Working Paper 63. STEPS Centre, Brighton.
- Arnold, R.D., Wade, J.P., 2015. A definition of systems thinking: a systems approach. *Proc. Proc. Comput. Sci.* 44, 669–678. <https://doi.org/10.1016/j.procs.2015.03.050>.
- Bhattacharyya, P.S., Bugatti, N., Baueet, H., 2015. A Bottom-up Approach to the Nexus of Energy , Food and Water Security in the Economic Community of West African States (ECOWAS) Region about the Nexus Network Think Piece Series. ESRC September 2015.
- Biggs, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., McNeill, K., Neef, A., Van Ogtrop, F., Curnow, J., Haworth, B., Duce, S., Imanari, Y., 2015. Sustainable development and the water-energy-food nexus: a perspective on livelihoods. *Environ. Sci. Pol.* 54, 389–397. <https://doi.org/10.1016/j.envsci.2015.08.002>.
- Brandi, C., Richerzhagen, C., Stepping, K., 2014. Post 2015: Why Is the Water-energy-land Nexus Important for the Future Development Agenda? German Development Institute/Deutsches Institut für Entwicklungspolitik Briefing Paper 3/ 2014.
- Chang, Y., Li, G., Yao, Y., Zhang, L., Yu, C., 2016. Quantifying the water-energy-food nexus: current status and trends. *Energies* 9, 1–17. <https://doi.org/10.3390/en9020065>.
- EC - European Commission, 2015. The Water-energy-food Nexus: Foresight for Research and Innovation in the Context of Climate Change.
- Endo, A., Tsurita, I., Burnett, K., Orenco, P.M., 2017. Journal of Hydrology : regional Studies A review of the current state of research on the water , energy , and food nexus. *Biochem. Pharmacol.* 11, 20–30. <https://doi.org/10.1016/j.ejrh.2015.11.010>.
- Endo, A., Burnett, K., Orenco, P.M., Kumazawa, T., Wada, C.A., Ishii, A., Tsurita, I., Taniguchi, M., 2015. Methods of the water-energy-food nexus. *Water* (Switzerland) 7, 5806–5830. <https://doi.org/10.3390/w7105806>.
- Flammini, A., Puri, M., Pluschke, L., Dubois, O., 2014. Walking the nexus talk: assessing the water-energy-food nexus in the context of the sustainable energy for all initiative. *Environ. Nat. Resour. Manag Working Paper* (FAO) eng no. 58.
- Glassman, D., Wucker, M., Isaacman, T., Champilou, C., 2011. The Water-energy Nexus: Adding Water to the Energy Agenda. World Policy Institute.
- Guta, D., Jara, J., Adhikari, N., Chen, Q., Gaur, V., Mirzabaev, A., 2017. Assessment of the successes and failures of decentralized energy solutions and implications for the water-energy-food security nexus: case studies from developing countries. *Resources* 6, 24. <https://doi.org/10.3390/resources6030024>.
- Halstead, M., Kober, T., Zwaan, B.C.C., 2014. Understanding the energy-water nexus. *Pol. Stud.* 2013, 2012.
- Hoff, H., 2011. Understanding the Nexus, Background Paper for the Bonn 2011 Conference: the Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm.
- IEA- International Energy Agency, 2010. World Energy Outlook 2010. International Energy Agency, Paris 2010.
- IISD - International Institute for Sustainable Development, 2013. The Water-energy-food Security Nexus: towards a Practical Planning and Decision-support Framework for Landscape Investment and Risk Management. IISD, Winnipeg. www.iisd.org/pdf/2013/wef_nexus_2013.pdf.
- IRENA, 2015. Renewable Energy in the Water, Energy and Food Nexus. International Renewable Energy Agency, pp. 1–125 (January).
- Leck, H., Conway, D., Bradshaw, M., Rees, J., 2015. Tracing the water – energy – food Nexus: description , theory and practice. 8, 445–460.
- Leese, M., Meisch, S., 2015. Securitising sustainability? Questioning the “water, energy and food-security nexus. *Water Altern.* (WaA) 8, 695–709.
- Middleton, C., Allouche, J., Gyawali, D., Allen, S., 2015. The rise and implications of the water-energy-food nexus in Southeast Asia through an environmental justice lens. *Water Altern.* (WaA) 8, 627–654.
- OECD - Organisation for Economic Co-operation and Development, 2016. Water - the Right price Can Encourage Efficiency and Investment. www.oecd.org/env/resources/water-the-right-price-can-encourage-efficiency-and-investment.html.
- Pittock, J., Dumaresq, D., Bassi, A.M., 2016. Modeling the hydropower-food nexus in large river basins: a Mekong case study. *Water* (Switzerland) 8, 1–18. <https://doi.org/10.3390/w8100425>.
- Prasad, G., Stone, A., Hughes, A., Stewart, T., 2012. Towards the development of an energy-water-food security nexus based modelling framework as a policy and planning tool for South Africa. In: *Strateg To Overcome Poverty Inequal.* . [www.carnegie3.org.za/docs/papers/255_Prasad_Towards the development of an energy-water-food security nexus based modelling framework as a policy and planning tool for SA.pdf](http://www.carnegie3.org.za/docs/papers/255_Prasad_Towards%20the%20development%20of%20an%20energy-water-food%20security%20nexus%20based%20modelling%20framework%20as%20a%20policy%20and%20planning%20tool%20for%20SA.pdf).
- SE4All, 2016. The Sustainable Energy for All Initiative. Ending energy poverty. www.se4all.org.
- Srivastava, S., Mehta, L., 2014. Nexus and Security Not Another Nexus? Critical Thinking on the New Security Convergence in Energy, Food, Climate and Water. STEPS Centre.
- Stevens, L., Gallagher, M., 2015. The Energy-water-food Nexus at Decentralized Scales: Synergies, Trade-offs and How to Manage Them. Practical Action Publishing, Rugby.
- Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., Kimmich, C., 2015. The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks. *Water Altern.* (WaA) 8, 735–755.
- Weitz, N., Nilsson, M., Davis, M., 2014a. A nexus approach to the Post-2015 agenda: formulating integrated water, energy, and food SDGs. *SAIS Rev. Int. Aff.* 34, 37–50. <https://doi.org/10.1353/sais.2014.0022>.
- Weitz, N., Nilsson, M., Huber-Lee, A., Hoff, H., 2014b. Cross-sectoral Integration in the Sustainable Development Goals: a Nexus Approach. SEI Discussion Brief. Stockholm Environment Institute, Stockholm. <http://www.sei-international.org/publications?pid=2474>.
- Yumkella, K.K., Yillia, P.T., 2015. Framing the water-energy nexus for the Post-2015 development agenda. *Aquat. Proc.* 5, 8–12. <https://doi.org/10.1016/j.aqpro.2015.10.003>.