This project is co-funded by the European Union

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DEUTSCHE ZUSAMMENARBEIT

nexus

The Water-Energy-Food Security Nexus

A review of Nexus literature and ongoing Nexus initiatives for policymakers

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Published by
Nexus Regional Dialogue Programme (NRD)

c/o Deutsche Gesellschaft für Internationale
Zusammenarbeit (GIZ) GmbH

Registered offices: Bonn and Eschborn, Germany

Global Nexus Secretariat (GNS)
Sector Programme Sustainable Water Policy
Division Climate Change, Environment & Infrastructure (G310)
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Programme
The Nexus Regional Dialogue Programme (NRD) is a programme
funded by the European Union and the German Federal Ministry
for Economic Cooperation and Development (BMZ).

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Bonn, November 2018

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List of Acronyms

ACCWaM	The Adaptation to Climate Change in the Water Sector in the MENA Region Programme
AMCE	Arab Ministerial Council for Electricity
AMWC	Arab Ministerial Water Council
ASFSD	Arab Strategic Framework for Sustainable Development
BMZ	Federal Ministry for Economic Cooperation and Development, Germany
CAREC	Regional Environmental Centre for Central Asia
DAFNE	Donors and Foundations Networks in Europe
ECAM	Energy Performance and Carbon Assessment and Monitoring Tool
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global Water Partnership
HIO	High Impact Opportunity
IASS	Institute for Advanced Sustainability Studies
ICIMOD	International Centre for Integrated Mountain Development
IUCN	The International Union for Conservation of Nature
IWA	International Water Association
IWRM	Integrated Water Resources Management
JRP	Joint Rules of Procedure of the Federal Ministries
LAC	Latin America and the Caribbean
LDCs	Least Developed Countries
MDGs	Millennium Development Goals
MENA	Middle East and North Africa
MSP	Multi-Stakeholder Processes
NBA	Niger Basin Authority
NGO	Non-governmental organisation
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SEforAll	Sustainable Energy for all
SPIS	solar powered irrigation systems
SUGI	Sustainable Urbanisation Global Initiative
UN	United Nations
UNECE	The United Nations Economic Commission for Europe
UN-ESCWA	United Nations Economic and Social Commission for Western Asia
USAID	United States Agency for International Development
WaCCliM	Water and Wastewater Companies for Climate Mitigation
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use
WEF	Water-Energy-Food

Introduction

The Nexus describes the interconnections and interdependencies between the water, energy and food (WEF) sectors. These interdependencies of the WEF securities have received growing attention in the past years by academia and policy-makers. In 2011, the World Economic Forum identified the lack of understanding of the Nexus as a major global economic challenge, and the Bonn conference in the same year put forward the Nexus approach as a fundamental necessary shift for sustainable development.

To address the need to inform policy-makers and other decision makers about research concerning the WEF Nexus, the need for a literature review was identified, with the aim to provide an overview of key Nexus concepts and tools that can be applied in policy and practice. This review aims to help bridge the gap between science and policy in the implementation of Nexus thinking. Furthermore, it investigates the question: where and how are Nexus concepts currently implemented, and by whom?

In recent years, numerous scientific conferences on the Nexus topic have brought scientists, policy-makers, civil society and the private sector together, over a spectrum of different disciplines. This has resulted in hundreds of published articles and reports as well as new initiatives, funding mechanisms and programmes to advance sector-wide Nexus management. Furthermore, several review papers of the WEF Nexus research field have been published in the past few years, and each of these reviews has a specific purpose and focus. The Nexus is extremely dynamic and state of the art developments in its study mean that the collective understanding of the topic within the scientific community is constantly expanding.

Other scientists are generally the primary target group of Nexus-related articles published in scientific journals. Many of the findings of scientific research, even if compiled in form of the above-mentioned comprehensive reviews, do not reach the stakeholders responsible for bringing the theory of the Nexus concepts into practice. Hence, identifying and using adequate mechanisms to transfer scientific knowledge to the relevant stakeholders is often perceived as one of the major shortcomings. There is a need to create awareness of advantages and opportunities of introducing a Nexus thinking to improve current policies of resources management. Liu et al. (2017) stated that while research on methods and tools to quantify, assess or plan to address the Nexus are plentiful in scientific literature, tools to support its implementation are only in the early phase of elaboration.

This situation mirrors the overall challenge of science policy interfacing. While the need to involve stakeholders and decision makers in research is frequently highlighted by the authors covering the topic, examples where this interfacing is practiced are very rare or they are usually not reported upon in scientific literature.

This review aims to be a resource for professionals responsible for Nexus relevant decisions either in planning, financing or implementation. It aims to provide an overview of the literature covering the WEF Nexus topic, with a discussion on how the approach can be effectively implemented on the ground. The review also aims to summarise ongoing WEF Nexus initiatives and regional applications of the WEF Nexus in Southern Africa, the MENA Region, Central Asia, Latin America and the Niger Basin. In addition, this review provides a summary of recent research findings on key topics of relevance to the assessment of the Nexus and Nexus interventions. Direct links to the original documents and websites are provided, allowing the reader to access the original publications to learn more about the methods and tools of interest.

Different types of data and tools can be used to assess different aspects of the Nexus, and these allow the comparison of different development scenarios (i.e. combining different planning scenarios modelling the interconnections between the WEF securities). But further to this, a dialogue is required to convey the necessity of adopting a Nexus approach and to show that its implementation is feasible. Implementation of the Nexus typically requires the linking of different policy domains. The connection of these "silos" of decision-making is typically a challenge to policy, though definitely not limited to the realm of the Nexus.

This literature review was prepared under the umbrella of the "Nexus Regional Dialogues Programme" co-funded by BMZ and European Union (EU) and implemented by GIZ in the Middle East and North Africa (MENA) region, in Latin America and the Caribbean (LAC) and in the Niger basin, by Regional Environmental Centre for Central Asia (CAREC) / International Union for Conservation of Nature (IUCN) in Central Asia and by the Global Water Partnership (GWP) in the Southern African Development Community (SADC) region. It summarises the currently available state of the art, addressing the conceptual understanding of the WEF Nexus and the application of the concept on the ground. A focus was placed on the implementation of the Nexus concepts in the focal regions addressed by the "Nexus Regional Dialogues Programme."

Chapters 1 and 2 provide an overview of the Nexus concept and its historical development, Chapter 3 discusses employing the Nexus approach, Chapter 4 provides a brief summary of the Urban Nexus concept, Chapter 5 analyses reports which describe the analysis or implementation of the Nexus within the five target regions and Chapter 6 contains a bibliography of selected literature.

This review is based on available and accessible online sources. However, the authors do not claim to provide complete coverage of the topic as many research issues and projects may address Nexus relevant topics even if they are not addressed as "the Nexus" or are beyond interactions of the WEF domains.

1. Overview of the Water, Energy and Food (WEF) Nexus

This chapter provides an overview of the literature that describes the Nexus concept, highlighting the importance of addressing the WEF Nexus in practice. This chapter is centred on addressing four key questions:

a) What is the problem setting?

b) What is the Nexus approach?

c) How is the Nexus related to the 2030 Agenda?

d) What are the challenges in the implementation of a Nexus approach?

What is the problem setting?

The world is currently facing a great challenge of securing water, energy and food for everyone. Due to rapid population and economic growth in combination with accelerated urbanisation and changing lifestyles, demand for these three services is increasing. However, the natural resources from which these services are derived, are limited. Additionally, drivers such as climate change and the degradation of natural resources are reducing our ability to provide more of these services. This great challenge requires new management approaches that ensure the adequate supply of these services to everyone while simultaneously ensuring the sustainability of natural resources. Providing services in the three sectors are founded on exploitation of the same natural resources base, and the processes of exploitation impact each other in numerous ways.

In this literature review, the following definitions of water security, energy security and food security are considered:

- Water security: "The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN Water, 2013).

- Energy security: "The uninterrupted availability of energy sources at an affordable price" (IEA, n.d.).

- Food security: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006).

Projections of future water, energy and food demands do vary, but they all agree that demand in the three sectors will significantly increase over the coming decades while the natural resources base will

simultaneously be weakened through environmental degradation and climate change. All of these threats are depicted on Figure 1, which describes the relationships between water, energy, food and climate in light of global projections which indicate increasing scarcities and growing demand. This set of projections predict that by 2030, the demands for food and energy will increase by 50% and the demand for water by 30%, while we also face the challenges of adapting to and mitigating climate change (Beddington, 2010; Allouche et al., 2014; Cairns and Krzywoszynska, 2016).

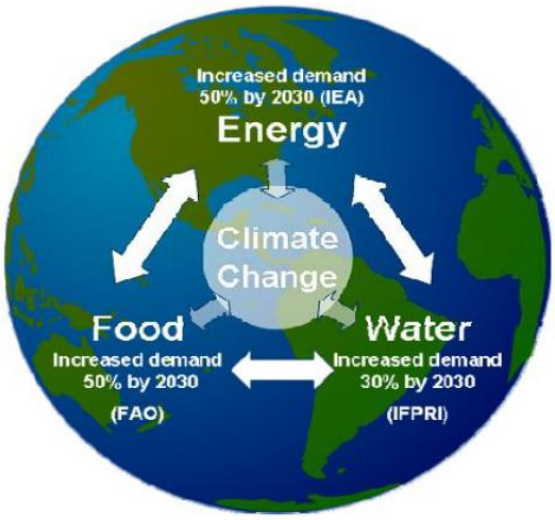

Figure 1: Water, energy and food projections (increases on 2009 levels) (Beddington, 2009)

The policy-making frameworks addressing natural resources management have historically been characterised by sectoral approaches and isolated policy responses, which undermine the complex relationships between sectors and resource systems. This has often resulted in segmented planning and resource stresses (Pittock et al., 2013). Isolated planning in the water, energy and agricultural sectors leads to unintended consequences and additional WEF resources stresses, which in turn worsens livelihoods and undermines sustainable development (Bizikova et al., 2013). It became evident and urgent that more responsible management of WEF systems was needed to cope with the changing lifestyles and growing demand for resources and services (Liu et al., 2017).

What is the Nexus approach?

The concept of the WEF Nexus emerged as a response to this problem setting. The WEF Nexus describes and analyses the interlinkages between the three sectors, with the ultimate goal to identify potential synergies and minimise trade-offs between the three sectors (Hoff, 2011). Natural resources scarcities are often placed at the centre of such debates (Allouche et al., 2014). The increasing pressures on scarce natural resources stemming from an ever-increasing demand for socio-economic development have encouraged the analysis of these interactions between the sectors in a more

systematic way. An intervention in one of these three sectors may induce positive or negative consequences on one or both other sectors.

It is noted that some literature includes the environment and/or ecosystems within the Nexus (labelled as the WEFE Nexus), as does the Nexus Regional Dialogues Programme. It is acknowledged that the environment and ecosystem play a fundamental role in the Nexus. In the use of the term WEF Nexus in this document, a consideration of the environment and ecosystem is implicit within the consideration of each of the three sectors. Figure 2 shows this integrated approach to the assessment of the WEF Nexus, with ecosystems located at the centre (GIZ, 2016). Furthermore, a Nexus problem is not defined as necessarily involving all three of the water, energy and food sectors; the interconnections between any two of these sectors constitutes a Nexus problem. In this document we therefore focus on the water-energy Nexus, the water-food Nexus, the energy-food Nexus and the water-energy-food (i.e. WEF) Nexus.

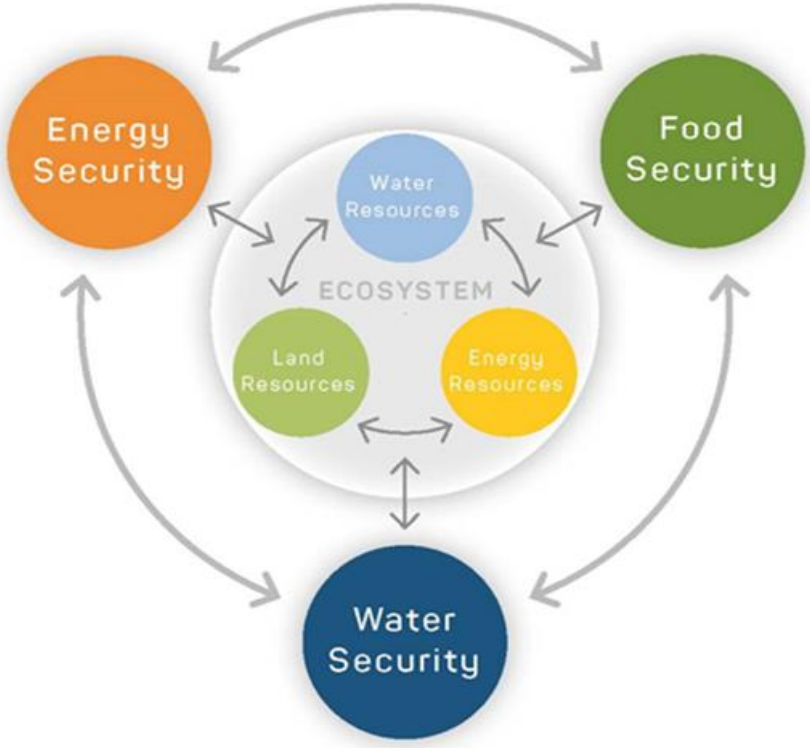

Figure 2: The WEF Nexus from the ecosystem perspective (GIZ, 2016)

Addressing challenges related to the WEF Nexus requires the assessment of trade-offs between the WEF sectors. For example, the spread in biofuel use could lead to a reduction in available water and land for other purposes, most importantly for food production; the increase in water demand for agriculture and energy competes with the demand for more drinking water; and increasing utilisation

of energy-intensive water desalination plants for drinking water and irrigation (Bazilian et al., 2011). Figure 3 shows some examples of the interconnections between the WEF Nexus elements.

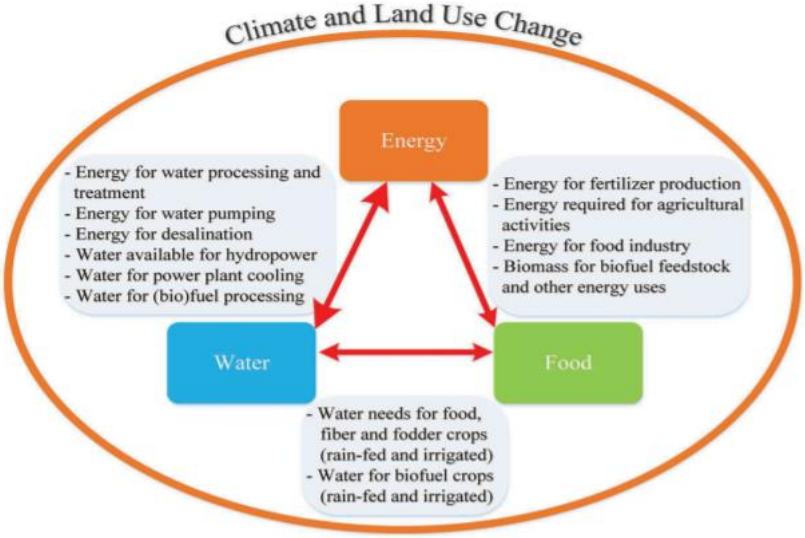

Figure 3: Illustration and examples of the WEF interconnections (Liu et al., 2017)

Although the systems are physically interconnected, decisions and policy planning in each sector are mostly made in isolation (Rasul, 2016; White et al., 2017). Thus, the Nexus governance discourse postulates that to manage risks, maximise gain and optimise trade-offs in resources use, we must not only understand how these systems are physically connected but how they are institutionally linked (see for example, Scott et al., 2011; Hoff, 2011; Flammini et al., 2014; Rasul, 2016; Scott, 2017). The crucial role that institutions and governance processes play in enabling policy coherence and a Nexus approach is underlined in several reports and frameworks.

Water is considered as the central element in many Nexus research examples. This is mainly because the WEF Nexus concept was originally developed within the water sector and a significant quantity of Nexus literature stems from water research projects. Reasons that could explain the central role of water in applying the Nexus are: (1) water represents a basic need for human life and for development, e.g. to produce food and energy; (2) the scarce nature of water and uneven distribution of the resource around the globe; (3) earlier awareness about the connectivity of this sector with many sectors; and (4) the Nexus approach has emerged from many recent approaches such as the concept of Integrated Water Resources Management (IWRM), which emphasise a multifaceted approach of addressing the resource.

How is the Nexus related to the 2030 Agenda?

Specific to Agenda 2030, three of the seventeen sustainable development goals (SDGs) are directly related to the water, food and energy sectors (UN, 2015a):

- SDG 2 (Zero Hunger): End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- SDG 6 (Clean Water and Sanitation): Ensure availability and sustainable management of water and sanitation for all.
- SDG 7 (Affordable and Clean Energy): Ensure access to affordable, reliable, sustainable and modern energy for all.

Although these three goals directly relate to the individual areas of water, energy and food security, progress in twelve of the seventeen SDGs is directly related to the sustainable use of resources (Mohtar, 2016), and some goals cannot be achieved without a holistic view of the WEF Nexus. The study of the Nexus has been identified as a useful approach for quantifying and assessing the interactions between the different goals, including the effects that the fulfilment of one goal may have on the fulfilment of others (Brandi et al., 2013; Weitz et al., 2014; Mohtar, 2016).

For example, SDG 11 covers sustainable cities and communities. Cities and communities could benefit heavily from the WEF Nexus approach to make use of the potential synergies between the three sectors and avoid the potential trade-offs between them. The Urban Nexus approach focuses on promoting the WEF Nexus approach in cities and metropolitan regions, an approach that, if adopted, would optimise the process of achieving SDG 11. Thus, there is a need to adequately incorporate the WEF Nexus thinking in the implementation of the SDGs.

What are the challenges in the implementation of a Nexus approach?

Despite the large body of literature on the concept and the many research projects applying the concept, there is an ongoing discussion on how to best transfer the concept from a theoretical framework to be implemented on the ground. To date, most literature covering the Nexus focuses on the theoretical and empirical justification of the need for an integrated approach and policy coherence to govern the WEF Nexus. This is because decisions which enhance security in one sector may compromise securities in others (e.g. Hoff, 2011; Rasul, 2016; Al-Saidi et al., 2017).

Nexus literature acknowledges that a Nexus approach requires coordination and integration across levels of government (vertical), as well as across sectors (horizontal) and emphasises the key role of institutional relationships and effective coordination mechanisms (Scott, 2017; Weitz et al., 2017). Having “stronger institutions that are better interlinked” is identified as the key to a Nexus approach (Hoff, 2011). However, considering the complexity emerging from horizontal and vertical interdependencies, the Nexus researchers identify several challenges to the implementation of the Nexus approach in decision-making.

The literature postulates that historically entrenched and vertically structured government departments as well as sector-based policies and regulatory mechanisms act as main barriers to the adaptation of a WEF Nexus approach in decision making (Bizikova et al., 2013; Conway et al., 2015; Rasul, 2016; Scott, 2017). Based on case studies, Scott (2017) concluded the effectiveness of the Nexus approach is determined by institutional relationships and the capacities of governing organisations to cooperate with each other.

Further key barriers to implementation highlighted in the current discourse emerge from the traditional, sector-based structures of political institutions and governance processes. The following barriers have been identified in literature:

- Lack of communication between the sectors (Bhaduri et al., 2015; Weitz et al., 2017).
- Divergent sectoral institutional frameworks and interests (Weitz et al., 2017).
- Unequal distribution of power and capability between the sectors (Bizikova et al., 2013; Conway et al., 2015; Rasul, 2016; Howarth & Monasterolo, 2016; Scott, 2017).
- A lack of willingness to cooperate and lack of trust across groups of actors belonging to different disciplines and government levels (Lele et al., 2013; Embid & Martin, 2017; Scott, 2017).

Numerous case studies investigate the barriers to the implementation of a Nexus approach. Some examples are:

- An analysis of institutions and decision-making mechanisms in the water-energy Nexus in the United States of America asserted that "there is a need to explicitly consider institutions and decision-making, not just input and output relationships between water and energy" when considering a Nexus approach (Scott et al., 2011).
- Based on a case study in southern Asian countries, implementation of the WEF Nexus approach requires a paradigm shift in the decision-making process towards adopting a holistic view and developing institutional mechanisms to coordinate the actions of diverse actors (Rasul, 2016).
- An investigation of WEF Nexus governance in Indonesia, Kenya and the Amazon basin identified the lack of strategic clarity among institutions, a lack of coordination between sectoral departments at the national level and lack of communication tools and institutional mechanisms to coordinate the actions of diverse sectors (horizontal and vertical) as main barriers to cooperation (Scott, 2017).

2. History and Development of the WEF Nexus

To understand the complexity of the WEF Nexus, a more holistic and interdisciplinary scientific effort was required. Although the idea of resources connectivity was known for decades, the complex interlinkages between water, energy and food and the positive and negative consequences of these interlinkages were only studied in more detail during the last ten years. This chapter presents a chronological overview of the development of the Nexus approach, focussing on conferences and scientific publications.

Before 2011

The Nexus framing has many similarities to other holistic approaches to environmental decision making (eg. integrated natural resource management), and it builds on these. Nexus-related conferences, research initiatives and projects have taken place as early as the 1980s; however, these early studies typically focussed on interconnections between two sectors (Endo et al., 2017). Framing resources problems in terms of the WEF Nexus was not formalised before the late 2000s (Leck et al., 2015).

The interrelations between the water, food and energy systems were brought into focus due to various global crises regarding food security in 2008. Combined with the stresses of climate change, Beddington (2009) highlighted the challenges that will be faced in providing adequate water, food and energy to a growing population.

2011

The report "Water Security: The Water-Food-Energy-Climate Nexus" was published by the World Economic Forum in 2011. In the report, the close interlinkages and future challenges between water security and nine other sectors (agriculture, energy, trade, national, security, cities, people, business, finance and climate) are described. The report also includes position statements towards the interlinked water challenges by influential representatives from governments, religious groups, NGOs and private businesses (World Economic Forum Water Initiative, 2011).

The first major Nexus event was the 2011 conference "The Water, Energy and Food Security Nexus - Solutions for the Green Economy" in Bonn (referred to as the Bonn2011 conference) (Leck et al., 2015). In the lead up to this conference, the background paper "Understanding the Nexus" was published (Hoff, 2011) and became an influential paper covering the WEF Nexus. Figure 4 replicates the schematic illustration of the WEF Nexus presented in Hoff (2011), highlighting the interdependencies and the change pressures that affect the concept. Three guiding principles for the Nexus approach are denoted as "action fields", and global trends are included as drivers (Hoff, 2011).

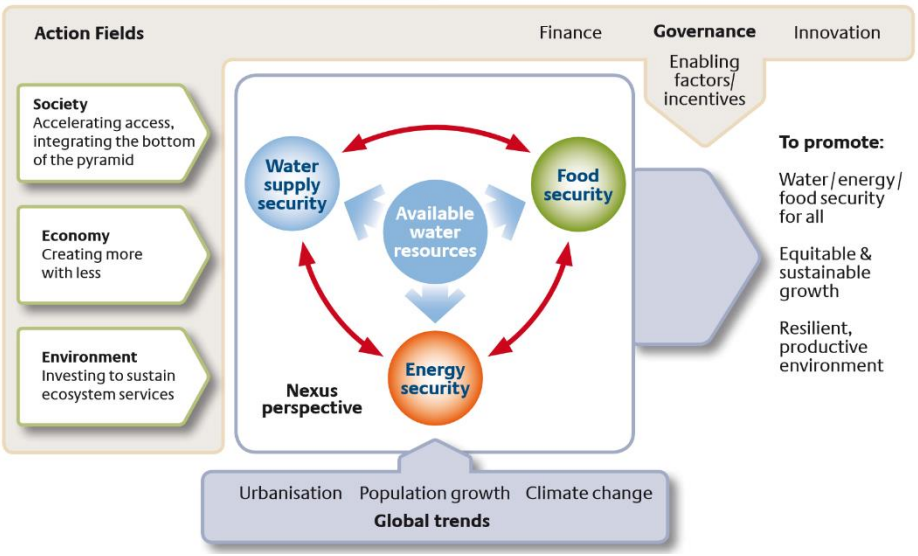

Figure 4: The water, energy and food security Nexus (Hoff, 2011)

As evident in Figure 4, "available water resources" is placed at the centre of the Nexus concept. This is because of the importance of water, which is non-substitutable in biomass production, and biomass is a central resource for energy and food security in a green economy (Hoff, 2011).

The publications by Hoff and the World Economic Forum are recognised as high-impact reports in several reviews of the WEF Nexus historical development (Leck et al., 2015; Mohtar and Lawford, 2016; Albrecht et al., 2018).

In its Global Risk Report, The World Economic Forum presented the risk-focussed WEF approach illustrated in Figure 5. The forum framed the WEF Nexus as a one of the major risk areas, together with illegal economies and macroeconomic imbalances. In this framework, water and food security are connected to failures in global governance and economic disparity, resulting in long-term water and food shortages and crises. Energy security is seen to have impacts on growth and social stability, where energy shortage is seen as an economic risk. Population growth, economic growth and environmental stresses are clearly viewed to affect the Nexus. This framework aims to give decision makers a better understanding of the risks in order to be able to develop proactive responses and quick mobilisation during crises (World Economic Forum, 2011; Allouche et al., 2014).

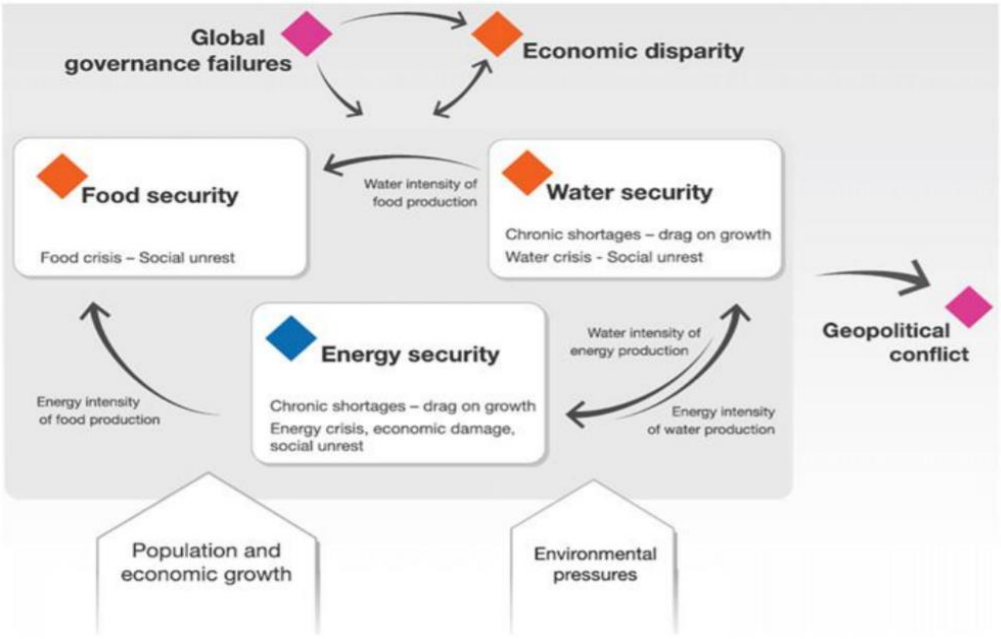

Figure 5: Illustration of the WEF Nexus adopted by the World Economic Forum 2011 (World Economic Forum, 2011)

2012

Building on the work from the Bonn2011 conference, the Rio+20 Conference on Sustainable Development took place in 2012. At the Rio+20 conference, "Future Earth", an interdisciplinary research initiative on global environmental change and global sustainability was launched. The first key challenge of the Future Earth 2025 Vision is: "Deliver water, energy, and food for all, and manage the synergies and trade-offs among them" (Future Earth, 2014).

Numerous other forums and conferences that specifically addressed the Nexus themes were held all over the world in 2012 (Leck et al., 2015), indicating the positive perception of the Nexus concept in different professional and academic communities.

Derivations of the first Nexus framework (i.e. Figure 4) began to develop. For example, the International Centre for Integrated Mountain Development (ICIMOD) developed an adapted Nexus framework for the Himalayas and South Asia region. As shown in Figure 6, ecosystem goods and services are integrated as key parts of the framework, connected to the water, energy, food and agriculture triangle. The resilience and productivity of the ecosystems are seen as crucial to achieving WEF security; therefore, their protection and enhancement is necessary (Rasul, 2012).

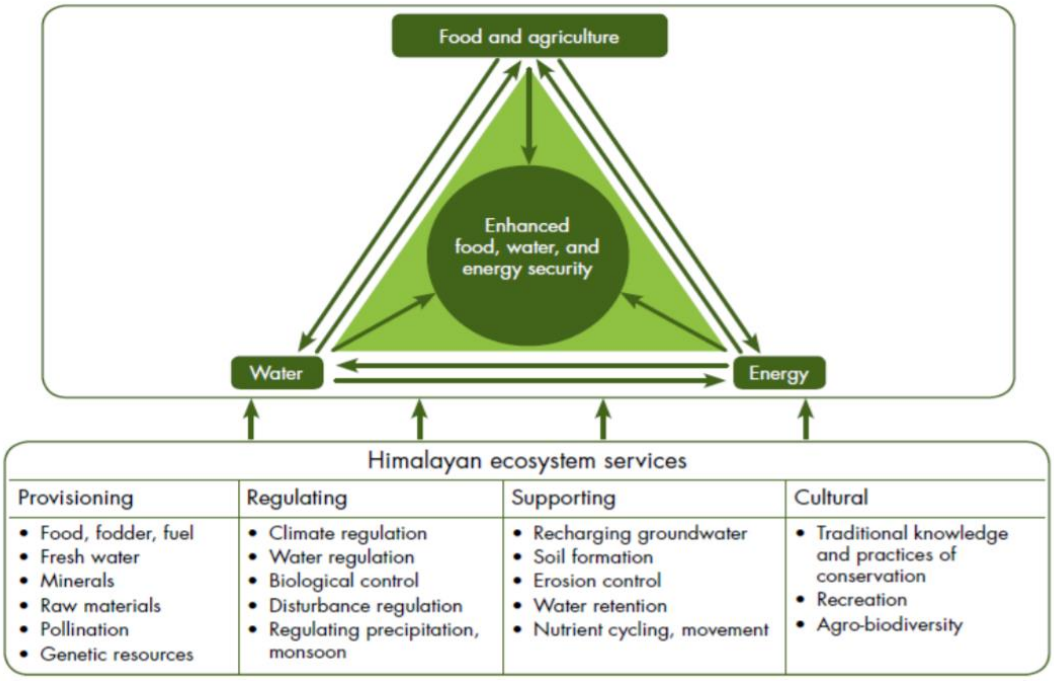

Figure 6: WEF Nexus approach in the Himalayas and South Asia (Rasul, 2012)

2014

The conference "Sustainability in the Water–Energy–Food Nexus. Synergies and Trade-offs: Governance and Tools at various Scales" was held in 2014 in Bonn under the framework of Future Earth (Endo et al., 2017). The conference addressed sustainability in the WEF Nexus as a key research-for-action initiative and addressed the following two main issues regarding a sustainable Nexus implementation: How can the Nexus be implemented across different scales and how can trade-offs be reduced due to governance practices (Bhaduri et al., 2015). As key result of the conference a Call to Action was issued to policy makers, practitioners and researchers requesting responsible governance of natural resources as a necessary first step for action, extensive participation of stakeholders to work toward sustainable development and the expansion of financial, institutional, technical and intellectual resources for Nexus research and applications (The Global Water System Project, 2014).

In 2014, the Water Institute at the University of North Carolina hosted the "Nexus 2014: Water, Food, Climate and Energy Conference" (and a follow up conference also took place in 2018). The key result was the input provided to the United Nations (UN) SDGs process. The Nexus Declaration pointed out the importance of an integrative approach in the definition of the SDGs (Dodds & Bartram, 2014).

2015

In 2015, the United Nations (UN) adopted the resolution "Transforming our world: the 2030 Agenda for Sustainable Development", which contained 17 SDGs and 169 associated targets (UN, 2015a). It should be noted that there is no specific mention of the term "Nexus" in the SDGs; however, a Nexus approach enables us to work towards simultaneously achieving water, energy and food security, thus ensuring access for basic human needs (Stephan et al., 2018). A Nexus approach allows potential trade-offs to be identified at the policy design stage, allows the identification and development of solutions that positively benefit multiple SDGs, and avoids the "silo" approach in implementation strategies (FAO, 2018).

The Paris Agreement was signed in 2015, which aims to limit the increase in global average temperatures to well below 2°C above pre-industrial levels (UN, 2015b). Climate change and the WEF Nexus are inextricably linked, and this has been recognised in current political and scientific discussion. It is critical to develop effective strategies to adapt to climate change and ensure water, energy and food security for a growing global population. An overall analysis of the links between the WEF Nexus, the SDGs and the Paris Agreement recognises the crucial role of WEF Nexus concept in achieving both the goals of the Paris Agreement and of the SDGs (FAO, 2018).

Current State

The Nexus approach is increasingly used at the project level and supported by some governments, civil society, international development partners, the private sector and research (FAO, 2018). Numerous conferences and international workshops have taken place in 2018 (eg. Nexus: Water, Food, Energy and Climate Conference at the University of North Carolina; the ResNexus Conference at Wageningen University; Water-Food Nexus High Level Panel at the World Water Forum in Brazil; various sessions at the Stockholm World Water Week; The Food-Energy-Water Nexus Mini-Symposium at Monash University). Many conferences and workshops are also taking place with a focus on addressing specific Nexus issues at the regional scale (Nexus Platform, n.d.; see https://www.water-energy-food.org/nexus-platform-the-water-energy-food-nexus/).

3. Employing the WEF Nexus Approach

This chapter considers how the WEF Nexus approach can be employed. This refers to the use of a Nexus style thinking in the assessment of a problem, modelling the Nexus, ensuring that the outcomes of a Nexus assessment are put into practice, and the governance of the WEF Nexus. An outlook on the WEF Nexus and research gaps are discussed at the end of the chapter.

3.1. Assessment of the Nexus

Three guiding questions are discussed in the assessment of the WEF Nexus. These are:

- How to evaluate the WEF Nexus interconnections
- WEF Nexus modelling
- Considerations in the WEF Nexus assessment

How to evaluate the WEF Nexus interconnections

Typically, when analysing the situation of the individual water, energy or food sectors, consideration is usually only given to the resource use and demand of the individual sector. This often involves the use of one of the water security, energy security or food security indices, without explicitly considering security aspects in the other two. Despite the availability of these indicators in each sector, they have a limited capacity to capture the interlinkages with the other two sectors.

Recently, many analysis frameworks and methodologies have been introduced to facilitate a better understanding of the WEF Nexus. Different methodologies have varying data requirement, benefits and limitations, and some only operate at particular geographical scales (Albrecht et al., 2018). Data and information availability are of paramount importance, as without them, the most important Nexus interactions cannot be properly identified (Embid & Martin, 2017).

The FAO developed an approach to address the synergies and interlinkages between human and natural resources. It focuses on the resource base, including the biophysical and socio-economic resources, as a basis for addressing the Nexus between water, energy and food securities. The first part of the approach is illustrated in Figure 7, which shows the steps from the analysis of interactions to the comparison of different interventions. The suggested rapid WEF Nexus assessment is based mainly on indicators that are already available in open access databases (Flammini et al., 2014).

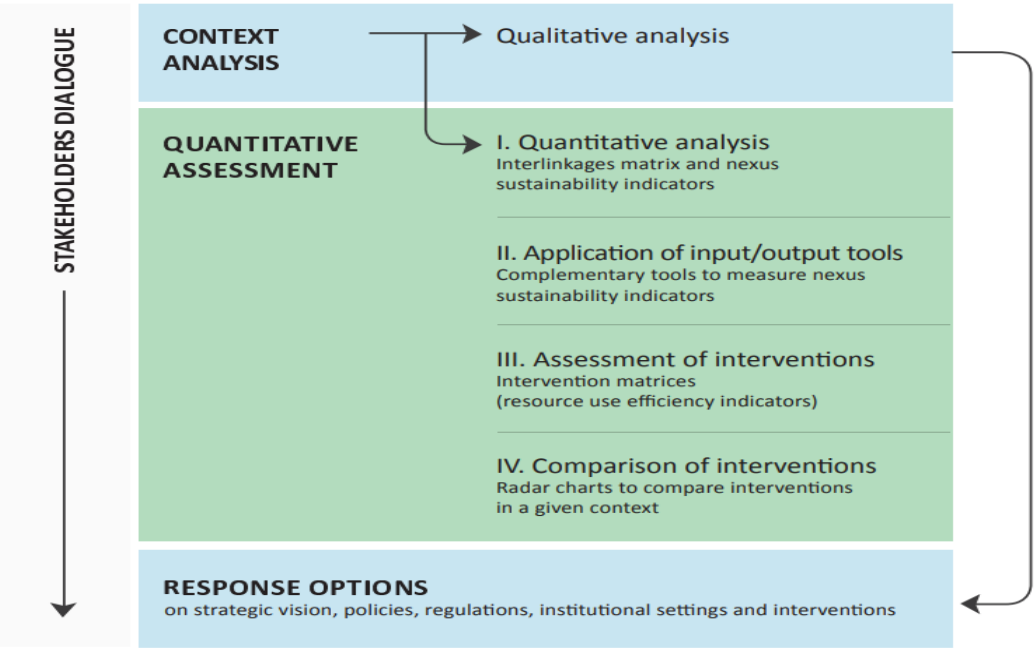

Figure 7: FAO components of the Nexus assessment (Flammini et al., 2014)

Modelling the WEF Nexus

Monitoring the many WEF interlinkages is crucial for a better understanding of the potential synergies and trade-offs between the three sectors. Quantification is needed to provide a better understanding of the numerous interlinkages and to improve decision making (Li et al., 2016; El-Gafy, 2017). Excellent reviews of the available methodologies introduced in the last few years can be found in Chang et al. (2016), Endo et al. (2017), Kurian (2017) and Albrecht et al. (2018). Importantly, each Nexus case is unique and there is no versatile and comprehensive WEF Nexus modelling approach that fits to modelling and quantifying every case. It is important to note that despite the variety of modelling options available, the complexity of the model required is always dependent on the Nexus situation being studied.

Table 1 summarises an extensive review of the available models to assess the Nexus (Dai et al. 2018). The methods listed describe both models and frameworks used to assess the WEFs Nexus. Three important classifications are made for each model:

- The type of model:
    - Quantitative analysis model - quantifies the resource flows but without modelling scenarios over temporal scales.
    - Simulation model - a single model for simulating scenarios over temporal scales.
    - Integrated model - a combined model with both quantitative and scenario functions.
- The geographical scale it addresses: from the city to the transboundary level

- The Nexus challenge level, which refers to the type of application of the model results. The three identified types are:
    - Understanding the Nexus: the data demonstrates linkages and identifies problems, risks or opportunities.
    - Governing the Nexus: has the purpose to guide an institutional or policy response.
    - Implementing the Nexus: has the purpose to guide policy and/or technical interventions to improve efficiency or effectiveness of resources uses.

Table 1: Summary of available methods to model the Nexus (Adapted from Dai et al., 2018)

Method	Geographical scale	Model type	Software	Purpose	Nexus challenge level
Methods covering the Water-Energy Nexus					
EI (Energy Intensity)	City level	Quantitative analysis model	No software	Quantify energy flows in urban water systems	Understanding
Linkage analysis	City level	Quantitative analysis model	No software	Explore the structure and interconnection of both water and energy resources in cities	Understanding
UWOT (Urban Water Optioneering Tool)	City level	Quantitative analysis model	Online tool UWOT	Quantify energy use in urban water supply systems	Understanding
MRNN (Multi-Regional Nexus Network)	City and regional level	Quantitative analysis model	No software	Explore the interconnection of energy consumption and water use for urban agglomerations	Understanding
System dynamic approach	Regional level	Integrated model	No software	Long-term regional water and energy resources management	Understanding
Jordan's framework	National level	Integrated model	No software	Link decision-making to higher use efficiencies of water and energy in Jordan	Governing
Methods covering the Water-Energy-Environment Nexus					
UWtoA (Urban Water to Air Model)	City level	Quantitative analysis model	Pacific Institute; A spreadsheet model	Simulate energy use and air quality in urban water systems	Understanding
WESTWeb (Water-Energy Sustainability Tool Web)	City level	Quantitative analysis model	University of California, Berkeley; Online tool	Assess energy use and GHGs in water supply and utilisation system	Understanding
GLEW (Great Lakes Energy Water model)	Regional level	Simulation model	Studio Expert 2008	Impacts of electricity generation portfolios on water resources in the Great Lakes region	Understanding
REWSS (Regional Energy & Water Supply Scenarios model)	Regional level	Quantitative analysis model	Open source REWSS	Calculate the annual environmental impacts of supplying energy and water to a specified region	Understanding
Integrated CGE (Computable General Equilibrium)	National level	Simulation model	No software	Forecast the impact of energy tax policy on energy and water use and demand	Governing

CMDP (Competitive Markov Decision Process model)	National level	Simulation model	No software	Impacts of carbon taxes and water on electricity systems	Understanding
MA (Meta-system architecture model)	National level	Quantitative analysis model	No software	Quantify material and energy flows in national electricity, water and wastewater systems	Understanding
SPATNEX-WE (SPAtial and Temporal NEXus-Water Energy)	National level	Integrated model	No software	Track energy flows and water withdrawal and consumption throughout water and energy systems	Implementing
Modified AQAL (All Quadrants All Levels)	Regional and national level	Integrated model	No software	Explore the water and electricity linkages under climate changes, and assess policy implications	Implementing
Mixed-unit MRIO (Multi-Regional Input−Output analysis model)	National and transboundary level	Quantitative analysis model	No software	Life cycle assessment of water use in energy production, and environmental impacts	Understanding
TIAM-FR (TIMES Integrated Assessment Model)	National and transboundary level	Integrated model	MINES Paris Tech Center of Applied Mathematics; NS	Forecast water demands in energy optimisation considering climate changes	Understanding
WCCEM (The Water and Carbon Conscious Electricity Market)	National or global level	Simulation model	No software	Assess water and carbon taxes impacts on national electricity generations, and to control water usage and greenhouse gases (GHGs)	Understanding
RRP (the integrated rainfall-runoff model and power system model)	Multi-scales	Integrated model	No software	Impacts of water flow and temperature on power systems	Understanding
WATER (Water Analysis Tool for Energy Resources)	Multi-scales	Quantitative analysis model	Argonne National Laboratory; Online tool	Assess water use and quality in fuels production	Understanding
WEAP-LEAP (Water Evaluation And Planning system and Long Range Energy Alternatives Planning)	Multi-scales	Integrated model	SEI; WEAP and LEAP software	Policy impacts on water and energy demands as well as GHGs	Governing
Methods about the Water-Energy-Food Nexus					
ZeroNet DSS (Decision Supporting System)	Regional level	Integrated model	Several free software	Decision support in resource management in basin	Governing
Nexus Assessment 1.0	Regional and national level	Quantitative analysis model	FAO; Online rapid appraisal tool	Qualitative and quantitative assessment of Nexus	Governing
IAD-NAS (Institutional Analysis and Development Frameworks combined with value chain analysis)	National level	Quantitative analysis model	No software	Impacts of institutions and policies on the sustainability of water, food and energy	Governing

WEF Nexus Tool 2.0	National level	Simulation model	Online tool	Quantitative assessment and forecast of WEFN	Governing
DEA (Data Envelopment Analysis)	Multi-scales	Quantitative analysis model	No software	Evaluate regional input-output efficiency of resources holistically	Understanding
WEFO (Water, Energy and Food security nexus Optimization model)	Multi-scales	Integrated model	WEFO tool	Quantitatively assess the interconnections and trade-offs among resource systems as well as environmental effects	Governing
Methods covering the Water-Energy-Food Nexus / Water-Energy-Land-Climate Nexus					
MSA (Multi-sectoral Systems Analysis)	City level	Quantitative analysis model	Matlab tool	Understand resource flows as well as human effects on the urban metabolism	Understanding
GCAM-USA (The Global Change Assessment Model in USA)	Regional level	Integrated model	Open source tool	Long-term analysis of water withdrawal and demand in electricity sector of USA states	Governing
PRIMA (Platform for Regional Integrated Modelling and Analysis)	Regional and national level	Integrated model	Velo	Simulate the interactions among climate, energy, water, and land at the decision-relevant spatial scale	Implementing
MuSIASEM (Multi-Scale Integrated Assessment of Society and Ecosystem Metabolism)	National and regional level	Integrated model	FAO, free online tool	Assess metabolic pattern of energy, food and water related to socio-economic and ecological variables	Governing
Foreseer	National and transboundary level	Integrated model	University of Cambridge; Online Foreseer tool	Map flows of water, energy, land use and GHGs	Understanding
Modified SWAT (Soil and Water Assessment Tool)	Transboundary level	Integrated model	Open source model	Water provisioning each economic sector in transboundary context	Understanding
TRBNA (Transboundary River Basin Nexus Approach)	Transboundary level	Integrated model	UNECE, NS	Assess the WEFEN in transboundary river basins	Implementing
CLEWs (climate, land, energy and water)	Multiscale	Integrated model	KTH; open source tool OseMOSYS	Assess climate impacts on resources and supply help in policies evaluation	Implementing

Considerations in Modelling the WEF Nexus

Daher et al. (2017) suggested that seven essential questions should be asked in order to select or develop the most appropriate modelling approach for each specific WEF Nexus case:

(1) What is the critical question in the case study?

(2) Who are the players/stakeholders?

(3) At what scale?

(4) How is the system of systems defined?

(5) What do we want to assess?

(6) What data is needed?

(7) How do we communicate it? Where do we involve the decision-maker in the process?

Similarly, McCarl et al. (2017a) identified numerous key challenges in the assessment of the Nexus. Some of these important challenges are:

- Establishing the scope of the Nexus issue.
- The appropriate selection, development and integration of diverse component models.
- Developing models that are useful and provide meaningful insight.
- Characterising uncertainties (eg. in future scenarios).
- Representing new technological and resource development alternatives that have not previously been adopted in the region.

Nexus assessments can be conducted at various scales and it is important to identify the scale at which a Nexus problem should be addressed. The identification of the scale has a major impact on the manner in which a model is created, identification of the stakeholders and a determination of the required data (Daher et al., 2017). Nexus studies are able to cover scales from the household level (eg. Hussien et al., 2017) to the country scale (eg. Daher and Mohtar, 2015; Li et al., 2016) to the transboundary scale (eg. Jalilov et al., 2015; Al-Saidi et al., 2017).

3.2. WEF Nexus Governance

Nexus governance tools have been recognised as vital to the Nexus approach and play a central role for policy makers who are responsible for Nexus implementation. Despite this, most scientific literature on WEF Nexus securities focus on the physical interlinkages between the sectors and technical governance aspects. The roles of institutional and political Nexus governance have received less attention.

From the current scientific discussion on Nexus governance, three key points are considered below:

(1) Institutional cooperation (between sectors and governance levels)

When initiating an action in a particular sector, consideration must be given to which other sectors are affected (Blumstein et al., 2017). Having institutional cooperation is considered as vital in the implementation of the Nexus concept into policies and practice. The literature clearly acknowledges that Nexus governance requires coordination and integration both across levels of government (vertical) as well as across sectors (horizontal). Institutional coordination mechanisms between sectors and governance levels are needed so that the Nexus approach is transferred into decision making processes (Bizikova et al., 2013; Conway et al., 2015; Rasul, 2016; White et al., 2017). Scott (2017)

concluded that the effectiveness of Nexus implementation is determined by institutional relationships and the capacities of governing organisations to cooperate with each other.

For example in Kenya, a lack of vertical cooperation and disputes over the functions of national and county level institutions has resulted in conflicting plans and duplication of efforts. The national water needs take priority over community water needs and this has caused water scarcity and affected agricultural production at the county level (Scott, 2017). A contrary example takes place in Germany, where in the Hessian Ried strong cooperation between the water and agricultural sectors has resulted in a successful reduction of water pollution caused by nitrate use in the agricultural sector (Infrastruktur & Umwelt: Professor Böhm und Partner, 2017).

The private sector has also been identified as an obstacle to the implementation of a Nexus approach, as the private sector sometime seeks opposing objectives to that of the Nexus approach (Embid & Martin, 2017).

(2) Institutional barriers to implementing the Nexus approach

Although the need for cooperation is recognised, there are several barriers to the adoption of a WEF Nexus approach in decision making, due to the complexity of interrelationships between sectors and governance levels. Conway et al. (2015) identifies historically entrenched vertically structured government departments and sector-based policies as central barriers to Nexus governance. Furthermore, a lack of communication between the sectors, divergent sectoral institutional frameworks and interests as well as unequal distribution of power and capability between sectors are identified as barriers in numerous studies (Bizikova et al., 2013; Conway et al., 2015; Rasul, 2016; Howarth and Monasterolo, 2016; Scott, 2017).

(3) Overcoming institutional barriers and promoting cross-sectoral cooperation

To strengthen the coordination between sectors, the adaptation of existing governance arrangements rather that creation of new or ideal arrangements is often discussed (Scott, 2017; Weitz et al., 2017). Numerous studies recommend using existing procedures and legislatives in order to identify institutional mechanisms for Nexus implementation, which would be adapted to the regional institutions and bureaucracies (Al-Saidi et al., 2017; Embid & Martin, 2017; Weitz et al., 2017).

Blumstein et al. (2017) analysed legislative procedures for the coordination of cross-sectoral interests in Germany and showed that a number of existing mechanisms at different levels such us inter-ministerial task forces and committees, round table discussions or the Joint Rules of Procedure of the Federal Ministries are adequate mechanisms to address Nexus related issues. Scott (2017) suggested three fields of action which can be addressed to improve the Nexus coordination:

(1) Make changes in the institutional structure of resource management (develop organisational instruments) for Nexus decision making.

(2) Make changes in the procedural instruments: create rules and standards for decision making and implementation.

(3) Make changes in the communication instruments: improve the communication between decision makers (create communication platforms, informal meetings and working groups, data sharing platforms).

The need for stakeholder involvement in decision-making processes is identified as a key element to determine what is politically acceptable, feasible and where there is space to improve policies (Hoff, 2011; Bizikova et al., 2013; Howarth and Monasterolo 2016; White et al., 2017). FAO (2014) designed practical tools for effective Multi-Stakeholder Processes (MSPs) such as: Stakeholder Mapping, MSP Facilitation Guidelines and Socratic Questions. Furthermore, many studies recommend that communication between sectors and government levels could be improved by the creation of dialogue platforms or other interagency communication mechanisms (Hoff, 2011; Weitz et al., 2014; Rasul, 2016; Weitz et al., 2017; Scott, 2017).

3.3. WEF Nexus Outlook and Research Gaps

Despite the WEF Nexus concept being well received in academic, business and policy sectors, it has not been widely implemented on the ground. One of the major discussions currently taking place is how to shift the concept from theory into practice. The complexity of the concept, especially where complicated interactions exist between the three sectors, adds many challenges in embedding the concept in policies and projects.

One of the emerging discussion topics on the WEF Nexus is from which perspective we should look at the Nexus. Some WEF Nexus methodologies place emphasis on water as a potential entry point for the Nexus (Bizikova et al., 2014; de Strasser et al., 2016), especially when the focus of the Nexus application is at the river basin scale. The water-food Nexus is typically studied from an ecological, hydrological or agronomic angle, with a limited focus on the governance issues of the resources (Theesfeld, 2018).

As discussed by many researchers who worked on WEF Nexus assessments (e.g. Li et al., 2016), a lack of a versatile methodology to quantify the interlinkages between the three elements of the WEF Nexus is one of the major weaknesses in the approach. That being said, no single approach is believed to fit to all conditions and every case (Endo et al., 2017). Improving the existing methods and formulating new ones is of high priority to advance the adoption of the Nexus approach.

Data availability is another concern, and it represents a major barrier for implementation of the WEF Nexus approach. The current WEF Nexus indicators are highly influenced by data availability (Yang et al., 2017). Public-domain data, derived from remote sensing, ground stations or models, offer valuable data with a spatial coverage that is helpful for many WEF Nexus assessments. Advancement in sensor technologies and remote sensing techniques have allowed many of the interlinkages between the WEF sectors to be quantified. For example, water use efficiency (the agricultural production relative to the quantity of water use) can be calculated using satellite data (eg. Khalifa et al., 2018). The ability to integrate data that are available at different spatial and temporal scales is also of high importance (Li et al., 2016).

The lack of comprehensive analytical tools is another highlighted concern (McGrane et al., 2018). The WEF Nexus can be very complicated and undertaking a manual analysis of data can be an unrealistic task. Developing integrated software and online platforms is helpful in addressing the potential synergies and trade-offs in the WEF Nexus (Liu et al., 2017). Reducing the uncertainties in WEF Nexus models is one important challenge, with questions persisting on how the Nexus interactions can be quantified in a reliable manner (McCarl et al., 2017a).

According to Chang et al. (2016), "quantifications of the WEF Nexus have become, and will continue to be, a vibrant research pursuit that advances integrated WEF modelling and management to provide important strategies for sustainable development in today's dynamic and complex world". Figure 8 provides a visual representation of the influences of the methodology supports of the key challenges that shape our understanding of the Nexus. These methodology supports and key challenges provide us with opportunities to improve our knowledge of this topic.

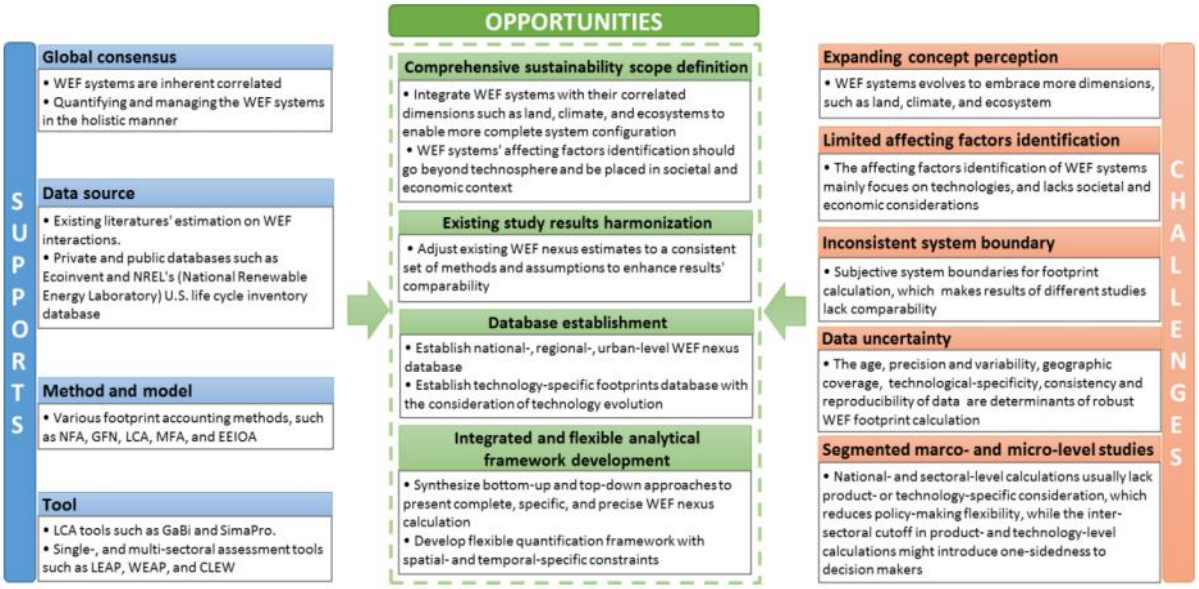

Figure 8: Methodological supports, challenges, and opportunities associated with a robust WEF Nexus quantification (Chang et al., 2016)

The impacts of climate change on the WEF Nexus is another critical topic, given the strong importance of resources availability on the WEF Nexus interconnections. Questions such as how change in climate affects the WEF Nexus, and how the WEF Nexus responds to the impacts of climate change is a rich area for discussion and needs to be answered. Projections of climate change show that the negative impacts on some regions (e.g. the MENA region) are more pronounced than the global average (ESCWA, 2016).

The institutions involved in the governance of the Nexus have received relatively little attention in literature. Suggested mechanisms and political instruments for an improved Nexus governance are often limited to general statements and recommendations such as the need to strengthen the horizontal and vertical cooperation or the creation of inter-sectoral communication mechanisms. In the governance of the WEF Nexus, some questions particularly relevant for policy makers are:

- Who should be the "Agent of Change" and take the initiative to implement WEF Nexus?
- Which institutions, governance levels and policies are adequate for vertical and horizontal coordination?
- How will communication be established between the involved sectors?
- How can a lack of political will be overcome?

One of the interesting discussions taking place is the possible entry points for implementing the WEF Nexus approach. Bellfield (2015) identified several possible entry points for the WEF Nexus: (1) international commitment; (2) climate change adaptation; (3) new infrastructure projects; (4) cities; (5) IWRM; (6) corporate commitment and stewardship; and (7) payment for ecosystem services.

Figure 9 summarises current state of the art in the literature on Nexus governance.

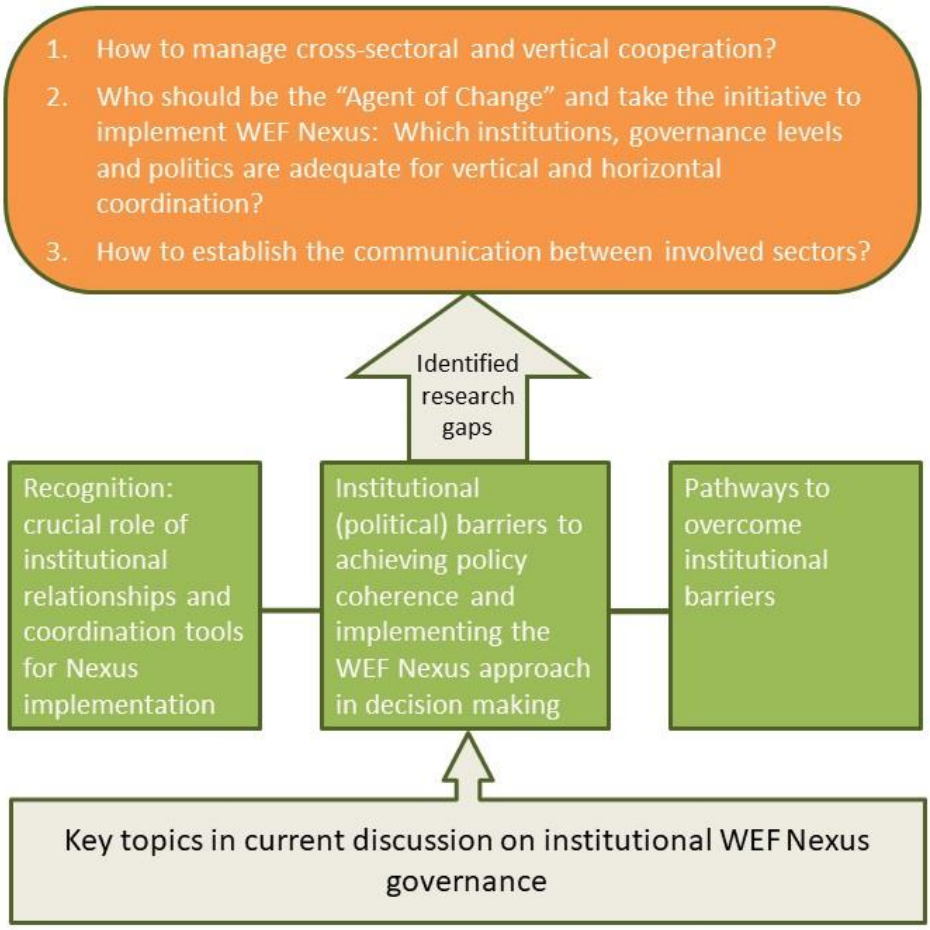

Figure 9: Key discussion trends on Nexus governance identified in the conducted literature review (own figure)

4. Urban Nexus

The Urban Nexus is an approach concerning the design of sustainable urban development solutions. The approach guides stakeholders to identify and pursue possible synergies between sectors, jurisdictions and technical domains, to increase institutional performance, optimise resource management, and service quality (GIZ and ICLEI, 2014). Recent studies have outlined the existing tools for quantifying the Urban Nexus approach with case studies (Scott, Crootof and Kelly-Richards, 2016; Wakeel and Chen, 2016; Ziogou and Zachariadis, 2016; Engström et al., 2017).

Urban water systems face socio-economic, sustainability and resilience challenges, including overuse due to population growth, underestimation of the value of water, lack of coordination among actors, operational issues (ageing, leakages, and quality), increasing energy prices and the need for responding to climate change issues. Many environmental data related to water are reported, from the local to the supranational level; however, the assessment of the resource efficiency or environmental performance of water utilities still lacks a holistic approach (Helmbrecht et al., 2016).

Specifically, water utilities have shown a strong interest in addressing the Nexus and the relationships and trade-offs between energy and water use for reducing energy consumption and increasing energy recovery. Water resource efficiency in its broader context is also of utmost importance for water utilities, which has defined the water-energy Nexus as one of their priority areas. It is also considered as one of the most important challenges that the global water market is to face in the future (Helmbrecht, Pastor, and Moya, 2017).

Energy is required in all stages of water production and distribution, from pumping and treatment to transportation. Energy costs are a prime concern for water utilities, regardless of geography, size and level of water network efficiency. It is difficult for water utilities to either improve their services or expand their networks to meet the water demand in developing countries (Helmbrecht, Pastor and Moya, 2017).

Many initiatives have demonstrated the Nexus approach in cities. For example, a project titled “Integrated Resource Management in Asian Cities” focuses on urban water security, energy security and efficiency, land use, physical planning and food security. The framework is based on a multi-level approach and has been implemented in cooperation with municipalities in in China, Indonesia, Mongolia, Philippines, Thailand and Vietnam. The project has shown how the Nexus approach could be integrated into urban planning and development processes (GIZ & UNESCAP, 2017).

The C40 Cities programme seeks to build the evidence base for the benefits of climate action and identify opportunities and synergies within the water, energy and climate Nexus. C40 Cities has built a platform of networks, communications, adaptation, finance and other programmes to provide cities

with the tools they need to tackle the most pressing issues in cities in an integrated manner (C40 Cities, n.d.; https://www.c40.org/).

The Water and Wastewater Companies for Climate Mitigation (WaCCliM) project[1] developed an innovative tool: the Energy Performance and Carbon Assessment and Monitoring Tool (ECAM) to drive greenhouse gases (GHGs) emission reductions in water utilities and to study the trade-offs between water, energy and climate at the urban level (WaCClim, n.d.).

[1] http://wacclim.org/ecam-tool/

5. Nexus Initiatives and Regional Implementation of the Nexus Concept

While the first chapters of this report describe the overall Nexus concept as well as aspects such as assessment and governance of the Nexus, this chapter summarises how international organisations and initiatives address the WEF Nexus through concrete initiatives. Examples of the application of a Nexus approach in specific regions are included, with the aim of enabling cooperation and exchanges on ongoing activities and projects.

The large acceptance of the Nexus approach has resulted in many regional and global initiatives aiming to advance the knowledge regarding the WEF Nexus and to provide examples how the approach could be applied. In line with the focus on the GIZ Nexus Regional Dialogues Programme, the regional analyses presented are for applications of the Nexus approach in Southern Africa, Central Asia, the Niger Basin, the MENA region and Latin America and the Caribbean. The outcomes of this review will assist in identifying the status quo implementation of the Nexus and major limitations in current practice and assist in providing opportunities to build upon existing efforts and developing a more integrated and robust framework towards the implementation of the Nexus.

5.1. WEF Nexus Initiatives

Multiple initiatives have been implemented across the globe to inform about, promote and implement a WEF Nexus approach in addressing resource securities. A summary of key initiatives is provided below:

The Nexus Regional Dialogues Programme [2]

Phase 1 of the Nexus Regional Dialogues Programme is funded by the EU and BMZ and runs from 2016 to 2018. The programme aims to develop Nexus policies and action plans at the national ministerial and regional policy levels and is implemented in five regions (MENA, Latin America, Niger Basin, Central Asia and Southern Africa). This programme manages the Water Energy & Food Security Resource Platform[3], which was launched at the Bonn Nexus conference in 2011 and provides up to date information on events, publications and projects from around the world. It is considered to be the most comprehensive information hub on the WEF Nexus (Nexus Platform, n.d.).

WEF Nexus as a High Impact Opportunity in the Sustainable Energy for All Initiative [4]

Sustainable Energy for All (SEforALL) is a global initiative launched by former UN Secretary General Ban Ki-Moon to advance action on SDG 7 (Ensure access to affordable, reliable, sustainable and modern energy for all). Part of the SEforALL is the High Impact Opportunities (HIOs) platform

[2] https://www.nexus-dialogue-programme.eu/

[3] https://www.water-energy-food.org/nexus-platform-the-water-energy-food-nexus/

[4] https://www.seforall.org/hio_water-energy-food-nexus

which engages all stakeholders in action areas that have significant potential to further the SEforALL objectives. The HIOs platform has adopted the WEF Nexus approach as a high-impact opportunity to guide the planning and implementation of projects (SEforALL, 2018).

WEF Nexus in the World Bank's Thirsty Energy Initiative [5]

Thirsty Energy is an initiative launched by the World Bank to face the challenges of the water and energy resources planning, by helping countries consider water constraints when planning in the energy sector. The initiative uses a Nexus approach in identifying synergies and trade-offs between water and energy in planning and use, piloting water-smart energy planning tools, enhancing governments' decision-making coordination, spreading awareness on water-energy challenges, and fostering multi-stakeholder dialogue. Case studies which developed and piloted water-smart energy planning tools were carried out in South Africa, China and Morocco (World Bank Group, 2018).

UNECE Task Force on the Water-Food-Energy-Ecosystems Nexus [6]

The United Nations Economic Commission for Europe (UNECE) mandated the establishment of the Taskforce to carry out thematic assessments on WEF-Ecosystems Nexus in transboundary basins. It addresses issues including low coherence and absence of integration between policies of various sectors, which negatively impact the conditions of shared waters. The Taskforce pursues efforts to enhance long-term WEF security and the transition to a green economy. A pilot project was undertaken in the Alazani / Ganykh basin (shared by Azerbaijan and Georgia) and the taskforce has carried out assessments of the Sava, Syr Darya, Isonzo / Soča and Drina river basins (UNECE, 2018).

WEF Nexus Dialogue on Water Infrastructure Solutions [7]

The International Union for Conservation of Nature (IUCN) and the International Water Association (IWA) have jointly launched an initiative in 2012 to address the demand competition over water resources across the WEF sectors. It aims to provide multi-sectoral solutions through infrastructure, up-to-date technology and investing in Ecosystem services. The initiative has held workshops in Africa, Latin America and Asia (Ozment et al., 2015).

WEF Nexus in the USAID Grand Challenges for Development on Water, Food and Energy [8]

The Grand Challenges for Development is a United States Agency for International Development (USAID) initiative to bring together governments, companies and foundations to solve development

[5] http://pubdocs.worldbank.org/en/778261525092872368/Thirsty-Energy-summary-of-the-initiative.pdf

[6] http://www.unece.org/env/water/nexus

[7] http://waternexussolutions.org/

[8] https://www.usaid.gov/grandchallenges

issues through innovative solutions, testing new ideas and up-scaling successful pilot projects. Two out of the 10 challenges launched build on the Nexus approach: the *Powering Agriculture Challenge* which aims to bring clean energy for agriculture; and the *Securing Water for Food Challenge* which promotes technology and scientific innovation to boost food production using less water (USAID, 2018).

WEF Nexus in the Science Initiatives

Nexus related projects have been or are being conducted at many universities and research centres. Most of the publications cited in the first four chapters of this report are from individuals or research groups in academia.

There are also some larger initiatives from research which create opportunities to link science, policy and practice on WEF Nexus implementation. Sometimes these initiatives have resulted from funding programs specifically calling for research on the Nexus. For example:

- There are 15 ongoing research projects under the JPI/ Belmont Forum call Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus (Urban Europe, n.d.).
- The United States National Science Foundation recently issued a call on "Seeking Applications for Innovations at the Nexus of Food, Energy and Water Systems" (INFEWS) (National Sciences Foundation, n.d.).
- Several EU Horizon2020 funded projects related to the Nexus form the "Nexus Project Cluster" (initiated by DAFNE, Sim4Nexus and United Nations University Flores) (UNU Flores, 2018).

Various scientific organisations have undertaken activities related to the WEF Nexus. For example:

- The Institute for Advanced Sustainability Studies (IASS Potsdam) published a special issue in 2015 titled "Soils in the Nexus" (IASS, 2015).
- The University of North Carolina has held Water-Food-Energy-Climate Nexus Conferences in 2014 and 2018 (Nexus Platform, n.d.).
- Future Earth has a Knowledge-Action Network called the "Future Earth Water-Energy-Food Nexus" (Future Earth, n.d.).

5.2 Case Studies: Regional Applications of the WEF Nexus

Building on the overview of literature describing the Nexus concept, its recent development and the tools that can be applied in policy and practice, this section investigates whether these tools are being

used and where and how the concept of WEF Nexus assessment, planning or implementation is being applied on the ground.

The section gives practical examples of experience from the five regions where the WEF Nexus Regional Dialogues Programme is conducted. The intention is to provide decision makers with examples where the theory of the Nexus concept has been made operational. These examples are often still at the small scale (pilot stage) and until now, there are few examples where the Nexus approach has been systematically applied at the large scale or has led to fundamental changes in policy or governance. In some countries, larger ministries have been created in recent years which combine the water sector with the energy and/or agricultural sector. However, there is no evidence that this has been driven by an explicit Nexus thinking.

It is worth noting that at a certain level, interlinkages between different policy domains or inter-sectoral coherence have always been considered or have been at the core of the debate of "good governance". Thus, it is difficult to trace examples of WEF Nexus implementation as an effect of a new "Nexus paradigm". Nevertheless, the following sections compile evidence of some WEF-Nexus applications.

5.2.1 The WEF Nexus in Southern Africa

There is a large variety of different resource and climatic environments with diverse supplies of water, food and energy throughout the whole southern African region. Nevertheless, there is a need for development in each of the fifteen-member states of the SADC. The rural areas, where approximately 60% of the whole population in the SADC live, are typically dependent on rainfed agriculture and are threatened by insufficient access to clean water and energy (Nhamo et al., 2018).

The role of the WEF Nexus is gaining increasing attention in the region from SADC, which is a partner in the Nexus Regional Dialogues Programme with an aim to create an enabling environment to drive cross-sectoral engagement and implementation of Nexus investment projects.

An example of the increasing attention paid to the WEF Nexus approach is that joint meetings of SADC Ministries on Water and Energy have taken place in 2016, 2017 and 2018. (SADC, 2016; SADC, 2017; SADC, 2018).

Another project currently being implemented is CapNex, coordinated by the Vienna University of Technology. It aims to build missing capacity on the WEF security Nexus through research and training in Kenya and Uganda (APPEAR, 2016).

Another initial implementation of the Nexus approach in the region is the case study "Modeling the Water-Energy Nexus: How Do Water Constraints Affect Energy Planning in South Africa?" by

Thirsty Energy in South Africa (World Bank Group, 2018). The case study focuses on incorporating a representation of water supply and infrastructure costs into an energy systems model and delivers a proof of concept for the integration of water constraints into an energy-planning tool to support decision making. One of the key messages of the report is that the cost of water supply has a "very significant impact on the optimal mix of energy technologies and on greater efficiency and sustainability in water use" (World Bank, 2017). Nevertheless, further work on several technical areas could improve the holistic performance of the tool. For example, a link to food production and potential risks of future climate change could improve the performance (World Bank, 2017).

5.2.2 The WEF Nexus in the MENA Region

The MENA region is considered one of the most water scarce regions in the world and it continues to become more water stressed. Not only has the decrease in precipitation quantities and groundwater depletion increased water scarcity, but pollution in the current water resources, industrial and agricultural growth as well as population growth have led to water being severely stressed (Sullivan, 2013). Although the MENA region contains 43% of the world's oil reserves and holds immense potential for renewable energy, 35 million of its people lack access to electricity. The MENA region is also the world's largest importer of wheat, and recent economic instability has increased food insecurity.

Ensuring water and food security has become one of the main challenges for sustainable development in the MENA region, as currently more than 75% of the freshwater resources in the MENA region are used by irrigation. Projections shows future water scarcity will likely make it more challenging to provide sufficient food for the population. Predictions indicate that the agricultural production from 2018 to 2027 could decrease by up to 20% from a 2000 base (OECD/FAO, 2018).

Water security, energy security and food security are inextricably linked in the MENA region, perhaps more than in any other region in the world. These interlinkages are intensifying in the region as demand for resources is increasing with population growth and consumption patterns are changing (Scardigno et al., 2017). This has been well recognised in the Arab Strategic Framework for Sustainable Development (ASFSD), adopted by the League of Arab States in 2013, which addresses the key challenges faced by the Arab States in achieving sustainable development during the period 2016-2030 (Al-Zubari, n.d.).

Many institutional arrangements and initiatives deal with the WEF Nexus at the regional level. The League of Arab States, supported by UN-ESCWA and GIZ, promotes regional dialogue on the WEF Nexus. The Arab Ministerial Water Council (AMWC) and Arab Ministerial Council for Electricity

(AMCE) have issued resolutions in support of intersectoral and regional exchange on the matter. (UN-ESCWA, 2015).

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) is implemented through collaborative partnerships to provide an integrated methodology combining climate change impact assessment and vulnerability assessment tools on natural resources, health and environment and socio-economic development. Moreover, the GIZ Programme Adaptation to Climate Change in the Water Sector in the MENA Region (ACCWaM) has successfully provided innovative climate change adaptation pilots as well as contributions to capacity building and knowledge creation on the WEF Nexus (UN-ESCWA, 2017).

Nexus Regional Dialogues in the MENA region have stressed the priority WEF Nexus interests of Arab countries, which include solar desalination, using solar energy to treat and reuse wastewater, solar powered irrigation systems (SPIS), rethinking the self-sufficiency food approach and offshore agricultural investment to ensure food security and preserve scarce water resources.

Some countries in the MENA region already practice the Nexus approach to some extent, and there are some good examples on the adoption of innovative solutions within the Nexus. For example:

- Coupling solar energy with desalination technologies in order to offer a sustainable route for increasing the supplies of desalinated water in Gulf Cooperation Council countries (World Bank, 2012).
- Energy recovery from wastewater by using the energy potential of biogas in wastewater treatment plants (Jordan), generating energy required for the plant's operations by the plant itself (Suez, n.d.).
- Supporting energy efficiency in water pumping for agriculture through SPIS, by subsidising the cost of solar pumping in Tunisia (FAO, 2015). However, groundwater depletion is a problem in parts of the country, and solar pumping is a cause of potential overexploitation of this resource (Keskes et al., 2018).
- Reducing the area of land available for cultivation of intensive water crops, in order to rationalise water consumption in Egypt (El-Fiqi, 2018).

These cases demonstrate the potential and benefits to be unlocked if technology and innovation are fully harnessed within the WEF Nexus.

5.2.3 The WEF Nexus in Central Asia

The Central Asia region is defined by a highly diverse landscape with high mountains, desert and steppes. The major water sources are the two key rivers Amu Darya and Syr Darya as well as the Aral Sea. There are numerous transboundary aspects that link water, energy and food security in the countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Furthermore, the governments face major challenges due to population growth, climate change and changing precipitation patterns (Global Nexus Secretariat, 2018).

Today's main issues regarding WEF securities in the region are related to the international cooperative management of the water resources. Pohl et al. (2017) stated that uncoordinated national strategies are causing intense competition over the transboundary water resources. The lack of cooperation between the involved countries can critically affect the agriculture and energy sectors, thus hindering future development within the region. They estimated the cost of insufficient water cooperation in Central Asia to be higher than 4,5 billion US$ per year.

Therefore, current research on the WEF Nexus in Central Asia is mainly focused on solutions for facilitating transboundary cooperation and the common management of the available water resources. Jalilov et al. (2015) provided a case study on how the concept of benefit-sharing between the riparian countries of transboundary river basins can be used for common resources management. Several scenarios with different benefit-sharing arrangements were analysed in a hydro-economic model to determine the impacts on energy and agricultural productivity. The analysis concluded that a benefit sharing approach would generate benefits in the energy and agriculture sectors.

Based on this situation, the "Central Asia Nexus Dialogue Project: Fostering Water, Energy and Food Security Nexus Dialogue and Multi-Sector Investment" was initiated in 2016. The project is jointly executed by CAREC and IUCN. According to CAREC (2017), the following objectives were defined:

- Support of intersectional cooperation in view of the WEF security Nexus approach in investment planning processes.
- Strengthening of capacities of regional partners in intersectoral planning.
- Mainstreaming of water-energy-food in linkages with ecosystems Nexus approach that can be used at the basin, national and regional levels.

To meet these objectives, the right communication strategy has to be defined. Therefore, a stakeholder analysis was implemented in line with the project. The detailed analysis of the key stakeholders aims "to facilitate improvements to inter-sectoral cooperation on Water-Energy-Food security" (CAREC, 2017).

5.2.4 The WEF Nexus in Latin America

Latin America is considered rich in terms of water, energy and land resources. As the demand for water energy and food increases, the WEF interlinkages become increasingly important and complex. In order to tackle future Nexus challenges in the region, there is a severe need to develop proper measures in the form of policies and infrastructure (Miralles-Wilhelm & Muñoz-Castillo, 2018).

According to Bellfield (2015), many Latin America countries have abundant water resources, but have nevertheless faced trade-offs between water, energy and food due to recent water crises such as the drought in 2014. Statistics at the national level often indicate that there is an abundance of resources, but due to their spatial distributions, shortages often occur in particular regions. For example, the Peruvian Amazon basin contains 97.5% of the country's surface water but is home to only 30% of the region's population, while water scarcity is a key issue in other parts of the country. In Mexico, more than 75% of economic activity, population and irrigated land is found in the central and northern region above 1000 m in altitude, while 72% of water availability is in the lower southern regions (Bellfield, 2015).

A study by Embid and Martin (2017) done on behalf of the Nexus Regional Dialogues Programme analysed the interrelations between water, energy and food in the region and concluded that: the water for energy Nexus should be highly prioritised due to the high share of hydropower in energy production in the region, and that the energy for water Nexus should have the second highest priority, as a large fraction of energy is used for abstraction of groundwater, water supply and usage, including irrigation. The third suggested priority was the water-food Nexus, considering the important role of irrigation in the region.

Miralles-Wilhelm & Muñoz-Castillo (2018) suggested a framework for action which is based on how to minimise the impacts of the trade-offs between Nexus terms. This framework comprises the main 4 interlinked elements to be considered in order to enable the Nexus approach for the region: investment, infrastructure, institutions and information, as shown in Figure 10.

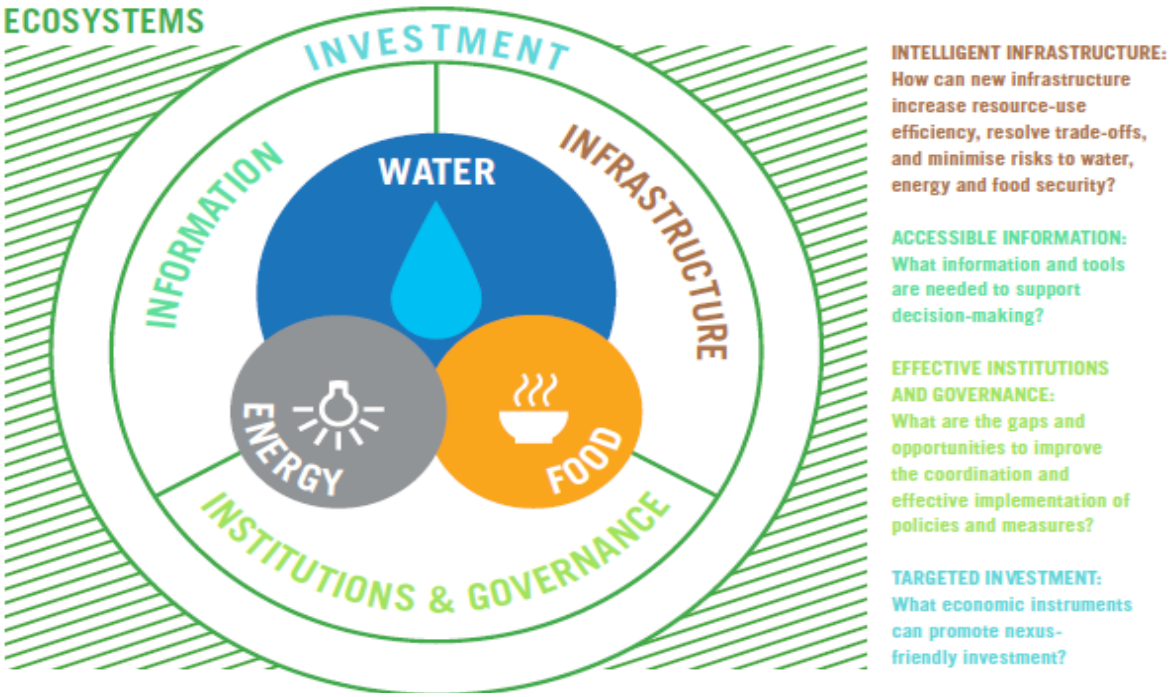

Figure 10: WEF Nexus approach illustration in Latin America (Miralles-Wilhelm & Muñoz-Castillo, 2018)

The Climate and Development Knowledge Network conducted a study on the Water-Energy-Food Nexus in the Amazon Basin and produced several infographics as an initial input to improved decision making in the region (CDKN, 2017).

5.2.5 The WEF Nexus in the Niger Basin

The Niger River Basin is in arid West and Central Africa and the Niger River is Africa's third longest river, extending 4200 km. The river basin is shared among nine riparian countries (Benin, Burkina Faso, Cameroon, Chad, Ivory Coast, Guinea, Mali, Niger and Nigeria), of which six are Least Developed Countries (LDCs). This river is an asset for West and Central Africa and is regarded as a source of identity, a trade and migration route, a cause of potential dispute, and an agent for cooperation. The Niger river contributes to shaping the geopolitics and livelihoods of its basin nations (Andersen and Golitzen, 2005).

Only one in three inhabitants in the basin have access to energy. Conflicts over resource use, degradation and increasing demand for sources of food, water and energy have major impacts, mostly on the poor and most vulnerable, which act as a catalyst for insecurity and displacement in the basin (Ferrini, 2018).

Several studies indicate that by 2050, climate change will cause significant reductions in the crop yields in Sub-Saharan West Africa, in which the Niger Basin is located. Studies also show that the region is projected to suffer from shortened agriculture growing seasons, which could worsen the

already underperforming agriculture in the basin. Given that the population of the region is projected to double by 2050, the region could be required to increase its food production by a factor of five to feed its people (Akumaga et al., 2018). Owing to the utmost importance of the Niger River for several sectors such as hydropower, crop production and fisheries, climate change impacts on the riparian countries' water resources are expected to exacerbate existing poverty and worsen inequality (Oyerinde et al., 2017).

The Niger River and its tributaries provide drinking water, irrigation, aquaculture, energy, and transport to the nine riparian countries. The Niger Basin Authority (NBA) is an intergovernmental organisation responsible for the joint management of the River and for sustainable development of the Basin. The "River Niger Commission" was created in 1964 and was renamed the NBA in 1980. All nine Niger riparian countries are members of the NBA, which promotes coordinated development in a broad range of sectors: water, energy, agriculture, livestock, fisheries, forestry, mining, transport and communication. The NBA has an increasingly central role in facilitating decisions and building consensus among governments, water users, civil society, and other key partners and is increasingly called upon to link national-level investments to regional processes.

Programme de Développement Durable du Delta Intérieur du Niger 2011-2020, Wetlands International, West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) and others have developed tools to build synergies between hydrology, economy and environment, with the aim to optimise surface water infrastructures planning and management in the Niger Basin.

Furthermore, many flood prediction tools have been developed (eg. OPIDIN) for all stakeholders and authorities in the basin to understand the behaviour of the floods in the river delta, using useful tools for planning activities of agriculture (particularly recession), fishing, livestock, logging and navigation.

A programme of development of Nexus Regional Dialogue in the Niger Basin has been studying the existing synergies between resources and complementarities with other ongoing actions. The outcomes of this programme are Nexus policy recommendations and concrete endorsed Nexus action plans to optimise the resources use and strengthen the resilience of Niger River Basin in the face of the global change pressures such as climate change and increasing demands (Ferrini, 2018).

6. Selected Bibliography of Literature

A selected bibliography of Nexus studies is presented in Table 2. The table has been divided into the following eight sections according to the focus of the papers:

(1) Principles of the WEF Nexus concept
(2) Reviews of the WEF Nexus
(3) WEF Nexus relations to sustainability and the SDGs
(4) WEF Nexus methods and tools
(5) WEF Nexus modelling
(6) WEF Nexus governance
(7) Urban Nexus
(8) Assessments and case studies

Some of the identified literature covers more than one of the aforementioned topics. These studies have been placed in the table at the point considered to be the most suitable topic to classify each study.

Table 2: Selected bibliography of literature covering the Nexus

Author(s)	**Keywords**	**Citation and link**
1. Principles of WEF Nexus concept		
Abdul Salam et al., 2017	Understanding the Nexus; operationalising the Nexus; Nexus in practice; future of Nexus;	Abdul Salam, P., Shrestha, S., Pandey, V.P., Anal, A., 2017. Water-energy-food Nexus: principles and practices. AGU. https://www.wiley.com/en-us/Water+Energy+Food+Nexus%3A+Principles+and+Practices-p-9781119243137
Flammini et al., 2014	Conceptualising the WEF Nexus; Nexus assessement; case studies	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; Climate, Energy and Tenure Division (NRC), Food and Agriculture Organization of the United Nations (FAO): Rome, Italy. http://www.fao.org/3/a-i3959e.pdf
Hoff, 2011	Principles; resources interactions; knolwedge gap; resources productivity; capacity building	Hoff, H., 2011. Background paper for the Bonn 2011 Nexus Conference: The water, energy and food security nexus. Stock. Environ. Institute, Stock. http://wef-conference.gwsp.org/fileadmin/documents_news/understanding_the_nexus.pdf
Kurian, 2017	Trade-offs; thresholds; critical mass; Nexus nodes; transdisciplinarity; wastewater reuse; effectiveness index	Kurian, M., 2017. The water-energy-food nexus: Trade-offs, thresholds and transdisciplinary approaches to sustainable development. Environ. Sci. Policy 68, 97–106. doi:10.1016/j.envsci.2016.11.006 https://www.sciencedirect.com/science/article/pii/S1462901116305184

Author(s)	Keywords	Citation and link
Liu et al., 2017	Trade-offs; synergies; IWRM; Panta Rhei; SDGs	Liu, J., Yang, H., Cudennec, C., Gain, A.K., Hoff, H., Lawford, R., Qi, J., Strasser, L. de, Yillia, P.T., Zheng, C., 2017. Challenges in operationalizing the water–energy–food nexus. Hydrol. Sci. J. 62, 1714–1720. doi:10.1080/02626667.2017.1353695 https://pdfs.semanticscholar.org/a4c2/2d07867bc5c354fe5455f8b7f2aed5e5ec51.pdf
Mohtar and Daher, 2010	Resources interlinkages; Silos;	Mohtar, R.H., Daher, B., 2010. Water, Energy, and Food: The Ultimate Nexus. Encycl. Agric. Food, Biol. Eng. Second Ed. 1–5. doi:10.1081/E-EAFE2-120048376 http://wefnexustool.org/docs/water,%20energy,%20and%20food_the%20ultimate%20nexus%20(mohtar,%20daher,%202012).pdf
Vivanco et al., 2018	Nexus pathways; comparative study; China; United States; economy	Vivanco, D.F., Wang, R., Deetman, S., Hertwich, E., 2018. Unravelling the Nexus: Exploring the Pathways to Combined Resource Use. J. Ind. Ecol. doi:10.1111/jiec.12733 https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12733
2. Reviews on WEF Nexus		
Albrecht et al., 2018	Methods; assessments	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. doi:10.1088/1748-9326/aaa9c6 http://iopscience.iop.org/article/10.1088/1748-9326/aaa9c6
Chang et al., 2016	Quantitative analysis on WEF Nexus, global	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. doi:10.3390/en9020065 http://www.mdpi.com/1996-1073/9/2/65
Conway et al., 2015	Climate; Early warning; WEF Nexus modelling; Southern Africa	Conway, D., van Garderen, E. A., Deryng, D., Dorling, S., Krueger, T., Landman, W., Lankford, B., Lebek, K., Osborn, T., Ringler, C., Thurlow, J., Zhu, T., Dalin, C., van Garderen, A., 2015. Climate and southern Africa's water–energy– food nexus Climate and southern Africa's water-energy-food nexus. Nat. Clim. Chang. 5, 837–846. doi:10.1038/nclimate2735 https://wle.cgiar.org/climate-and-southern-africa%E2%80%99s-water%E2%80%93energy%E2%80%93food-nexus
Dai et al., 2018	WEF Nexus methods and tools	Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., Song, X., Jia, B., Xue, W., Yang, Q., 2018. Water-energy nexus: A review of methods and tools for macro-assessment. Appl. Energy 210, 393–408. doi:10.1016/j.apenergy.2017.08.243 https://ideas.repec.org/a/eee/appene/v210y2018icp393-408.html
Endo et al., 2015	Methods; quantitative; qualitative	Endo, A., Burnett, K., Orencio, 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. doi:10.3390/w7105806 http://www.mdpi.com/2073-4441/7/10/5806
Endo et al., 2017	Nexus projects, Nexus research	Endo A., Tsurita I., Burnett K., and Orencio P.M., 2017. A review of the current state of research on the water, energy and food nexus. Journal of Hydrology: regional Studies, 11, 20-30. https://www.sciencedirect.com/science/article/pii/S2214581815001251

Author(s)	Keywords	Citation and link
Galaitsi et al., 2018	Governance; Nexus intervention	Galaitsi, S., Veysey, J., Huber-Lee, A., 2018. Where is the added value? A review of the water-energy-food nexus literature SEI working paper. June 2018. https://www.sei.org/wp-content/uploads/2018/07/review-of-the-water-energy-food-nexus.pdf
Hussey and Pittock, 2012	Case studies from Australia, Europe, and the United States	Hussey, K., Pittock, J., 2012. The energy-water nexus: Managing the links between energy and water for a sustainable future. Ecol. Soc. 17. doi:10.5751/ES-04641-170131 https://www.ecologyandsociety.org/vol17/iss1/art31/
McCarl et al., 2017a	Modelling; complex relationships; uncertainty; resource allocation; decision support	McCarl, B.A., Yang, Y., Schwabe, K., Engel, B.A., Mondal, A.H., Ringler, C., Pistikopoulos, E.N., 2017a. Model Use in WEF Nexus Analysis: a Review of Issues. Curr. Sustain. Energy Reports 4, 144–152. doi:10.1007/s40518-017-0078-0 https://link.springer.com/article/10.1007/s40518-017-0078-0
McCarl et al., 2017b	Data; data systems; model requirements; stakeholder analysis; stochastic variation	McCarl, B.A., Yang, Y., Srinivasan, R., Pistikopoulos, E.N., Mohtar, R.H., 2017b. Data for WEF Nexus Analysis: a Review of Issues. Curr. Sustain. Energy Reports 4, 137–143. doi:10.1007/s40518-017-0083-3 https://link.springer.com/article/10.1007/s40518-017-0083-3
Rasul and Sharma, 2016	Adaptation measures; climate change; Hindu Kush, Himalayan region	Rasul, G., Sharma, B., 2016. The nexus approach to water–energy–food security: an option for adaptation to climate change. Clim. Policy 16, 682–702. doi:10.1080/14693062.2015.1029865 https://www.tandfonline.com/doi/full/10.1080/14693062.2015.1029865
3. Sustainability and SDGs		
Bhaduri et al., 2015	Nexus implementation; governance; capacity building; SDGs	Bhaduri, A., Ringler, C., Dombrowski, I., Mohtar, R., Scheumann, W., (2015): Sustainability in the water–energy–food nexus. In Water International 40 (5-6), pp. 723–732. DOI: 10.1080/02508060.2015.1096110 https://www.tandfonline.com/doi/full/10.1080/02508060.2015.1096110
Biggs et al., 2015	Water-energy-food security; livelihood; Environmental Livelihood Security (ELS) framework	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. Policy 54, 389–397. doi:10.1016/j.envsci.2015.08.002 https://www.sciencedirect.com/science/article/pii/S1462901115300563
Bizikova et al., 2014	WEF Nexus components; operationalising the Nexus; transformation; agriculture	Bizikova, L., Roy, D., Venema, D.H., McCandless, M., Darren Swanson, Khachtryan, A., Borden, C., Zubrycki, K., 2014. The Water-Energy-Food Nexus and Agricultural Investment: A sustainable development guidebook. International Institute for Sustainable Development (IISD). http://www.iisd.org/pdf/2014/WEF_guidebook.pdf
Brears, 2015	Circular economy; European Union; Asia-pacific region	Brears, R.C., 2015. The circular economy and the water-food nexus. J. Food, Agric. Soc. 3, 53–59. http://www.asianperceptions.fu-berlin.de/system/files/private/pp715-water-energy-food-nexus.pdf

Author(s)	Keywords	Citation and link
Brandi et al., 2013	Post-2015 Development Agenda; sustainability; SDGs; Rio+20	Brandi, C., Richerzhagen, C., Stepping, K.M.K., 2013. Post 2015: why is the water-energy-land nexus important for the future development agenda? German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Bonn https://www.die-gdi.de/briefing-paper/article/post-2015-why-is-the-water-energy-land-nexus-important-for-the-future-development-agenda/
FAO, 2018	SDG 7; priority actions; challenges and opportunities	FAO, 2018. Water-Energy-Food Nexus for the review of SDG 7. POLICY Br. #9, FAO. https://sustainabledevelopment.un.org/content/documents/17483PB_9_Draft.pdf
Gupta, 2017	Capacity development; Millennium Development Goals (MDGs); national policy frameworks	Gupta, A.D., 2017. Water-Energy-Food (WEF) Nexus and Sustainable Development. American Geophysical Union (AGU), pp. 221–241. doi:10.1002/9781119243175.ch19 https://agupubs.onlinelibrary.wiley.com/doi/10.1002/9781119243175.ch19
Mohtar, 2016	Implementation of SDGs; Trade-offs analysis	Mohtar, R., 2016. The importance of the Water-Energy-Food Nexus in the implementation of The Sustainable Development Goals (SDGs). OCP Policy Centre. http//www.ocppc.ma/sites/default/files/OCPPC-PB1630_0.pdf
Stephan et al., 2018	Implementation of SDGs	Stephan, R.M., Mohtar, R.H., Daher, B., Embid Irujo, A., Hillers, A., Ganter, J.C., Karlberg, L., Martin, L., Nairizi, S., Rodriguez, D.J., Sarni, W., 2018. Water–energy–food nexus: a platform for implementing the Sustainable Development Goals. Water Int. 43, 472–479. doi:10.1080/02508060.2018.1446581 https://www.tandfonline.com/doi/abs/10.1080/02508060.2018.1446581?journalCode=rwin20
Weitz et al., 2014	SDGs; governance	Weitz, N., Nilsson, M., Davis, M., 2014. A Nexus Approach to the Post-2015 Agenda: Formulating Integrated Water, Energy, and Food SDGs. SAIS Rev. Int. Aff. 34, 37–50. doi:10.1353/sais.2014.0022 https://www.sei.org/publications/a-nexus-approach-to-the-post-2015-agenda-formulating-integrated-water-energy-and-food-sdgs/
4. WEF Nexus methods and tools		
Daher and Mohtar, 2015	WEF Nexus Tool 2.0; Qatar	Daher, B.T., Mohtar, R.H., 2015. Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making. Water Int. 40, 748–771. doi:10.1080/02508060.2015.1074148 https://www.tandfonline.com/doi/abs/10.1080/02508060.2015.1074148
Damerau et al., 2016	Modelling and scenarios, global	Damerau, K., Patt, A.G., van Vliet, O.P.R., 2016. Water saving potentials and possible trade-offs for future food and energy supply. Glob. Environ. Chang. 39, 15–25. doi:10.1016/j.gloenvcha.2016.03.014 https://www.sciencedirect.com/science/article/pii/S0959378016300358
El-Gafy, 2017	WEF Nexus index; productivity	El-Gafy, I., 2017. Water–food–energy nexus index: analysis of water–energy–food nexus of crop's production system applying the indicators approach. Appl. Water Sci. 7, 2857–2868. doi:10.1007/s13201-017-0551-3 https://link.springer.com/article/10.1007/s13201-017-0551-3

Author(s)	Keywords	Citation and link
Karnib, 2017a	The Q-Nexus Model	Karnib, A., 2017a. Water, energy and food nexus: The Q-Nexus model. Eur. Water 60, 89–97. http://www.academia.edu/35029537/Water_Energy_and_Food_Nexus_The_Q-Nexus_Model
Simpson and Berchner, 2017	WEF Nexus Index; integration	Simpson, G., Berchner, M., 2017. Water Wheel - Water-energy nexus - Measuring integration : towards a water-energy-food nexus index - feature. Water Res. Comm. 16, 22–23. https://journals.co.za/content/journal/10520/EJC-5656d40ae
Yang et al., 2016a	Hydro-economic water system model; Brahmaputra River Basin	Yang, Y.C.C.E., Wi, S., Ray, P.A., Brown, C.M., Khalil, A.F., 2016a. The future nexus of the Brahmaputra River Basin: Climate, water, energy and food trajectories. Glob. Environ. Chang. 37, 16–30. doi:10.1016/j.gloenvcha.2016.01.002 https://www.sciencedirect.com/science/article/pii/S0959378016300036
5. WEF Nexus modelling		
Hussien et al., 2017	End-use; household scale; income; seasonal variability; system dynamics modelling;	Hussien, W.A., Memon, F.A., Savic, D.A., 2017. An integrated model to evaluate water-energy-food nexus at a household scale. Environ. Model. Softw. 93, 366–380. doi:10.1016/j.envsoft.2017.03.034 https://www.sciencedirect.com/science/article/pii/S1364815216306594
Jalilov et al., 2016	Hydro-economic model; Amu Darya River Basin, Central Asia	Jalilov, S.M., Keskinen, M., Varis, O., Amer, S., Ward, F.A., 2016. Managing the water-energy-food nexus: Gains and losses from new water development in Amu Darya River Basin. J. Hydrol. 539, 648–661. doi:10.1016/j.jhydrol.2016.05.071 https://www.sciencedirect.com/science/article/pii/S0022169416303481
Karnib, 2017b	Simulation; optimisation; sustainable development	Karnib, A., 2017b. Water-Energy-Food Nexus: A Coupled Simulation and Optimization Framework. J. Geosci. Environ. Prot. 05, 84–98. doi:10.4236/gep.2017.54008 http://www.scirp.org/journal/PaperInformation.aspx?paperID=75605
Kling et al., 2017	Integrated assessment; Nexus modelling; review of the WEF Nexus; research needs	Kling, C.L., Arritt, R.W., Calhoun, G., Keiser, D.A., 2017. Integrated Assessment Models of the Food, Energy, and Water Nexus: A Review and an Outline of Research Needs. Annu. Rev. Resour. Econ. 9, 143–163. doi:10.1146/annurev-resource-100516-033533 https://www.annualreviews.org/doi/abs/10.1146/annurev-resource-100516-033533
Wicaksono et al., 2017	Review; simulation model; stakeholder involvement; sustainable development	Wicaksono, A., Jeong, G., Kang, D., 2017. Water, energy, and food nexus: review of global implementation and simulation model development. Water Policy 19, 440–462. doi:10.2166/wp.2017.214 https://iwaponline.com/wp/article-abstract/19/3/440/20565/Water-energy-and-food-nexus-review-of-global?redirectedFrom=fulltext
Yang et al., 2016b	Nexus thinking; hydro-agro-economic model; water allocation policies; climate change; agriculture	Yang, Y.C.E., Ringler, C., Brown, C., Mondal, M.A.H., 2016b. Modeling the Agricultural Water–Energy–Food Nexus in the Indus River Basin, Pakistan. J. Water Resour. Plan. Manag. 142, 04016062. doi:10.1061/(ASCE)WR.1943-5452.0000710 https://ascelibrary.org/doi/10.1061/%28ASCE%29WR.1943-5452.0000710

Author(s)	Keywords	Citation and link
6. WEF Nexus Governance		
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Artioli et al., 2017	Urban governance; resources management; infrastructure	Artioli, F., Acuto, M., McArthur, J., 2017. The water-energy-food nexus: An integration agenda and implications for urban governance. Polit. Geogr. 61, 215–223. doi:10.1016/j.polgeo.2017.08.009 https://halshs.archives-ouvertes.fr/halshs-01654764/document
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Carius and Kramer, 2017	Regional strategies related to WEF Nexus; entry points for WEF Nexus; institutional set up; coordination mechanism of WEF Nexus; Arab region	Carius, A., Kramer, A. 2017. Regional Policy Guidelines. Mainstreaming the Water-Energy-Food Security Nexus into Sectoral Policies and Institutions in the Arab Region. Bonn/Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.water-energy-food.org/fileadmin/user_upload/files/documents/giz/nexus-mainstreaming/3_Regional_Policy_Guidelines_Final_Report-final.pdf
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