UTRECHT UNIVERSITY

MASTER THESIS

The contribution of a mixed-methods approach on urban resource nexus governance

-

operationalizing nexus footprints and policy integration in two case studies

Author:
Linda MAIWALD

Supervisor:
Dr. Marjanneke J. VIJGE
Examiner:
Prof. Dr. Bernd KLAUER

A thesis submitted in fulfillment of the requirements for the degree of Sustainable Development M.Sc.

Faculty of Geosciences
Copernicus Institute
August 23, 2021

Master thesis

Submitted by:

Linda Clea Elisabeth Maiwald
Student number 6955037
Sustainable Development M.Sc.
Joint Master Program
Earth System Governance track
l.c.e.maiwald@students.uu.nl

Supervisor:
Dr. Marjanneke J. Vijge
Assistant professor of Sustainability Governance in the Developing World
at the Copernicus Institute of Sustainable Development

Examiner:
Prof. Dr. Bernd Klauer
Professor for Sustainability and Water Resources Management University of Leipzig,
Deputy head at Department of Environment and Society at Helmholtz Centre for Environmental Research - UFZ Leipzig

This thesis is the result of a cooperation between Utrecht University and UFZ Leipzig.

UFZ HELMHOLTZ Centre for Environmental Research

Utrecht University

UTRECHT UNIVERSITY

Abstract

Faculty of Geosciences
Copernicus Institute

Sustainable Development M.Sc.

The contribution of a mixed-methods approach on urban resource nexus governance

by Linda MAIWALD

The concept of urban nexus and its governance has been gradually evolving during the past years. Yet, urban nexus studies still appear as majorly underrepresented compared to a broad range of nexus research focusing on the international or national context. The nexus concept for local studies is still undertheorized. Therefore, the thesis targets on a sharper characterization of nexus to conclude on urban nexus governance. For this reason, the mixed-methods study examines the interactions between water and energy resources and the interaction between institutions facing the nexus issue in two case studies (Amman, Jordan and Pune, India). The Socio-Ecological Systems (SES) concept is utilized to establish a theory-neutral framework that bridges both material and institutional analysis. Concerning the material part of the work, the nexus footprint concept is elaborated to operationalize the nexus term in order to reflect on micro-scale resource interlinkages. In the institutional analysis, policy integration as complementary theory to nexus governance is utilized. As a final step, the thesis discloses the alignment of governance with the respective urban water-energy nexus issue in the regarded cases. The explorative approach of the work closes a persistent gap in urban nexus research as it combines both the study of material conditions and the subsequent implications for policy. Additionally, it gives valuable insights in the nexus challenges of two specific cities in the global south. Concludingly, the practicality of the nexus footprint concept to operationalize the nexus is confirmed. Thus, the mixed-methods approach of the thesis enhances the local perspective on resource interrelations and stresses the importance of the urban level for nexus governance. Policy integration theory for analyzing nexus governance in the face of a resource challenge is found to be beneficial in establishing a horizon for institutional comprehension of the nexus. Both case studies reveal a low governmental recognition concerning the identified nexus issues. Lastly, the approach of the thesis offers a template for future nexus studies by strengthening the attractiveness of urban nexus research. The template could be expanded to include the full spectrum of FEW (food-energy-water) nexus resources in the study approach which is already incentivized by the nexus footprint concept.

Key words urban nexus, nexus footprints, nexus governance, urban system, policy integration, resources, water-energy nexus, mixed-methods

Utrecht University

Acknowledgements

At this point, I would like to thank Marjanneke for her commitment as supervisor. Your thoughtful mentoring has been of incredible value, pointing out opportunities to me and inspiring me to develop ideas further. Equally valuable for me was the collaboration with Bernd. Despite the pandemic situation, you made it possible for me to be part of a collegial and dedicated research team for the duration of my master's thesis. Thanks to both of you!

During the period of collaboration with the UFZ, my colleague Heinrich became my closest mentor. Thank you for your continuous collaboration, your untiring feedback and your impulses, especially in the area of nexus footprints! Building on this, I would like to express my gratitude to all other members of the FUSE team for their openness and willingness to support my research.

I would also like to thank all available interview partners anonymously for their advice and insights. I do not see it as a matter of course to open up to strangers from a different context.

In addition, many thanks to people who substantially stood by me during the master's thesis phase. Among those, thanks especially to Marlies and Johannes, who provided me with a pleasant workplace close to nature. Thanks to Steffen and Sebastian for their constant availability for technical support and thanks to Nicola for her formal advice.

I want to thank Franzi and Naomi for supporting and guiding me not only during the master thesis process at any time of the day or night, but also continuously during the whole master program. Because of you, I never felt alone in this challenging phase of life. I am forever grateful for your friendship.

Finally, I thank Max who always took care of me, especially during the difficult study conditions. You made me not losing my smile despite of most stressful times. Thank you for being my rock.

Contents

List of Figures

List of Tables

List of Abbreviations

ACWADAM	Advanced Center for Water Resources Development and Management
AGCP	Amman's Green City Plan
CH_4	Methane
CO_2	Carbon dioxide
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GAM	Greater Amman Municipality
GDPR	General Data Protection Regulation
GHG	Greenhouse gas
IWRM	Integrated Water Resources Management
JWA	Jordan Water Authority
kwh	kilowatt-hour
LCA	Life cycle assessment
LPG	Liquefied petroleum gas
MEDA	Maharashtra Energy Development Agency
MEMR	Ministry for Energy and Mineral Resources
MERC	Maharashtra Electricity Regulatory Commission
MoE	Ministry of Environment
MPIC	Ministry of Planning and International Cooperation
MWRRA	Maharashtra Water Resource Regulatory Authority
N_2O	Nitrogen
NEPCO	Nationl Electric Power Company
NGGP	National Green Growth Plan
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
PMC	Pune Municipal Corporation
PMRD	Planning and Development Authority for the Pune Metro Region
POR	Pune Office of Resilience
RIVM	National Insti-tute for Public Health and the Environment
RKI	Robert KochInstitute
RSDS	Red Sea–Dead Sea (Conveyance)
SDG	Sustainable Development Goals
UCLG	United Cities and Local Governments
UN	United Nations
WHO	World Health Organization

Dedicated to a little growing soul reminding me on the potential of life . . .

Utrecht University

Chapter 1

Introduction

Pressing environmental issues in urban surroundings have been concern of sustainability discourse since the institution of Local Agenda 21 at the 1992 Rio Earth Summit (Artioli et al., 2017; Bosworth, 1993). Yet, cities call for more attention in sustainability science as globalization, rising urban populations and climate change intensify environmental threats in urban areas severely (Artioli et al., 2017; Astleithner and Hamedinger, 2003; Swilling and Hajer, 2017; Urbaniec et al., 2017; Zhang et al., 2019). One of the most relevant threats resulting to cities is their stress on resources. Thus, urban sustainable development is in need of bold concepts for progressive urban resource governance. Within the past two decades, there has been a growing awareness in the scientific community of the interdependence of resources. Especially, the interlinkages of food, water and energy resources, called Food-Energy-Water (FEW) nexus[1], developed to a prominent research concept in academia within the past ten years (Artioli et al., 2017; Zhang et al., 2019). This is due to the fact that food, energy and water systems form the fundamental resources on which humanity can build on (Artioli et al., 2017; Biggs et al., 2015; Smajgl et al., 2016). The nexus concept avoids approaching food, energy and water systems separately. Instead, it strives for systemic thinking regarding resources issues. Therefore, the nexus concept assumes interdependence across the three resources systems (the "nexus"), wherefore in turn, resource interactions ultimately affect their availability (Artioli et al., 2017). Past disruptive events like the instability of food prices in 2008, or repeated water and electricity shortages in emerging countries stressed the interdependencies of the three domains (Al-Saidi and Elagib, 2017). Nevertheless, the FEW approach has received only marginal attention at the urban level so far.

Primarily, the topic has been called to the attention of international organizations and governance as a crucial policy matter (FAO, 2014; Halbe et al., 2015; Hoff, 2011). The United Nations (UN) and World Economic Forum emphasizes intensely the risks of nexus failures. The link between resource security and economic growth has framed the emergence of the "nexus approach" in policy-making over the past decade (Artioli et al., 2017; Hoff, 2011; UN, 2020). Through the push from the highest political level, nexus matters became an integral subject of governance research. In opposite, the lowest level of nexus issues has been neglected in the past because of this top-down agenda setting (Newell et al., 2019; Zhang et al., 2019). Also, the global discourse on the FEW nexus concept does not explicitly determine a role for cities and local governments (Al-Zu'bi, 2017; Bank, 2010). Yet without localized action concerning resources management, it is certain that national governments will not be able to meet their international commitments for addressing climate and environmental mitigation and adaptation (UN, 2011). Also, the Sustainable Development Goals (SDGs) highlight the urban scale as a priority for global and national governance as they prioritize urban resilience and sustainability (Parnell, 2016; UN, 2020). But these insights have only had a limited impact on nexus research in academia. Nexus research on the global and national scale grew incrementally, while urban resources interrelations have received far less scientific attention (Artioli et al., 2017; Newell et al., 2019; Zhang et al., 2019). Additionally, urban nexus studies are even less conducted in the global south although these are the urban place where resource issues tend to exacerbates the fastest due to climate vulnerability and overpopulation (Albrecht et al., 2018; Artioli et al., 2017; Hagemann and Kirschke, 2017;

[1] This paper does not distinguish between the common terms water-energy-food (WEF) nexus, food-water-energy (FWE) nexus and water-energy-food (WEF) nexus, but continues to use the last one for the sake of consistency.

Newell et al., 2019). Hence, it is time to face the topic of urban resource nexus in research intensely.

Practically, the nexus can be understood as an integration across systems through technological and institutional change (Allan et al., 2015; Gondhalekar and Ramsauer, 2017; Märker et al., 2018; Villamayor-Tomas et al., 2015). In governance, the nexus conceptualizes a holistic treatment of interdependent sectors or subsystems as a policy frame in opposite of silo thinking (Muller, 2015). Silo thinking means strong divisional thinking and also action, resulting a lack of boundaryless and interdisciplinary cooperation (Kurian et al., 2019; Szerszynski and Galarraga, 2013). Governance of resource use and service provision may engage multiple causal pathways. Through these, resources interact with each other wherefore policy makers are encouraged to consider broader interdependencies and to accentuate trade-offs and complementarities between systems (Al-Saidi and Elagib, 2017; Artioli et al., 2017). As a result, the governance perspective on nexus emphasizes policy coherence, integrated and coordinated decision-making, as well as management, planning and governance across sectors and scales of the respective resources (Weitz et al., 2017b). This nexus paradigm includes also external factors like population growth, environmental change and increasing urbanization putting systems under greater pressure. As ultimate goal, the nexus approach aims for integration to enable resource security in a global context of increasing and competing demands (Artioli et al., 2017).

However, it must be noted that the nexus term is used ambiguously. Cairns and Krzywoszynska, 2016 observe that the term is used in a variety of ways. This earns it the criticism of being just an empty "buzzword" with no deeper background. Yet, strong nexus phenomena have been proven sufficiently (Märker et al., 2018; Zhang et al., 2019). From the nexus concept, it is thus at least theoretically possible to derive policy makers to push towards localized interventions, increased cooperative action, increased resource efficiency and adaptive capacity (Kurian, 2017; Kurian et al., 2019; Lyytimäki et al., 2020). Nevertheless, it persists the impression that the concept of nexus seems more like an abstract ideal than an operator in broader nexus literature. Thereby, criticisms of the approach fall on fertile ground because the nexus concept is only vaguely operationalized so far. Yet, to establish the concept and make it applicable particularly in the local context, further operationalization of the nexus is required (Artioli et al., 2017; Benson et al., 2015; Zhang et al., 2019).

Hence, future urban research on nexus must improve characterization of resource interrelation to advise on suitable local resources governance (Zhang et al., 2019). This thesis aims to take up these challenges through an explorative mixed-methods concept. Previous scholarship already discussed that mix-methods approaches towards nexus matters might be advantageous to understand the nature of nexus for governance purposes (Hagemann and Kirschke, 2017; Heard et al., 2017). Key for an evaluation of the material nexus is identifying the full interactions between the involved resources on a material basis (Al-Saidi and Elagib, 2017; Olsson, 2015). However, it remains challenging to map a material nexus depending on data complexity and purpose of research (Newell et al., 2019). A comprehensive and lean way to analyze and demonstrate resource consumption is the so-called footprint approach (Al-Saidi and Elagib, 2017; Hoekstra et al., 2011; Rees, 1992). A growing number of resource footprint indicators have been developed to contribute to a better understanding of human-natural system interactions and their unsustainable patterns (Vanham et al., 2019). But until today, footprints have not yet been sufficiently operationalized as a tool to evaluate nexus issues. Footprints typically consider only one aspect (e.g., carbon or water) (Al-Saidi and Elagib, 2017). Nevertheless, Hoff, 2011 contoured shortly that footprints could also be used as nexus measurement tool. Recently, Vanham et al., 2019 proposed combining various indicators within a "footprint family" which is basically the precursor of a nexus footprint. Also, Vanham, 2016 elaborated in detail how footprints are expandable to illustrate nexus interrelations. Whereas footprints entail a broad scientific literature body, nexus footprints are a comparably new field of study that received little scientific attention so far.

Still, the researcher sees potential in the nexus footprint approach to make crucial nexus issues visible for urban context as they can reveal micro-scale resources interlinkages. This study intends to draw from those advances in the field of nexus footprints while further operationalizing them to conclude on appropriate nexus governance for specific urban places. The thesis builds on the hypothesis nexus issues occur inevitably. It is task of governance

to capture this nexus structurally (Urbinatti et al., 2020). To capture specific nexus issues per city, a nexus footprint framework is proposed as part of this work. Thus, scholarship must address how governance around an urban nexus issue is practically shaped in reality and what to learn from that for governance (Urbinatti et al., 2020). Therefore, the thesis intends to build on both advances in systemic research on nexus characterization and nexus governance to better understand pressing problems of urban nexus complexities. As such, this work pursues an explorative approach that bases on two urban case studies, Amman (Jordan) and Pune (India). In doing so, the thesis acknowledges two core themes of nexus research: the nature of relationships between resources and its implications for policy (Bizikova et al., 2013). Most research focuses on either the interactions between material resources or the (lack of) interaction between institutions, but not on both. **Hence, this study explores (i) the interactions between material resources and (ii) the interaction between institutions in charge towards the nexus.**

Due to the centrality of the two resources water and energy (Hamiche et al., 2016; Scott et al., 2011), the focus of the work lies only on the water-energy nexus, embedded in the overarching comprehension of the FEW nexus. Water and energy are key resources in the provision of urban life. As stated in literature but also shown in this work, various possibilities exist regarding how water-energy nexuses within the boundaries of a city appear (Ahmad et al., 2020; Dai et al., 2018; De Stercke et al., 2020; Malik, 2002). Two specific cases are explored to grasp a more detailed understanding of nexus. How and why the cases have been selected for analysis is stated in the methodology chapter.

Conclusively, the specific research question of this thesis is:

What are the strengths and weaknesses of nexus governance in Amman and Pune and how can a mixed-methods approach operationalizing nexus footprints contribute to it?

As the thesis follows an inductive approach, the main research question is gradually addressed by the subsequent three sub research questions.

1. How can a nexus footprint contribute to an advanced understanding of a water- energy nexus issue?
In this step, the nexus footprint methodology is applied on the two cases Amman and Pune to characterize a water-energy nexus in each case coherently. Through applying the nexus footprint approach, the research aims to enhance understanding of the nexus concept by the results gathered in the empirical application.

2. How are nexus issues governed institutionally in the cases of Amman and Pune?
Here, it is analyzed how the institutional systems of both cases reflect the specific nexus issue in their subsystem involvement, policy goals and policy frame.

3. How can a mixed-methods approach contribute to determining strengths and weaknesses of urban nexus governance?
Through the case studies, the strengths and weaknesses of nexus governance in regard to the findings under sub questions one and two are discussed. Ultimately, the usefulness of this mixed-methods approach is considered.

In the subsequent chapter, the theoretical background for this thesis is elaborated. The Socio-ecological Systems (SES) approach is considered as a theory-neutral framework to establish the mixed-methods approach of this work. The framework is complemented on the material side with the nexus footprint concept and on the institutional side with the policy integration concept that are both directly related to the scientific consideration of nexus issues. Next, the theory is operationalized in the methodology chapter to be utilized in the explorative urban case studies.

Chapter 2

Theory

2.1 Simplified overview of the theoretical approach

This work ultimately targets on conclusions for urban nexus governance about the interaction between institutions and simultaneously the nature of nexus. Nexus governance was not directly defined by scholarship so far. Though, the term appears equally to integrated governance for resources nexus challenges (Märker et al., 2018; Visseren-Hamakers, 2015; Weitz et al., 2017a). Thus, policy integration is operationalized as key theory to analyze nexus governance. But the explorative aspiration of the thesis facing the contribution of a mixed-methods on nexus governance analysis requires further theorization. Socio-ecological Systems (SES) research provides a theory-neutral framework to set policy integration for nexus issues in a context of material conditions (Chini and Stillwell, 2020; Covarrubias, 2018; Ghodsvali et al., 2019; McGinnis and Ostrom, 2014). Thereby, the reflection on interaction between material resources is possible. These material conditions are to be analyzed utilizing nexus footprints, a concept that is evolved extensively in this section as well. Conclusively, a multi-dimensional theoretical concept for the thesis arises which aims to elaborate a broad picture of urban nexus challenges (see figure). Subsequently, the theoretical approaches are elucidated in detail.

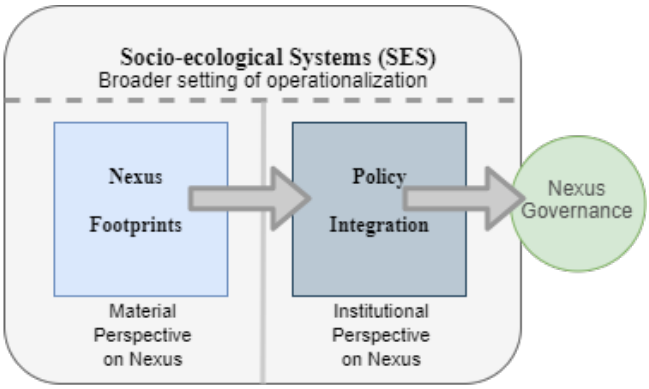


FIGURE 2.1: Theory framework.

2.2 Socio-ecological Systems (SES) for urban complexities

FEW resources are interrelated systems that majorly influence each other. Therefore, the topic roots deeply in systems theory (Bizikova et al., 2013). In this work, it is acknowledged that nexus systems perspective is to be complemented by the term "complex". Already in the 1970s, Rittel and Webber noted nexus, and nexus governance, obtaining characteristics of so called "wicked" problems (Rittel and Webber, 1973). Thus, nexus governance is a true "wicked problem", in which "the process of solving the problem is identical with the process of understanding its nature" (Rittel and Webber, 1973, p.162). In the thesis, it is accordingly assumed that the nature of a nexus must be explored extensively to understand governance on it. In environmental scholarship, such a systems approach has been conceptualized by the Socio-Ecological Systems (SES) literature. SES is considered as a theory-neutral framework to analyze the linkages and relations of an ecological (non-human, physical or material) system with one or more social systems (Anderies et al., 2004; McGinnis and Ostrom, 2014). Research assumes that actors (e.g. producers or users) and governance systems (e.g. government, monitoring rules, etc.) interact and connect with resources units, resource systems (e.g. water sector) and vice versa. Herby, actors and governance systems form specific action situations such as drinking water provisioning (Anderies et al., 2004; McGinnis and Ostrom, 2014).

Such social-ecological systems may also be represented by urban settings. Urban environments are recognized by SES research as urban dynamics that are integrated and multi-scale systems (Artioli et al., 2017; Newell et al., 2019). This comprehension of a city broadens the perspective from focusing on the biophysical features of urban surroundings (i.e., ecology of cities) to the inclusion of complex socio-ecological relationships of cities in urban studies (Frank et al., 2017). It arises from the fact that the ecology of cities bases upon the city as a reservoir of land uses and management practices, subjected to biophysical and human (i.e., households, municipalities, agencies) driven influences and feedback loops (Franco et al., 2017; Grove et al., 2013). Hence, the socio-ecological perspective on cities emphasizes that urbanization influences the biophysical landscape and its functioning and quality. Likewise, urbanization structures change human behavior, community and social organization. Therefore, urban nexus research can make use of a complex systems approach like SES to capture interaction across different components of the urban system (Al-Saidi and Elagib, 2017; Bazilian et al., 2011; Newell et al., 2019; Zhang et al., 2019).

The thesis chooses the SES approach to situate the research in a systemic understanding of urban environment. It does acknowledge the core argument of addressing environmental issues from a socio-environmental perspective as done by the schools of thought from SES research. However, SES scholarship has been criticized for a reductionist perspective in terms of theorization, operationalization, and conceptualization of the socio- and ecological domains (Stojanovic et al., 2016). Yet, this remains negligible for this work as SES is rather operationalized here as conceptual umbrella. Thus, SES bridges the analysis of interactions between water-energy resources and the interaction between institutions in charge of the nexus. As such, SES appears as the broader setting in which the thesis operates. The study consequently differentiates between material system and institutional system as equivalent to the socio- and ecological tiers of SES theory. These are then perceived as two defined domains entailing own methodological considerations (cf. Covarrubias, 2018). In consequence, the material nexus is to be determined firstly, before the institutional analysis follows and builds on the previous one (Chini and Stillwell, 2020; Covarrubias, 2018). This theoretical concept urges the researcher to identify key variables of resources interaction that determine the urban system in order to narrow down the expected outcome of governance analysis (Clark et al., 2016). The approach bases on the aim to holistically understand a particular nexus issue and builds the way working towards the research question. By this means, the SES concepts opens space for an in-depth analysis of an urban-situated nexus issue. Likewise, SES facilitates transdisciplinary and mixed-methods nexus application as requested by previous research (Ghodsvali et al., 2019). This may set the base for a deep understanding for urban nexus challenges and their complementary urban nexus governance. The two theoretical approaches for the two-fold SES approach on urban resource interactions are elaborated in the following sections.

2.3 Nexus Footprints as material perspective on nexus

In this chapter, the material interconnection of resources is highlighted and the question of how to pursue the urban nexus interface is being investigated. For that purpose, a nexus footprint analysis tool for the material nexus is developed. This nexus footprint approach is derived from the prior advances in water and carbon footprint research while also including food as common component. Therefore, it is applicable for FEW nexus studies, yet only applied in the thesis to reveal water-energy concerns.

The nexus footprint concept bases on Vanham's findings that the footprint concept is enlargeable for a nexus analysis (Vanham, 2016; Vanham et al., 2019). But in opposite to Vanham's detail- and data-extensive nexus footprint concept, a rather simple but explorative approach towards nexus footprints is developed hereafter. As Chen and colleagues state in their work, a nexus footprint can built on elements of two distinct footprints (Chen et al., 2019). Thus, both concepts complement each other with regard to certain objects of inquiry. Concretely, this means footprints such as carbon footprints, mirroring energy consumption, detect water use and water footprints assess energy consumption simultaneously (Chen et al., 2019). The extent and limitations of this complementarity are examined and systematized as contribution of this thesis. For an urban nexus footprint, these interrelations must be elaborated as key characteristics of footprint indicator design. In doing so, it is primarily integral to comprehend the concept of footprints in general terms. Then, the water and carbon footprint and its complementarities are compiled.

2.3.1 Footprint indicators

An ecological footprint is generally understood as sustainability indicator and may be useful for identifying the concrete material challenges of a nexus as argued in the following. A footprint combines human carrying capacity and natural capital to prevailing resources depletion (Rees, 1992). Footprints reveal resources complexities and components that lie within one good, action or land. Hence, they are able to display indirect resources consumption (Al-Saidi and Elagib, 2017; Bazilian et al., 2011; Newell et al., 2019; Zhang et al., 2019). As an accounting tool, a footprint approach can aggregate material consumption in an ecologically meaningful way. Therefore, it offers a realistic picture of material consumption (Wackernagel et al., 1999). There are different subjects that underwent environmental footprinting, among those scholarship found especially broad interest in water and carbon footprinting.

The water footprint concept was introduced for the first time by Hoekstra in 2002 as multidimensional indicator displaying not only direct but also indirect water consumption (Hoekstra et al., 2011). Over time, the concept was refined by Hoekstra himself (Hoekstra, 2016; Hoekstra et al., 2011; Hoekstra et al., 2019), but also further scholars expanded and sharpened the ambit of water footprints (Chini and Stillwell, 2020; Koteswara Rao and Chandrasekharam, 2019; Paterson et al., 2015). Among the different designs of the water footprint three general aims persist in all studies. (i) The concept aims to quantify and locate the water footprint of a process, product, produce or consumer or to quantify in space and time the water footprint in a specific geographic area. (ii) The footprint assesses the environmental, social and economic sustainability of water consumption. (iii) The footprint application aims to formulate response strategies to revealed resource tensions (Hoekstra et al., 2011). In sum, the goal of assessing water footprints is to analyze how human activities or specific products relate to issues of water scarcity and pollution.

The carbon footprint can be understood as an equivalent tool to assess the energy-related components of resources consumption. The carbon footprint is characterized and weighted in a variety of greenhouse gas (GHG) emission such as carbon dioxide (CO_2), methane (CH_4) and nitrogen (N_2O). This footprint model did not undergo the same degree of standardization like the water footprint model yet. This results from the complexity due its range of analysis subjects in opposite to water footprint accounting. Thereof, less generalizable approaches for carbon footprint accounting occur. The carbon footprint of a city is the total

carbon dioxide emissions caused directly and indirectly by the activities of its citizens and businesses (Wiedmann and Minx, 2008). It comprises the emissions through the burning of fossil fuels, land clearance and the production and consumption of goods and services (Wright et al., 2011). In this paper, the carbon accounting through product and process analysis is paramount. Through their analysis, valuable information about a geographical area concerning its energy consumption and related environmental consequences can be provided. In this regard, the work of Ramaswami and colleagues (Ramaswami et al., 2017; Ramaswami et al., 2011) serves as inspirational source for urban footprint accounting thanks to comprehensive standardization and traceability of results.

2.3.2 Resources interrelations

Learning from these footprint study approaches, numerous interrelations embedded between resources are conceivable. But these interrelations are only traceable when considering not only direct but also indirect resource consumption. How such interrelations appear can be explained most simply by means of a practical example. Provided one has a connected faucet, one can tap water directly through it. However, by turning on the faucet, one also (indirectly) consumes energy for water distribution and/or water heating. Finally, by the outflow of the water indirect processes are set in motion, which spend energy for the wastewater treatment (Chini et al., 2016). Chini and Stillwell, 2020 define these phenomena in a more abstract way, as different types of resource consumption. Following them, resources systems can be understood to consist of (i) direct (physical) resources, (ii) direct resources externalities, and (iii) indirect resources embedded in other material fluxes. Due to the ambiguity of the word "externality" caused by the slightly different context in economic theory, the term is not used in the subsequent work (Arrow, 1969; Laffont, 2008). Instead, the expression "indirect resource effects" is operationalized. In the case of water, indirect resource effects may be factors like energy consumption for water pumping, filtration, etc. and other material fluxes can be virtual water. Considering a carbon footprint, indirect resources and other material fluxes are adopted that contribute to the carbon consumption. One of such resources is often water (Koteswara Rao and Chandrasekharam, 2019; Lombardi et al., 2017). For the following, indirect resources embedded in other material fluxes are neglected as they do not play a role for the intention of this work. The fact that energy appears to be an indirect resource effect involved in water resource consumption and the other way around, as proven by previous research (see among others DeNooyer et al., 2016; Macknick et al., 2012; Sanders, 2015), is however the starting point for the nexus footprint methodology.

For the nexus footprint methodology, these indirect resource effects across resources consumption are highlighted and build integral part of the study. The urban nexus footprint orientates on goods that are originally discussed in many footprint studies. Yet, in the nexus study, the focus lies rather in finding relevant water-energy interactions within integral consumption goods in opposite to conventional footprints accumulating the total amount of water or energy consumed. Using a single footprint account principle does not obtain the ability to reveal nexus tensions (Chang et al., 2016). In turn, a nexus footprint approach may demonstrate resource overuse or mismanagement, that is resulted by indirect resource effects. The reasons for the overuse might not be detected without analyzing the second resource that shapes the indirect resource effects on another one. Therefore, a nexus footprint, that at least in theory captures these interrelations, is subsequently developed. Especially for governance and sustainability issues the reveal of such interactions can be relevant. This is due to the fact that accounting also for indirect material uses makes policy-makers able to understand the potential damage generated indirectly by resource consumption and the embeddedness of FEW resources in complex systems (Ascione et al., 2008).

2.3.3 Conceptualizing the nexus footprint

There are two principal ways in which footprints can be designed (Hoekstra et al., 2011; Kounina et al., 2013; Lombardi et al., 2017; Loubet et al., 2014; Paterson et al., 2015). On the one hand, top-down approaches exist that concentrate on sectoral level, environmentally extended input– output, approaches. These analyses identify the hot spot sectors as

key resources users and resource dependency among sectors. On the other hand, bottom-up approaches using life cycle assessment (LCA) on the product level (bottom-up) are applicable. Both approaches yield interesting insights (Lombardi et al., 2017; Paterson et al., 2015). The top-down approach is advantageous when considering a macro-scale. If however, one is interested in nexus interaction on the meso- or micro-scale, e.g. within a city or a household, top-down approaches have clear limitations. Additionally, a top-down approach practically often draws from national or trans local data. Thus, the scope of a municipality can be hardly captured empirically. Given the focus of this thesis is on two urban case studies, a bottom-up nexus footprint concept is developed below.

To assess a bottom-up nexus footprint a variety of consumer goods and services are to be considered to illustrate the indirect resource effects resulting a nexus issue. The anchor point of the nexus footprint analysis is the concept of the three key FEW resources. The FEW resources appear either directly or indirectly in earlier water and carbon footprint studies. The following figure systemizes these interrelations across FEW resources captured by previous footprints. From there, a nexus footprint concept is derived shifting the focus of previous footprint studies to indirect resource effects.

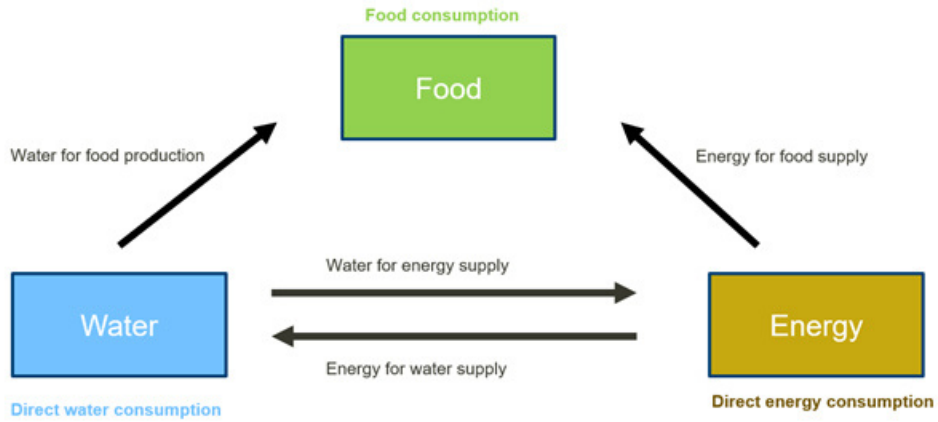


FIGURE 2.2: Nexus triangle - Dimensions of FEW nexus covered by footprint studies.

The illustrated three key resources offer basic indicators that serve as products to conduct a bottom-up footprint assessment. Subsequently, these indicators are elaborated to consider a bottom-up, household consumption focused footprint approach. Here, the aim of the analyses is not only to determine the product consumption, but one step further, the interactions among them expressed in the involvement of at least two FEW resources.

- **Water**

  One of the key consumption goods in urban households is water. The direct water consumption depends on ground and external surface water. To assess the direct water consumption, one may adopt a simple average method over the total urban population (Koteswara Rao and Chandrasekharam, 2019). When considering indirect resource effects of water consumption, the way how water is made accessible requires additional attention. Hussien et al., 2018 prove a consistent water-energy nexus in the domestic water supply. Therefore, water pumping are to be enclosed in a nexus footprint analysis. In the case of water pumping, two possibilities of resources interaction occur. Water pumping to the general urban water supply stations and for the municipal water distribution is evident in many regions in the world (such as in DeBenedictis et al., 2013). Additionally, depending on the local water infrastructure, private water pumping can occur as well. In this case, valid data is required and should be compared to pertinent literature like Gleick, 1994. Finally, indirect water consumption through food is key in a household footprint. For this regard, see food section further below.

• **Energy** and related products
With respect to energy consumption in households, the most important category is residential electricity consumption (Lombardi et al., 2017). Furthermore, carbon emissions may be caused by energy products as illustrated further below. In energy provision there is frequently an indirect water consumption embedded. A high percentage of hydropower in the energy mix increases the overall urban water footprint per household slightly (Gleick, 1994; Mekonnen and Hoekstra, 2012a; Scherer and Pfister, 2016). From the environmental perspective, this figure is ambiguous because it raises the footprint but is simultaneously beneficial in contrast to carbon-intensive power generation forms (Gleick, 1994; Stillwell et al., 2011). Therefore, this figure needs an own evaluation in the light of specific urban circumstances in regard to local water resources. Additionally, the water percentage of other power contributors in the regional energy mix is required (first indicators can be found in Gleick, 1994 and Koteswara Rao and Chandrasekharam, 2019). They give an overview of the water consumption attributed to the energy mix in a city and may have a major impact on the urban water footprint. In the field of energy consumption, energy products and their indirect resources effects must be determined simultaneously. Water is consumed indirectly in the processes aimed at making energy products available. Commonly used energy commodity products in households are kerosene, diesel, liquid petroleum gas (LPG) and petrol, mostly used for cooking and heating. All contain crucial significance for the water- energy nexus. Consumption data per household on these goods is required as first indicator. Obviously, these figures give insights in the general household energy consumption situation. For further information, the data of the IPCC (Intergovernmental Panel on Climate Change) on greenhouse gas inventories and energy associated can be utilized (IPCC, 2006a; IPCC, 2019). To assess the water need for these energy products, Gleick, 1994 is to be used.

• **Food**
Food holds indirect significance for the nexus as it combines great amount of water and carbon in its production (Yue and Guo, 2021). Even though there is no general scientific research direction on such things as own footprints on foods, food builds an integral component of both water and carbon footprints. Therefore, research achieved major data on water and carbon consumption of food. For the general approach of a nexus footprint, it is crucial to determine the average diet of the local circumstances that are reviewed. However, if no particular local diet is identifiable, the national diet is to be adopted and adjusted. Hence, the most popular food products together of approximately 2000 kcal (according to the average caloric requirement following WHO, 2020) are to be charged in water and carbon units. Mekonnen and Hoekstra, 2012b as well as Mekonnen and Hoekstra, 2011 attain valuable data on the average water consumption of various food goods which can be utilized. Leach, 1976 offers an overview of the energy inputs needed for different kinds of food. In summary, household footprints can be increased or reduced tremendously if diet is changed (de Boer et al., 2016; Hoekstra, 2012).

• **Other possible variables**
To extent the subject of an urban nexus footprint study, further consumption factors can be included. Another crucial material allocated to urban households is for example waste. Emission factors of solid waste and waste water are to be derived from IPCC, 2006b and IPCC, 2019 and be offset with the household "consumption" of waste. At the same time, it has to be considered that the waste does not only emit emissions and consume energy, but it also produces energy in some urban settings (Eriksson et al., 2005; Soltani et al., 2016). Therefore, this must be included in the urban energy balance. Moreover, waste, particularly in form of wastewater, consumes a great amount of energy due to waste water treatment (Chavez et al., 2012; Gao et al., 2014; Gleick, 1994).
Additionally from interest are factors like in-urban and transboundary transportation.

In the case of mobility, generally valid water consumption data have not been determined so far but the carbon footprint set in context to a specific urban case however might give conclusion on an urban nexus directly (Chavez et al., 2012; IPCC, 2006a and IPCC, 2019). Other parameters might be the industrial and commercial use of energy. For the inclusion of cement use, Barcelo et al., 2014 and Gerbens-Leenes et al., 2018 inform about the relating water and carbon consumption data. In the case of industry and commercial sector, the before stated goods are to be elaborated once more. Yet, in various urban cases, the municipal data do not include the industry sector as they are mostly provided by own energy but also partly water sources. This makes data acquisition structurally different from the ones purely based on households. All considered parameters are demonstrated in the following figure.

FEW resources	Direct household consumption	Water metric in Nexus Footprint	Carbon metric in Nexus Footprint	Reference
Water	Household network water consumption	Average piped water consumption in m^3	Carbon emissions per m^3 associated with municipal water pumping	(DeBenedictis et al., 2013; Gleick, 1994)
	Household consumption of water from other sources	Average non-piped water consumption in m^3	Carbon emissions per m^3 associated with private water pumping	(Hussien et al., 2018)
	Household wastewater discharges	Average domestic wastewater discharges in m^3	Carbon emissions per m^3 associated with municipal wastewater treatment	(Chavez et al., 2012; Gao et al., 2014; Gleick, 1994)
Energy	Household electricity consumption	Average water use for generation per kWh	Average carbon emissions per kWh	(Gleick, 1994; Mekonnen & Hoekstra, 2012b; Scherer & Pfister, 2016)
	Household consumption of energy products (kerosene, diesel, liquid petroleum gas (LPG), fuels for mobility)	Average water use for production per kWh	Average carbon emissions per kWh	(Chavez et al., 2012; Intergovernmental Panel on Climate Change (IPCC), 2006, 2019)
Food	Household average diet	Average water use for production of different food items (orientated on local diet, in total 2000 kcal)	Average carbon emissions associated with production of different food items (orientated on local diet, in total 2000 kcal)	(Leach, 1976; Mekonnen & Hoekstra, 2011, 2012a)

FIGURE 2.3: Nexus Footprint Methodology - an overview.

2.3.4 Methodological concerns on nexus footprinting

In sum, a sharper concept to approach nexus issues results. From this footprint contrast, it is derived that the two footprint concepts of water and carbon for a specific geographic area, like a city, are majorly intertwined, which in turn can be used to capture nexus challenges. Still, it is crucial to highlight several methodological concerns. The methodology demands municipal data, the more the more meaningful. The accuracy of results relates to the quality and quantity of data available (Koteswara Rao and Chandrasekharam, 2019). To examine a nexus footprint of any urban city, commodity data is significant. This data gives some information about the extent of resources consumption in the city. However, at the city level, thus a small spatial scale, it is not easily possible to obtain these data. City consumption data contains many gaps, wherefore it is necessary to pay attention to the accuracy of data. In this

draft, monthly per household consumption expenditure is considered. Generally, it is central to harmonize data sources for both water and carbon metrics. There is overlap in some indicators which is the reason why it is so important to use the same baseline values to be later able to detect interesting nexus correlations. Without harmonization, these correlations might not be visible or appear arbitrarily. Also, for a bottom-up approach, focusing on the household level is recommended. A broad range of footprint studies source their regarded values from national statistical data resulting an urban picture that is not able to characterize peculiarities of the regarded place. Only urban and related regional data can deliver valuable outcomes that breaks down specific urban complexities. In this regard, the focus on direct consumption patterns is additionally central. Eventually, the coupled footprint model turns out to be a promising tool to understand urban water-energy nexuses from a purely material perspective.
In the course of the further piece of work, the nexus footprint concept is utilized. Even though it is demonstrated that the nexus footprint concept is applicable to reveal most dimensions of the FEW nexus, a particular focus is to be placed on urban water-energy nexus cases. The subsequent case studies strive to emphasize the systemic complexity of a specific water-energy resource issue operationalizing nexus footprints for the urban places Amman and Pune. Since the concept of nexus footprints can show indirect impacts of resources, it is considered appropriate for drawing conclusions about related governance areas. How this is achieved in detail is discussed after the application of nexus footprints in the specific case studies. For this concern, policy integration theory appears as integral wherefore it is introduced in the next section. Accordingly, the application of nexus footprints, such as other footprints, is assumed to advise policy structures around related resources (Galli et al., 2012; Hoekstra et al., 2011; Hoekstra et al., 2019; Karandish and Hoekstra, 2017; Turner, 2014).

2.4 Policy integration to assess urban nexus governance

As the SES concept approach on complex issues indicates, a concrete nexus case analysis requires an institutional analysis to complement the material perspective on the nexus. Among past nexus governance analyses, the theoretical movement of policy integration has been shaped significantly the comprehension of nexus in governance (Märker et al., 2018; Weitz et al., 2017a). This work equally draws on the concept of policy integration since it provides most suitable operationalization of nexus governance. Policy integration evolves around cross-cutting issues as subjects of governance. Cross-cutting issues regarding resources can be equally understood as nexus issues since nexus as term reflects the intersection of domains (Urbinatti et al., 2020). Policy integration is a key concept to approach environmental issues, particularly there, where interrelations across domains are proven, such as in the case of FEW resources (Visseren-Hamakers, 2015). Thus, policy integration can be understood as the theoretical complementary part of resources nexus issues as the approach aims to strengthen the coherence of policies across different sectors and policies regarding a common subject (Visseren-Hamakers, 2015).

The prominence of policy integration developed from the recognition of complex problems like globalization and resource depletion requiring special and holistic approaches. The concept was firstly introduced by (Underdal, 1980). He defines "integrated policy" as one in which "constituent elements are brought together and made subject to a single, unifying conception" (Underdal, 1980, p.159). After his publication, the term was centrally used in various trends of sustainable development science. There, it is mostly referred to as environmental policy integration (Jordan and Lenschow, 2010; Lafferty and Hovden, 2003; Runhaar et al., 2014) and, more recently, as climate policy integration (Adelle and Russel, 2013; Dupont and Oberthür, 2012; Nilsson and Nilsson, 2005; Runhaar et al., 2018). In all these approaches the general principle of policy integration can be summarized as incorporation and prioritization of environmental matters in non-environmental policy domains with the purpose of enhancing environmental policy outcomes (Candel and Biesbroek, 2016). Therefore, policy integration is effective in addressing nexus problems (Briassoulis, 2004), since it may reduce inefficiencies in public policy making and it supports political function (Peters, 2015; Peters, 2018). This is particularly the case when working towards overarching goals

(Adelle et al., 2015). Such overarching goals might be the integrated, cross-departmental governance of a nexus issues.

For analyzing policy integration one can draw from a pool of conceptual pieces. Some authors outlined frameworks addressing policy integration and related concepts, which also includes the question of how policy integration affects policy making (May et al., 2006; Runhaar et al., 2014). Others focused more concretely on how political parties can help achieve policy integration (Bolleyer, 2011). Candel and Biesbroek, 2016 pushed forward a progressive framework offering an assessment tool to evaluate current degrees of policy integration in governance concerning a specific cross-cutting issue. In this thesis, that framework is adopted as key analysis tool for the institutional perspective on the nexus case studies. The framework is chosen as it synthesizes fragmented aspects of policy integration into a single coherent structure. In opposite to other policy integration approaches, it highlights a shift towards a more process-based view on policy integration (Adelle and Russel, 2013). The process-oriented approach implies research that goes beyond examining whether environmental policy has been implemented. The framework is able to display the dynamics and reasons for (dis)integration while taking the core question into account how policy integration performs in the face of a specific nexus issue. Therefore, the concept enhances a comprehensive understanding of nexus governance.

2.4.1 Policy frame

To put it concretely, the policy integration framework by Candel and Biesbroek, 2016 offers a multilevel structure. For the following work, three of four dimensions of policy integration are distinguished which indicate different degrees of policy integration. One of them is the policy frame. It is defined following Peters, 2005 as the perception of a particular cross-cutting issue within a given governance system. More details can be derived from the following figure.

	Low amounts of policy integration ←			→ High amounts of policy integration
Policy frame	The problem is defined in narrow terms within the governance system; the cross-cutting nature of the problem is not recognized and the problem is considered to fall within the boundaries of a specific subsystem. Efforts of other subsystems are not understood to be part of the governance of the problem. There is no push for integration	There is awareness that the policy outputs of different subsystems shape policy outcomes as well as an emerging notion of externalities and do-no-harm. The problem is still predominantly perceived of as falling within the boundaries of a particular subsystem. There is no strong push for integration	As a result of increasing awareness of the cross-cutting nature of the problem, an understanding that the governance of the problem should not be restricted to a single domain has emerged as well as associated notions of coordination and coherence	General recognition that the problem is and should not solely be governed by subsystems, but by the governance system as a whole. Subsystems are desired to work according to a shared, 'holistic' approach, which is particularly recognized within procedural instruments that span subsystems

FIGURE 2.4: Policy frame - extracted from Candel and Biesbroek, 2016, p.219.

2.4.2 Subsystem involvement

Subsystem involvement is another core dimension that sheds light on the actors and institutions formally or informally involved in the nexus issue. Hereby it is important to note, that subsystems do not necessarily be determined exactly (Koppenjan et al., 2004). It is more important to identify relatively stable groups of actors and institutions that do not need to represent entire subsystems (Jochim and May, 2010). The dimension itself is conceptualized along two indicators by the authors. On the one side, it is important to recognize which subsystems are involved in the governance of a nexus issue. On the other side, the dimension aims to reveal the density of interaction between involved actors. Since the density of interactions is actually a whole additional scientific field related to network research (Sabatier and Jenkins-Smith, 1993; Zafonte and Sabatier, 1998), this work leaves this aspect regarding density of interactions aside without compromising the quality of the analysis.

Low amounts of policy integration ←			→ High amounts of policy integration	
Subsystems involved	One dominant subsystem, which governs the issue independently Formally, no other subsystems are involved, although they may be in terms of substantial, non-intentional policymaking	Subsystems recognize the failure of the dominant subsystem to manage the problem and externalities which results in the emergence of concerns about the problem in one or more additional subsystems	Awareness of the problem's cross-cutting nature spreads across subsystems, as a result of which two or more subsystems have formal responsibility for dealing with the problem	All possibly relevant subsystems have developed ideas about their role in the governance of the problem. The number of subsystems that are formally involved is equal to or higher than at previous manifestations, but complemented with a less engaged set of alternative subsystems

FIGURE 2.5: Subsystem involvement - extracted from Candel and Biesbroek, 2016, p.221.

2.4.3 Policy goals

The framework also concentrates on policy goals. Here, a goal is either understood as a specific concern within the policies or strategies of a governance system, including its subsystems. There, policies can entail concrete programs or only abstract plans (Ramesh, 2003). There exist fundamental differences in the way in which various policy goals are formulated, also in terms of temporality or geographical scale (Adelle et al., 2009). Therefore, the coherence among those policies is evaluated.

Low amounts of policy integration ⟷			High amounts of policy integration	
Range of policies in which problem is embedded	Concerns only embedded within the goals of a dominant subsystem	Concerns adopted in policy goals of one or more additional subsystems	Possible further diversification across policy goals of additional subsystems	Concerns embedded within all potentially relevant policy goals
Policy coherence	Very low or no coherence. Occurs when cross-cutting nature is not recognized, or when subsystems are highly autonomous in setting (sectoral) goals	Because of rising awareness of externalities and mutual concerns subsystems may address these to some extent in their goals	Coordinated sectoral goals, which are judged in the light of coherence Subsystems attempt to develop synergies	Shared policy goals embedded within an overarching strategy

FIGURE 2.6: Policy goals - extracted from Candel and Biesbroek, 2016, p.222.

Lastly, policy instruments are described by the framework. This aspect of the framework is particularly from interest if one nexus issue in a determined setting with a foreseeable number of involved actors is examined. As the following two case studies encompass an uncertain amount and a variety of actors attached to an urban issue, this dimension is neglected. However, it is noted that an additional study on the issue might be promising. For the moment, it is expected that reflecting on policy frame, subsystem involvement and policy goals is sufficient to draw conclusions on the general status of nexus governance regarding specific resource interfaces. How the elaborated framework is operationalized and applied to sub research questions, is stated in the subsequent methods part.

But before doing so, several points on the construct of policy integration must be highlighted. Most policy integration literature focuses on horizontal integration across domains only (Tosun and Lang, 2017). However, in the urban case, administrative and political domains are often majorly involved in vertical structures, for example in regional and national ones. Therefore the recognition of a multi-level governance context is crucial (Briassoulis, 2011). This work follows the proposition of Candel and Biesbroek, 2016 to expand the framework by the notion of "functional regulatory spaces", which comprise several policy sectors, governance levels, and institutional territories across various levels (Varone et al., 2013). Overall, the thesis approach acknowledges a government-centered approach to coherently conclude on nexus governance in the institutional perspective (Tosun and Lang, 2017).

Chapter 3

Methodology

The conceptual framework of the thesis is deducted from nexus literature and its gaps. However, the framework aims to be applied on specific cases to draw inductively conclusions on their resource governance and mixed-methods contributions on nexus issues in general. This results in a unique characteristic of study design. In the following, the methodology is presented in detail.

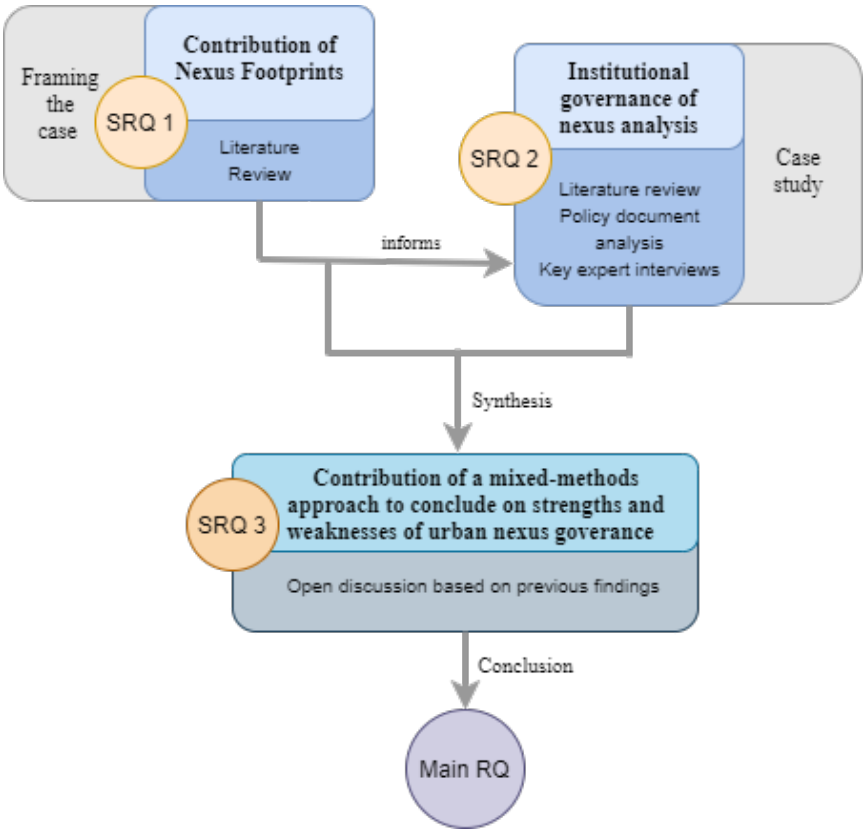


FIGURE 3.1: Research framework.

3.1 Case studies

In order to meet the explorative character of the thesis, the further work is based on two case studies (Hartley, 1994, Leonard-Barton, 1990; Meyer, 2001). This poses the advantage to detect interrelated aspects in a holistic perspective through an inductive approach (Meyer, 2001). Two cases studies have been selected to conduct the research on. These case studies have been focal point of the Helmholtz Centre for Environmental Research – UFZ's FUSE team (FUSE, 2021; UFZ, 2021), with whose cooperation this thesis evolved. The objective

of the project is to develop feasible solutions to challenges in providing FEW resources to urban centers. The pre-selected cities Amman (Jordan, semi-arid climate) and Pune (India, tropical climate) were the motivation to form part of the research team as the project study sites exemplify different urban nexus challenges.

The environmental challenges in Amman stem directly from its fast-growing dynamics. Located in the central and water-poor region of Jordan, it forms a transit hub between the north and south of the country. At the same time, Amman has become one of the most important locations in this world region for immigrants and refugees during the last decades. Palestinians and Syrians that had lost their homes permanently came to stay and built a new existence in Amman (Içduygu and Nimer, 2020). In its Jordan Response Plan for the Syria Crisis the Jordanian Ministry of Planning and International Cooperation reports of 1.3 million Syrian migrants between 2011 and 2018, of which many are not officially registered (MPIC, 2020). This makes Jordan the country with to the second largest uptake of migrants relative to its population and puts obvious pressure on the development of Amman (Içduygu and Nimer, 2020).

Pune's challenges in the field of water and energy are closely related to its status of an emerging mega city with high growth in terms of population, spatial extension, and economy. The urban area has a combined population of 5.05 million inhabitants while the population of the metropolitan region is estimated at 7.4 million the urban area (PMRDA, 2018). Between 1973 and 2013, Pune's built- up area increased by the factor 7.5 to then ca. 140 km² and more than 200 km² are expected to be built-up by 2030 (Butsch et al., 2017). Today, around half of the city's population growth trend can be attributed to (domestic) migration, while ca. 20% of Pune's residents are migrants (Butsch et al., 2017). A significant share (30-40%) of urban population lives in slums (Nolan, 2015; PMC, 2020). Metering of energy and water in informal housing is thus partly absent. Pune is part of an urban-industrial corridor connecting to Thane and Mumbai and is planned to be integrated further into the Delhi-Mumbai Industrial Corridor (DMIC), bringing further infrastructural upgrades and industrial zones with it. Pune's total carbon dioxide (CO_2) emissions are rising continuously. Between 2011 and 2017, the yearly emissions grew by 29% to 6 million tons (Jadhav, 2018). Pune's contribution can largely be explained by the energy requirements of water and sewage treatment and street lighting (Jadhav, 2018).

It was of interest that both case studies are situated in the global south as these are commonly neglected but from major interest for nexus research (as explained in chapter 1). But also methodologically, the FUSE project appeared attractive for research as the team follows a transdisciplinary concept embedded in a systems approach to map connections and interactions between consumers, producers, resources, and distribution mechanisms and has prior experience in field studies in the designated cities. The team's prior experience made it possible to conduct sound case studies on a remote basis despite the Covid19 pandemic. For example, as explained below, several data sources of the team have been utilized for this study. The unit of analysis are Amman, within the borders of Greater Amman Municipality (GAM) (Government, 2021b), and Pune, within the borders of Pune Municipal Corporation (PMC) (PMC, 2021a). Both case boundaries have been determined representing the municipal entity as the urban governance of the specific cities are integral part of analysis.

3.2 Operationalization of theory and research questions

In opposite to other qualitative designs, the case study is orientated on guiding theory aligned with the topic of interest (Hartley, 1994; Thomas, 2021). The following section outlines the sub research questions. These contribute to the overarching research aim while each question is linked to the specific part of the prior presented theory framework. The theoretical grounding supports the researcher to have a view for the substantial aspects of the cases and their related questions (Hartley, 1994; Meyer, 2001).

Main research question:

What are the strength and weaknesses of the nexus governance in Amman and Pune and how can a mixed-methods approach contribute to it?

Sub research questions:

1. ***How can a nexus footprint contribute to an advanced understanding of a water-energy nexus issue?***

   In chapter 4, a crucial material water-energy nexus interrelation is determined in the first place by literature review and unpublished internal FUSE project documents for both cities. The empirical figures discussed are actually excerpts of a fully comprehensive nexus footprint as presented in the theory chapter. Because such a comprehensive assessment for two case studies is beyond the scope of this thesis, the nexus challenges were mainly identified through the FUSE Discussion Paper (Athauda, 2021; C). In the paper, a FUSE colleague firstly applies the, in this thesis introduced, nexus footprint approach. The application of the nexus footprint is based on literature research and affiliated data (among others, Zozmann et al., 2019, Seo et al., 2016, Sigel et al., 2017a and Sigel et al., 2017b) and, in the Pune case, an exploratory analysis of survey data (FUSE, 2020). The survey was conducted in various neighborhoods of Pune to assure a broad depiction of the water situation in the city.
   In Amman, the thesis considers the energy consumption for public water provision of urban households. The subject of interest of this urban case consists of household network water consumption, which comprises on the water-side of average piped water consumption per household per year in m^3. On the energy-side carbon emissions per water m^3 are associated with municipal water pumping. Additionally, water sourced from tanker trucks are considered. Hence, water consumption in m^3 delivered by tanker trucks is taken into account to associate relevant carbon emissions per m^3. Concerning Pune, private energy use for water provision on a household basis is reflected in the form of water pumping. Thence, the emissions through energy demand associated with average piped water consumption per household per year in m^3 is reviewed. Both approaches are demonstrated in detail in the FUSE Discussion Paper (Athauda, 2021), on which results this thesis relies on and is attached in the appendix. From the application of nexus footprint, a conclusion is expected as to what extent the use of nexus footprints is advantageous to grasp nexus challenges, in this case interrelations of water and energy.

2. ***How are nexus issues governed institutionally in the cases of Amman and Pune?***

   Regarding this question, the policy integration approach may complement the material nexus analysis as it is able to assess how the nexus is reflected on the institutional side. To determine which institutions are relevant for the nexus resources discussed above, the specific institutions in the case studies dealing with these resources' domains are identified while acknowledging various political levels. Then, policies of the nexus relevant institutions are reviewed and estimated in their role for policy integration. Hereby, the assumption is made that material nexus interrelations are in need for policy integration to sufficiently tackle nexus challenges in governance (Al-Masri et al., 2019; Bauer et al., 2014; Runhaar et al., 2018; Scott et al., 2011; Venghaus et al., 2019). In order to make the analysis, especially the assessment of the degree of policy integration, more comprehensible, the rating is expressed in a four-level system at the end of the concerning section (see chapter 5). 1 represents low degree of policy integration, 4 means high degree of policy integration. The rating system is based on the closeness to the levels described in the respective categories in Candel and Biesbroek, 2016.

   The subsystem involvement aspect of the framework by Candel and Biesbroek, 2016 helps to categorize and characterize the crucial institutions on this point. The associated institutions are listed and described towards their role in resource governance

and simultaneously related to the nexus topic. Based on this analysis, the rough governance structure around the nexus is determined. Accordingly, it is discussed which subsystems dominate the nexus or enhance policy integration towards the nexus. Thereby, the number of institutions dealing with this particular cross-cutting issue may also be seen as a first indication on policy integration (cf. Candel and Biesbroek, 2016). The thesis specifies subsystems as single institutions or closely related institutions due to thematic or structural proximity.

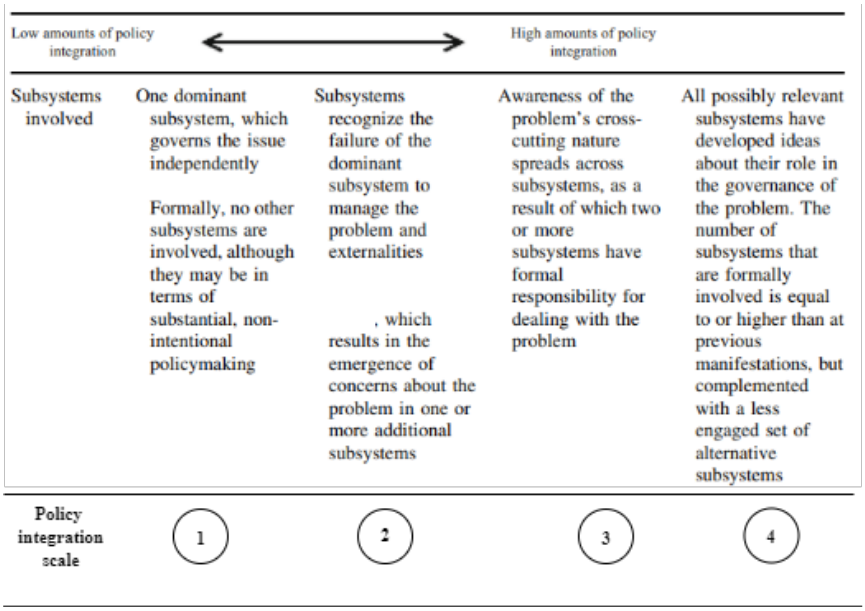


FIGURE 3.2: Scale of Subsystem Involvement.

Next, the policy frame is estimated. This step bases on the previous steps as it assesses the perception of the nexus topic within given subsystems. Here, the range reaches from a problem definition, where the resource challenge is considered to fall within the boundaries of a specific subsystem to general recognition that the challenge affects the urban system as a whole and requires a holistic approach (Candel, 2019).

Low amounts of policy integration ⟷				High amounts of policy integration
Policy frame	The problem is defined in narrow terms within the governance system; the cross-cutting nature of the problem is not recognized and the problem is considered to fall within the boundaries of a specific subsystem. Efforts of other subsystems are not understood to be part of the governance of the problem. There is no push for integration	There is awareness that the policy outputs of different subsystems shape policy outcomes as well as an emerging notion of externalities and do-no-harm. The problem is still predominantly perceived of as falling within the boundaries of a particular subsystem. There is no strong push for integration	As a result of increasing awareness of the cross-cutting nature of the problem, an understanding that the governance of the problem should not be restricted to a single domain has emerged as well as associated notions of coordination and coherence	General recognition that the problem is and should not solely be governed by subsystems, but by the governance system as a whole. Subsystems are desired to work according to a shared, 'holistic' approach, which is particularly recognized within procedural instruments that span subsystems
Policy integration scale	1	2	3	4

FIGURE 3.3: Scale of policy frame.

Eventually, policy goals are taken into account (Candel and Biesbroek, 2016). These reflect the range of policies in which the problem is embedded. Additionally, it gives an opportunity to assess coherence and discrepancies among multiple policy goals.

Low amounts of policy integration ⟷				High amounts of policy integration
Range of policies in which problem is embedded	Concerns only embedded within the goals of a dominant subsystem	Concerns adopted in policy goals of one or more additional subsystems	Possible further diversification across policy goals of additional subsystems	Concerns embedded within all potentially relevant policy goals
Policy coherence	Very low or no coherence. Occurs when cross-cutting nature is not recognized, or when subsystems are highly autonomous in setting (sectoral) goals	Because of rising awareness of externalities and mutual concerns subsystems may address these to some extent in their goals	Coordinated sectoral goals, which are judged in the light of coherence Subsystems attempt to develop synergies	Shared policy goals embedded within an overarching strategy
Policy integration scale	1	2	3	4

FIGURE 3.4: Scale of policy goals.

In sum, a comprehensive picture of which and how institutions including policies govern the case-specific water-energy interrelations arises.

3. ***How can a mixed-methods approach contribute to determining strengths and weaknesses of urban nexus governance?***

   The last sub research question is discussed rather openly in chapter 6. However, the integral contribution of this chapter is the assessment of strength and weaknesses of the nexus governance in the two case studies by comparison to what extent the nexus is reflected in the respected governance systems. For this purpose, the results of the institutional analysis are contrasted with those of the material analysis since it appears as crucial to what extent governance covers resource interrelation by policy integration across institutions (Al-Masri et al., 2019). Matching components of the institutional system with the material nexus are considered as strengths, weaknesses of the institutional system are elements that do not cover the nexus issue or even hinder policy integration reflecting the nexus issue in the two specific cases. Conclusively, an attempt is made to describe generalizable points that indicate how a mixed-methods approach can portray the quality of urban nexus governance.

3.3 Data collection

3.3.1 Literature review

For sub question one, a simple literature review was conducted. The integral source of this chapter is the FUSE Discussion Paper (Athauda, 2021). The paper provides tangible nexus footprint figures for the cases Amman and Pune on which basis it can be argued on the appearance of nexus challenges in the respective cities and the contribution of a footprints. To put the gained insights into context, further literature was considered. These pieces were selected based on database searches on Scopus, Web of Science, Google Scholar and occasionally Google for keywords "nexus", "water-energy nexus", "water consumption", "energy consumption", "resources challenges" and "water supply" paired with the concerned city's name. These key words are derived from the general subject of research of this thesis and the recognition of the two nexus challenges through the FUSE Discussion Paper (Athauda, 2021). To collect and analyze data for research question two, a rather complex procedure was applied. Apart from literature concerning the two cities which was acquired in the previous step, semi-structured interviews and policy documents build the basis of data collection for this part of the thesis.

3.3.2 Semi-structured interviews

Semi-structured interviews as a method of data attainment were selected since they provide an explorative research approach with in-depth information on the topic (Adams, 2015). Semi-structured interviews were chosen as tool *to confirm* (the identified urban water-energy nexus), *to identify* (institutions and policies associated to the nexus issue) and *to comprehend* (the cause of the phenomena and institutional action towards the nexus). The around 30 minutes interviews allowed the researcher to gather in-depth, detailed accounts of institutional discrepancy and interlinkages towards the specific nexus issue through dialogue with on-site key experts.

An exemplary interview guide is attached in the appendix (A) that was developed like the general interview preparation process in accordance to Adams, 2015 and Longhurst, 2003. The questions consist of standardized, mostly open-ended questions. These facilitate both presenting views on the nexus issue as well as stating opinions and concerns towards the governance system. Also, the questions determine the matter of discussion but simultaneously leave space for researcher and interview partners to discuss matters in more detail. Occasionally, the questions were slightly adjusted, depending on the professional background of the interviewee and previous gathered findings.

All interviews were conducted in English which, however, was no issue to the interview partner selection process since the selection referred to a range of high-positioned experts. The interviews were conducted via the video calling platform Zoom while audio was recorded by mobile device with the consent of the concerning interviewee. Conducting this

part of the research on a remote basis appeared challenging, yet the audio files worked as an aid to remedy content-related unclarities during interviews. Afterwards, the interviews were transcribed. All interview partners agreed that the information shared may be processed anonymously in this thesis.

The selection of key experts for interviews was based on the outcome of the nexus footprints that indicates crucial water-energy interrelations for both cases. For the Amman case, experts that are related to the Jordan water, energy or both sectors were searched. Also, they should have experience in Amman resource provision. Since Jordan is ruled by dictatorship and the researcher received informal insights by fellow scholars on the bias of government employees, it was decided to focus majorly on scholars and policy advisors in Amman. In Pune, the nexus challenge arises directly through the poor water provisioning system of the city, wherefore the selection of interviewees emphasized water-related actors or actors that are experienced in the field of integrated resource management. Initially, more interview partners from the PMC were planned, for example from the water department. This turned out to be difficult as no one except the environmental officer made himself available. However, this was not detrimental in the end, as it turned out that the PMC does not address the nexus issue yet anyway. In opposite to Amman, all interviewees in Pune are excludingly related to the urban governance level since the city has more independence in the political system here. Priority was given to experts that lived or live in Amman or Pune. In this way, it was assured that the interviewees obtained professional but also practical relation to the matter of research.

The interview partners were mostly determined via the "snowball" technique starting with contacts obtained by the FUSE team and Copernicus Institute of the Utrecht University. Furthermore, employees of decent institutions on site and scholars related to the issue were approached through the online professionals platform LinkedIn. The overall response rate was moderate despite letters of recommendation from colleagues. In some cases, the interview partners did not appear to the interview despite having made an appointment. Therefore, the process of finding interview partners on a remote basis can be described as onerous overall. Yet, ten interviews were successfully conducted, in the period from June 1 to August 1, 2021, and provided comprehensive insights for the cases. Below, an overview of interviewees and their abbreviation for the further thesis is given.

TABLE 3.1: List of interview partners and their abbreviations.

City	Position	Abbreviation
Amman	Researcher, FEW nexus expert and political consultant for Jordan	IA1
Amman	Senior Policy Advisor on Water at the Embassy of the Kingdom of the Netherlands in Jordan	IA2
Amman	Professor at the Civil Engineering Department of Jordan University of Science and Technology	IA3
Amman	Head of Environment, Climate Change & Disaster Risk Reduction Programme UN Jordan	IA4
Amman	Director of Renewable Energy & Energy Efficiency Department at MEMR	IA5
Pune	Environmental commissioner Pune Municipal Corporation (PMC)	IP1
Pune	chief resilience officer for Pune	IP2
Pune	Environmental researcher Gokhale Institute of Politics and Economics in Pune	IP3
Pune	Executive director at ACWADAM Pune	IP4
Pune	Water activist and political consultant for Pune	IP5

3.3.3 Policy documents

Policy documents were chosen to enrich the selection of data sources for the thesis. The documents were determined by in-page search on the respective web sites of the crucial institutions which were identified by literature review and interviews. Also, the semi-structured interviews offered the opportunity to ask for specific policies related to the case. Moreover, the key experts were requested to state their perspective on the documents.

3.4 Data analysis

The data analysis of interviews and policy documents is based on the concept-driven coding accordingly to Gibbs, 2007. Due to the exploratory nature of the research, it is essential to

create space for relevant dynamics unfolding from the data. Hence, this research allows inductive reasoning on the matter of policy integration in the urban cases and mixed-methods analysis of nexus in the end of the work. The transcripts and documents were analyzed by utilizing characteristics of the revealed nexus issues as codes to identify to what extent the regarded policies issue the nexus topic. Additonally, further theoretically-informed codes, derived from policy integration theory (Candel and Biesbroek, 2016), were applied to capture arising patterns of governance towards the nexus. The codes are attached in the codebook (B). The analysis of codes was conducted in the data analysis software MaxQDA, due to its ease of use, consistency, and analytical transparency. The procedure facilitated a iterative and multi-perspective consideration of collected data (Yin, 2009).

3.5 Discussion of methodology

Critics argue especially qualitative research lacks of "trustworthiness" due to the seemingly great dependency of the researcher's perspective (Lincoln and Guba, 1985). Yet, by reduction of the gap between reality and representation, the principles of reliability and validity can be established in qualitative research. For this purpose, four principal criterions of quality are key: credibility, dependability, conformability, and transferability. Compliance with the first three criteria within the thesis is discussed below. Transferability is a central aspect of this explorative work, thus it is the subject of the discussion chapter 7.

Credibility is to be understood as the believability of research results (Merriam and Tisdell, 2015). To assure the confidence in the value of research findings, several techniques are adopted within the work for the thesis (Lincoln and Guba, 1985). Firstly, the researcher spends adequate time to grasp an in-depth understanding and various facets of the topic. Apart from the literature review, the semi-structured interviews give special insights to the cases even though the research was conducted on a remote basis. Thus, prolonged engagement and persistent observation is given. Secondly, triangulation is sufficiently applied in the thesis study. Triangulation generally means that the approach of research is extended and assures credibility through different perspectives. Here, theory triangulation (nexus footprint concept and policy integration theory) and data triangulation (literature, semi-structured interviews and policy documents) are applied. As a strength of this research, the different information offered by triangulation was constantly compared and mostly thematized in this work. Eventually, credibility of the determined nexus interaction is assured by key expert debriefing of the issue (Creswell and Miller, 2000).

Moreover, the thesis aims to assure a genuine consistency between data collected and findings (Lincoln and Guba, 1985). Therefore, the process of knowledge gain is transparently presented to allow the reader to assess the quality of research practice. This goes so far that the research design can be considered as a prototype model (Shenton, 2004). Though, if the structure of this research is applied to other cases, the results are not necessarily the same due to differences in data collection.
Finally, confirmability was enforced trough strategies which limit bias of the researcher (Shenton, 2004). Key strategy was the explained triangulation in research. Also, the semi-structured interviews being recorded and transcribed formed another tool to eliminate the researcher's influence on the outcome through personal bias.

3.6 Ethical considerations

Four measures are taken to cover ethical issues in this research: informed consent, anonymous information, ethical reflexivity, and epidemic prevention measures.

Firstly, to secure an informed decision for interviewees about whether to participate in this research, they were provided sufficiently with information about the research to decide beforehand. This includes stating an informed consent based on the General Data Protection Regulation (GDPR) principles of the EU (Voigt and Von dem Bussche, 2017). Secondly, to assure anonymity, the respondents interviewed are not named. The data, such as recordings for transcription were safely documented and saved on a password-protected laptop and deleted after the thesis was completed (accordingly to Arifin, 2018). Thirdly, the author

incorporated ethical reflexivity to ensure awareness regarding the different cultural backgrounds and social structure of the researcher and the research (accordingly to McCurdy and Fitchett, 2011). The complex dimensions of research ethics are recognized in terms of procedural ethics in the case of interviews with locally engaged people. Practical ethics were integrated by identifying and responding to circumstances and cultural discrepancies identified over the course of research. Finally, since research is conducted during the Covid-19 pandemic, research methods obeyed the advice of the National Institute for Public Health and the Environment (RIVM) of the Netherlands and Robert Koch Institute (RKI) of Germany, wherefore interviews were set up online and research work was conducted on a remote basis continuously (RIVM, 2021; RKI, 2021).

3.7 Research limitations

The research is subject to a range of general limitations. A general one is that the research draws majorly on qualitative data which intrinsically bases on interpretation. To ensure reasonable conclusions of the thesis, the research design is transparent regarding data collection, analysis and points of discussion (Merriam and Tisdell, 2015). Furthermore, the analysis depends highly on nexus footprint data acquired by a colleague the accuracy of which the researcher cannot guarantee. For this reason, the researcher included the selection of crucial water-energy interrelations in the semi-structured interviews which built the chance to confirm their relevance. The nexus footprint data point to a further limitation of this work. The thesis aims to elaborate the contribution of a mixed-methods approach on urban water-energy nexus. However, the thesis is unable to provide a coherent mixed-methods analysis including own quantitative data collection. Regardless, if the empirical application of a nexus footprint had also been the task of the researcher, this would have exceeded the scope of a master's thesis. In this way, the researcher could concentrate on the conceptualization of the work and the argument of the research question. Building on the concept of the thesis to elaborate urban nexus issues through the empirical lens of nexus footprints and to contrast this with a policy integration analysis is an opportunity for future research.

Moreover, the positionality of the researcher may limit the data collection. On the one hand, because the researcher was perceived as an external person from a foreign country, some interviewees may have wanted to convey a certain image about the local situation. To receive more critical and truthful answers, the goal of research was presented in the beginning of every interview to create comprehension of why certain questions were asked. Also, all interview partners were reminded that all research records are kept confidential and anonymized and that they can stop at any point during the conversation. By doing so, the researcher attempted to create a trusting atmosphere. On the other hand, the limitation through positionality of researcher is because the researcher conducted case studies on locations she had never visited. Increased literature review and media consumption of the places during the time of research attempted to balance this limitation by building an increased comprehension for the selected urban places. Yet, the researcher is aware of her persisting different cultural background stemming from a privileged background in the global north that regardless of efforts influences, at least to some degree, her perception and approach to conceptualization (Doiron and Asselin, 2015).

Irrespective of these challenges in research design, the study has great potential for nexus research due to its innovative approach. The study acquires unique data of two explanatory urban places and conceptualizes them in an equally new way. As such, the study offers a holistic way to approach urban nexus issues.

Chapter 4

Material perspective on urban nexus

This chapter discusses the application of nexus footprints on two distinct urban cases, Amman and Pune, to conclude on the contribution of an advanced understanding of water-energy nexus issues. The application is conducted based on literature, including significant data. In each case, only specific parts of the water-energy interactions are illuminated and do not represent a complete nexus footprint. The water-energy interactions ground on empirical salience.

4.1 Amman

Within the semi-arid climate city, water is one of the most valuable and at the same time scarce resource for Amman. As Bonn describes, the national regime likes to stress the "geopolitical misfortune" of the whole country in terms of water resource availability, having its fair share of the region's water sources taken by the stronger neighbors (Israel: Jordan River, Syria: Yarmouk River, Saudi Arabia: Disi Aquifer) (Bonn, 2013a, p.731). In contrast, domestic high water consumption factors are commonly neglected in the discourse, such as the groundwater abstraction for irrigation purposes in the north-eastern and south-eastern parts of the country (Al-Bakri et al., 2013; Bonn, 2013a; Talozi et al., 2015).

To provide Amman, and other parts of the country, with water, there are mega projects serving cross-border water infrastructure. The first mega water project, the billion dollar Disi Water Conveyance, transports water from the Disi Aquifer, a fossil water resource beneath southern Jordan and northern Saudi Arabia, encompassing over 325km distance and 800m altitude difference to Amman. The Jordanian government is currently pushing for an even larger cross-border project, the Red-Sea-Dead-Sea project (RSDS, also Red-to-Dead). Still, the project does not have any implications for the current water provision situation of Amman (Klassert et al., 2018; Sigel et al., 2017b; Talozi et al., 2015). The huge distance for water transport results in a high amount of energy, thus emissions, needed to provide Amman's households with water. The extent of Jordan's total primary energy demand having more than doubled in the last two decades (Lahn et al., 2016) stresses the onerous and mostly intermittent public water supply situation in Amman (Mustafa and Talozi, 2018). Sigel et al., 2017b elaborated the various options for water provision in Amman. Piped water is used commonly but there are also tanker trucks for further water household supply that arose as a response to excess demand. These tanker trucks emit crucial emissions by exploiting wells in the area around Amman and delivering the water to urban households. Additionally, there exists private drinking water vendors for bottled water (Sigel et al., 2017b). This aspect is however neglected in the following, as this is an entirely private and in many places around the world appearing phenomenon.
The FUSE Discussion Paper recognizes in these circumstances of household water supply a key water-energy nexus for Amman of

> **40,7 kg CO_2, compiling 4.2 kg CO_2 by tanker water supply and 36.5 kg CO_2 by network water supply** (Athauda, 2021).

The associated emissions from tanker trucks stem directly from surveys with tanker truck drivers (Athauda, 2021), the emissions by network water supply can be retraced by public sources (Almuhtady et al., 2019; Zawaydeh and Al-Ghandoor, 2017). The defined nexus is further underpinned by the literature review. Lahn et al., 2016 highlight 14% of the country's electricity used for water, with a rising trend for following years until mid-2020s (MWI, 2016a). This makes Jordan, including Amman, one of the greatest energy-for-water consumption places in the world. To put the Amman cases into context, there are urban places in the world like Vienna (Athauda, 2021), which accomplish water provision without spending even one kilowatt-hour (kwh) of electricity. Therefore, the amount of energy situated in water consumed in urban households, differs significantly across the world.

No specific literature piece is found that focuses on the specific water-energy nexus emerging in Amman's households while additionally taking water from tanker trucks into account. However, as the subject is likely to increase in the future due to population growth, determining the nexus that results from an unreliable water supply system is of great importance. The high carbon emissions for public water conveyance to the city and water tanker supply raise questions about the extent to which the urban nexus is recognized by governance structures. This is addressed in the following chapter 5.

4.2 Pune

Pune has been struggling with serious water problems for several years. These stem less from an acute regional water shortage. Rather, unequal water distribution between the city and agriculture in the surrounding area, which also draws water from the four dams in the surrounding areas, enhances water challenges (Joshi, 2017). In addition, the water pipes within the city lead downhill towards the center. As a result, low lying urban areas are advantaged and higher areas are starved in water supply (PMC, 2014). As the city is constantly growing, the population is rising especially in the outskirts of the city. For given reasons, these parts have poorer access to the water supply network. A further factor that aggravates Pune's water supply situation is the intermittent water supply being around 6h a day (PMC, 2014; Rode, 2009; a more recent figure was not determinable).

As a result, water storage tanks are needed to bridge water provision gaps. Though, the water pressure is too low due to infrastructural weakness of the water provision system. In response, private water pumps on the thresholds are usual to make the public water available to households (Athauda, 2021). Additionally, to bridge the public water provision shortage, private groundwater wells emerge across the city to generate additional water for households (Kulkarni et al., 2019; Athauda, 2021). Energy used for both types of private household pumping, is generated primarily with coal power which intensifies CO emissions (Kale and Pohekar, 2014; Madurai Elavarasan et al., 2020; Mahatransco., 2017). Thereof, a significant water-energy nexus is derived on a household basis in the context of private water pumping:

> **10,7 kg CO_2, entailing 3.6 kg CO_2 emissions by network piping and 7,1 kg CO_2 emissions by well water consumption as well as residential augmentation of public water supply system** (Athauda, 2021).

In result, a crucial nexus is recognizable initiated by additional private water supply and water supply auxiliaries. Thus, the identified nexus figures indicate a severe pressure factor for the city that is already facing rising emissions (Jadhav, 2018). The groundwater well problem is issued in literature previously (Kulkarni et al., 2019; Kulkarni and Shankar, 2014). But the topic has not yet received full attention in relation to the general water supply situation and its related governance. Regarding the water access issue, there is no literature piece detectable that is dedicated to the specific topic. The following work aims to issue both components under the topic of increased private energy consumption for water supply in urban households of Pune to analyze relating factors to the found nexus.

4.3 Implications from the nexus footprint approach

As shown above, resource interrelations can be revealed and quantified through the nexus footprint approach by very simple means. From this application, several essentials for general nexus study are detectable.

Nexus footprints only achieve a bottom-up perspective on the urban nexus issue. Hence, the concept neglects macro-scale interdependencies of resources (Hoekstra et al., 2011). Nevertheless, the associated top-down approach relies on trade data and its quality. Therefore, the result of a top-down approach can be very susceptible to relatively small defects in the input data. In addition, the top-down approach often leads to a reductionist representation of local realities such as in urban cases (Koteswara Rao and Chandrasekharam, 2019; Lombardi et al., 2017). In contrast, nexus footprints shed light on specific urban circumstances utilizing a bottom-up approach. They facilitate a micro perspective on urban resource interrelations. This, in turn, supports problem understanding for specific local conditions as demonstrated.

The nexus footprint is suitable for determination of a specific resource nexus. Thus, it offers a practical method to implement the FEW nexus concept as requested by previous research (Artioli et al., 2017; Benson et al., 2015; Leck et al., 2015; Zhang et al., 2019). It is useful in that it can express the relationships between resources in tangible figures. In this way, nexus footprints can illustrate unique nexus characteristics and can make them comparable through quantification. This applies in particular not only for the consideration of the resource interrelations between the three FEW resources, but for interactions between two specific resources, embedded in the systemic FEW nexus understanding. Therefore, it is applicable for a water-energy nexus study.

Eventually, the application of the nexus footprints is only simply presented. Yet, the nexus footprint is proven to be a suitable tool to identify a specific subject of matter on household basis without background information. The nexus footprint study does not require more detailed information for nexus determination, as shown in the case of Pune. The clear denomination of the nexus in regarded cases can potentially specify an awareness of occurring resources challenges. Hence, the nexus subject may be recoginized and understood in an improved way for governance purposes. This enables a comprehension of the often imprecisely handled nexus concept. Consequently, the nexus footprint offers an advancement in small-scale nexus scholarship as it is able to operationalize the nexus term (Hoff, 2011; Zhang et al., 2019). This sets the basis for the following assessment of the institutional system in the respective case studies dealing with nexus challenges.

Chapter 5

Institutional perspective on urban nexus

This part of the thesis elaborates on sub research question two, which and how institutions govern the previous identified nexuses. Therefore, institutions, categorized as subsystems majorly in charge of nexus-related domains, are revealed and discussed regarding their degree of integration towards the nexus. Additionally, the overarching policy frames and goals towards the specific nexus issue in the water and energy domains are analyzed. This is accomplished by assessing the degree of policy integration for the nexus issue of key policies in both cases (Candel and Biesbroek, 2016). The procedure intends to conclude coherently on the acknowledgement of the nexus in the two urban governance cases. For background information, both study cases are introduced stating the general overarching institutional logic of the respective institutional system.

5.1 Amman

Amman is the primate and capital city of the kingdom of Jordan, holding over 4 million people. The city obtains an enormous value for the whole country and is even beyond national boarders a center of attraction for people and economy in the Arabic region (Al-Zu'bi, 2017). However, institutional patterns are scarce and less democratic. Over the past decade, the term shadow state gained popularity in describing the informal neopatrimonial structures behind several regimes in the Middle East, such as Jordan. There, a network of alliances and dependencies undermine state institutions (Yorke, 2013). Hussein characterizes it as follows (Hussein, 2018, p.170):

> *"Within a shadow state, authority belongs to an individual or group of individuals; it is a neo-patrimonial regime that can also have a facade of laws, procedures, and governmental institutions. The official ruler maintains the support of key actors, who are linked to him through tribal or regional affiliation, and through privileged access to economic assets."*

Such key actors surrounding the king can be found in the military and intelligence services, ministries, parliament, national and local government, and business. In the case of Jordan, political decisions that are clearly contrary to the general interest of the state highlight the great influence and power of this shadow state (Yorke, 2013).

Administratively, the state is divided into three major levels. At the national level, Jordan has been a constitutional monarchy since 1952, with the king at the head of the state. The ruling family of the monarchy is the Hashemite dynasty, which claims descent from the Prophet Muhammad. The king is the head of state, commander-in-chief of the armed forces, and appoints the prime minister and the council of ministers (Al-Zu'bi, 2017). Executive power rests with the king and is exercised by the prime minister and the council of ministers or cabinet. The cabinet is accountable to a bicameral parliament. The king appoints the Senate, while members of Parliament are elected by popular vote. Also, the king holds extensive veto and proposal powers.

On the regional scale, Jordan is divided into twelve governorates administrable. Each Governorate is headed by a Governor nominated by the King through the Minister of the Interior (Al-Zu'bi, 2017). The Governors can be seen as extensions of the national government

as they are supervised by the Ministry of Interior Affairs.

Locally, Jordan obtains 93 municipalities and additionally the Greater Amman Municipality (GAM). GAM holds a special position among the municipalities as the king reserve rights to directly affect the capital's politics. This is expressed in the appointment of Amman's mayor by the central government as well as half of the city's council's members (Al-Zu'bi, 2017). Jordanian municipalities focus mainly on service-oriented tasks, meaning they have limited influence on political issues (SOFRECO, 2010). Accordingly to the organization United Cities and Local Governments (UCLG), the central government urges municipalities to remain silent in political debates (UCLG, 2013).

5.1.1 Subsystem involvement

Firstly, to draw conclusions on the subsystem involvement, one must identify the institutions concerned with the nexus issue. Based on the general hierarchical political setting as described above and in literature (Al-Masri et al., 2019; Al-Zu'bi, 2017; Bonn, 2013b; Bonn, 2013a; Hussein, 2018), the identified urban nexus issue is exposed governmentally to a field of tension between national and urban governance level.

The management of natural resources is traditionally centrally governed on the state level. Jordan's **Ministry of Water and Irrigation (MWI)** in charge of the water supply (Government, 2021a; all interviewees). Yet, there are several public functions of resource management that are coordinated by a mix of public and private, but state-owned, bodies on the city level. In Amman and further regions, the Jordan Water Company **Miyahuna** provides distribution of water and treatment services (Miyahuna, 2021). Miyahuna obtains the right to extract groundwater and surface water from, e.g., springs, for drinking water supply (Sigel et al., 2017b). The company provides piped water intermittently, with individual weekly durations between 12 and 168 hours (JWA, 2015).

The energy provision, including the energy needed for the water supply for Amman, is centrally governed by the **Ministry Energy and Mineral Resources (MEMR)** (Al-Masri et al., 2019; Al-Zu'bi, 2017; all interviewees). The **National Electric Power Company (NEPCO)** plans and conducts the power system, purchases electricity from different sources and sells the electricity to distribution companies. It mainly serves Amman and central Jordan (Al-Zu'bi, 2017). Also, it operates electricity imports and exports with neighboring countries (Al-Masri et al., 2019;). NEPCO is another example of a fully privatized, but partly state-owned body that provides the capital with crucial resources, in this case energy.

Furthermore, the conducted interviews demonstrated and related documents confirmed that the **Ministry of Environment (MoE)** faces the high emissions for water supply. This applies both to the country and to Amman as a general concern with regard to the sustainability of the country's economy (MoE, 2017; IA1; IA2; IA4).

In Amman itself, the **Greater Amman Municipality (GAM)** inherits administrative control of the city's development. Main aim of the GAM is to improve municipal services (Government, 2021b). In this role, GAM is building partnerships with various parties and supervises organization operating on the city level. However, GAM depends directly on the advices from higher administrative levels, particularly in the case of water and energy management. Thus, the GAM can hardly incentivize new policies and strategies to cope with the occurring nexus issue in the city (Al-Zu'bi, 2017; IA1; IA2; IA3). In sum, the water supply by the public water pumping system is clearly shaped by less but powerful actors that operate top-down.

In contrast, the provision of water by tanker trucks turns out to be more branched. Even though all water resources, surface and ground waters, are owned and controlled by the state, the Amman water tanker market is highly shaped by **private actors** (Sigel et al., 2017b). Only in times of predictable water scarcity like during summer, Miyahuna, advised by MWI, sends its own water trucks (IA1; IA2). Apart from that, a license system, established by MWI (IA1; IA2), regulates the abstraction of water from wells and its purpose (Sigel et al., 2017b). Still, water is often extracted illegally from wells for the tankers (Sigel et al., 2017b; IA1; IA2; IA4) whereby the institutional structures do not fully cover the reality of the nexus.

Based on the institutional structures impacting the governance of the nexus issue, one can determine a clear dominance of the central government. Formally, there is no other subsystem involved than the state itself. However, it needs to be highlighted that the state's structure is split into various organizational domains. The MWI and the MEMR are the clear key, but separate, actors in the governance domain of water and energy issues as demonstrated in the institutional analysis taking into account the answers of all interviewees.

Although IA1, IA2 and IA5 have reported that there are now commissions between representatives of the water and energy sectors who are cooperating in tradition of the nexus idea, but they do so only for certain projects. In the case of the Amman water-energy nexus challenge, such commissions have not yet been formed. Beyond that, IA5 highlights that these commissions have rather practical than governmental character. Mostly engineers meet there to discuss common plans that were previously established by both MWI and MEMR. Despite the occasional nexus commission that is formed regarding other issues, there are essentially no continuous governmental structures that incentivize such integrated approaches for resources issues. Still, all interviewees stress that this is mainly due to the relative novelty of the nexus term in Jordan politics. IA1 highlights that Jordan actors have only known the nexus approach approximately five years, therefore they still need time to adapt to the idea and the awareness for policy integration for nexus issues.

The GAM seems to obtain at least integrated observing character regarding the specific water-energy nexus issue (IA1; IA2; IA4). Nevertheless, the GAM obtains limited power by being directly subordinated of the central government. Also, the GAM itself is clearly divided internally by different areas of responsibility. There, the domains of water and energy are again clearly divided and the complexity of the nexus issue is not reflected in the institutional subsystems (Al-Zu'bi, 2017; Government, 2021b). Therefore, the GAM maintains only coordination and demand-side management tasks.

In summary, the urban nexus issue is structurally less acknowledged by institutional integration for two reasons. On the one side, the urban component of the issue is not mirrored in the current institutional system due to the general governance structures in Jordan and its strong national actors. On the other side, the nexus characteristic of the water-energy issue is institutionally less demonstrated. Water and energy and their common challenges are consistently not reflected jointly on all levels, except for MoE and practical such as project-related commissions, indicating a low degree of institutional integration regarding subsystem involvement towards the specific nexus issue (cf. Candel and Biesbroek, 2016).

5.1.2 Policy frame

In the following, the before stated actors are analyzed as to what extent they perceive the concrete water-energy nexus issue in Amman (Candel and Biesbroek, 2016). This step aims to assess a further aspect of policy integration. Though, according to all interview partners, the nexus term is a generally known term in Jordan politics by now. But only partly, Jordan governance actors would also be aware that there exists a specific local nexus issue in Amman with specific urban threats.

The MWI does highly acknowledge the general water-energy nexus issue in Jordan's water supply. Both key policies, the National Water Strategy 2016-2025 (MWI, 2016b) as the Energy efficiency and renewable energy policy for the Jordanian water sector (MWI, 2016a) reflect a great awareness for the nexus in water provisioning itself. However, the first one is the only policy document to explicitly mention the nexus and the specific question of water provision in Amman. The national water strategy acknowledges the nexus in the sense that resources and particularly the local water issues are interconnected. Practically, the MWI plans to adopt Integrated Water Resources Management (IWRM) as a strategy and process to promote the coordinated development and management of water, land and related resources "in order to maximize the resultant economic and social welfare gains in an equitable manner, without compromising the sustainability of vital ecosystems" (MWI, 2016b). Detailed factors of the water-energy nexus in Amman as the tanker truck market are not considered in the documents.

Reflecting on the executive level of water governance and supply, the Jordan water company Miyahuna does not yet reflect the before stated nexus perspectives in the Jordan water

sector. Based on the most recent annual report (Miyahuna, 2019), engergy is not yet considered as an integrative task in the interaction with water or other resources in practice. Nor is Amman explicitly mentioned. All interviewees stated that even though the nexus topic is present at the top level right now, especially in the water sector, on the executive level the issue has not yet fully arrived.

In the energy sector, there is generally not much recognition of the nexus perspective found. This impression was confirmed by four interviewees and no one neglected the subject. According to IA1 this is also as the energy sector is privatized to a larger extent and therefore less easily receptive to reforms. At the same time, the government has enormous additional costs in the water sector due to exploiting costs for energy (MWI, 2016a). This results in more pressure for the water sector to deal with the topic of nexus and initiate policy integration - in contrast to the energy sector.

The MoE frames water and energy issues as crucial embedded tasks. IA4 clarifies that the ministry is also aware of the specific water-energy in Amman's water provision. Yet, the ministry did not frame the issue but it is indirectly covered in some way by the MoE (MoE, 2017), as discussed in the next section. Their policies initiate key governance processes that relate to the process of policy integration regarding policy framing for a water-energy nexus (Candel and Biesbroek, 2016).

As reported by IA1 and IA2, there is a general awareness for the nexus issue in Amman within the GAM. However, there is no evidence if and how GAM frames the concrete issue. Only some policies, initiated by GAM, thematize required improvements in the field of water and energy as reflected in the next subsection. However, considering the general institutional logic of Jordan, the absence of problem framing by the GAM does not appear curiously. On the contrary, the GAM is obligated to frame no subjects which have not received coherent framing at a higher level (Al-Zu'bi, 2017).

Eventually, one must stress in this subsection the difference between problem awareness and problem framing within the regarded institutional system. This might be one of the methodological ambiguities along with assessing the hermeneutic construct of the policy frame (Rayner and Howlett, 2009). The issue seems to be commonly known across various subsystems based on all interviews and taking additionally the broad amount of literature into account that at least partly discusses the nexus issue (Al-Masri et al., 2019; Al-Zu'bi, 2017; Talozi et al., 2015). However, the water-energy nexus issue in Amman is incoherently framed as the policy subject itself. Only the institutional water domain acknowledges the issue roughly in its policies. Therefore, in accordance with Candel and Biesbroek, 2016, there is a medium to low degree of policy integration to be estimated as the issue is still perceived as falling within the boundaries of one particular system, the water one.

5.1.3 Policy goals

Reflecting on policy goals reveals a further possible dimension of policy integration. The policy goals are assessed to understand to what degree the governance system, to be precise, the identified subsystems, issue policies and strategies to cope with the nexus issue in an integrative way aiming to emphasize integrative water solutions to reduce the energy consumption for water supply in Amman. As in most cases the nexus issue itself is not sufficiently framed by the policies this analysis draws attention towards policy content, that is critical for further policy integration enhancing the nexus perspective.

Ministry of Water and Irrigation (MWI)

In their *National Water Strategy Paper*, the MWI introduces Integrated Water Resources Management (IWRM) to cope with nexus challenges in the water provision of Jordan (MWI, 2016b, p.22). Certainly, IWRM is closely related to the nexus perspective on policy integration, but holds a significant difference as it acknowledges less the holistic nature of the nexus approach (Benson et al., 2015). IWRM still targets at water-centrism while the nexus itself and the general nexus concept appears to emphasize a multi-centric view. Additionally, other differences occur regarding the relevance of resource security, scales, optimal governance, participation and resource use in the direct comparison of the IWRM and the nexus approach. Therefore, it should be clearly emphasized that the main body of Jordan's water

supply recognizes nexus as a fundamental term. However, it cannot be clearly concluded from this that holistic policy integration is applied as an integral goal in the governance structures. Still, the MWI stresses that it will build on coordination with other stakeholders for a better understanding of the interdependence of water, food, energy and climate resources (MWI, 2016b, p.49). As an additional factor to take the nexus seriously, the SDGs are cited and planned to be monitored to track their progress in implementation (MWI, 2016b, p.36). The particular water-energy nexus of Amman is not emphasized in the document. Amman itself is also not mentioned. But the case of tanker trucks is touched upon as the paper reports from "unauthorized groundwater abstraction or service connections" (MWI, 2016b, p.15). A concrete plan to tackle the issue is thus not given here.

Additionally, the MWI issued the *Energy Efficiency and Renewable Energy Policy* for the Jordanian water sector (MWI, 2016a). In the document, it is claimed that the reason the MWI issues an own energy policy is due to the fact that according to data of the MEMR, 17.6 % of the Kingdom's GDP of 2014 (and around the same figure of the national water budget according to IA1) is spent on energy for the national water supply (MWI, 2016a, p.5). Also, a significant rise of the energy consumption throughout the following years is expected. Thus, in this policy document, the MWI directly refers to the water pumping issue, which is responsible for a large part of Amman's emissions. The document suggests improving the efficiency of energy use in the water sector and introducing renewable energy technologies to the sector that aims to lead to a reduction in water supply costs and avoidance of unnecessary losses in the sector, as well as 15% reduction in the specific energy consumption of billed water corresponding to a 0.47 kg reduction of CO2 emissions for the production per each billed cubic meter of water. Achieving such results would contribute to the sector optimization and hence to solving serious challenges for Jordan's sustainable development caused by the various pressures on its limited resources and their inefficient management (MWI, 2016a, p.8). Also, the paper states participating institutions for implementing this policy. Among those, the MEMR is stated as a key actor from the energy governance side. But the inclusion of this actor remains limited as it is only responsible for licensing and issuing permits (MWI, 2016a, p. 4). Although the integrative water-energy approach demonstrates clear ambitions towards characteristics of the nexus problem at least nationally, the term nexus itself nor clear pathways towards policy integration is mentioned in the document. Instead, the document keeps rather on technological solutions while neglecting governance processes for improvement of water-energy challenges.

Miyahuana

Miyahuana regularly publishes an energy report, which proves that the issue of energy in the water sector is taken seriously at implementation level (Miyahuna, 2019). Yet, no further relevant information regarding the nexus can be determined.

Ministry Energy and Mineral Resources (MEMR)

MEMR only superficially mentions water-related topics in its last published report (MEMR, 2017). Though, it specifically mentions energy-intensive water pumping but without a deeper push for policy integration and collaboration with stakeholders nor the Amman case itself. Moreover, the MEMR is pushing for nuclear energy to provide 30% electricity through nuclear power by 2030 (MEMR, 2017). The most recently published national energy strategy paper 2020-2030 does neither focus on the water-energy nexus nor on integrated solutions in collaboration with the water sector (Dayyeh, 2020). But it strives for an increased carbon reduction in the energy generation sector (Dayyeh, 2020; IA5). Thus, this would contribute to less carbon emissions through the water pumping, also in the city of Amman.

National Electric Power Company (NEPCO)

Also, the NEPCO as the energy supplier does not particularly mention nexus nor nexus related issues. This is probably where the problem discussed above comes into play, namely that nexus themes are still hardly perceived at the executive level, which was further all interviewees (NEPCO, 2019; IA1; IA2).

Ministry of Environment (MoE)

Four years ago, the MoE introduced the *National Green Growth Plan (NGGP)* (MoE, 2017). Part of the policy are their own publication on the topics of energy and water development of the country (MoE, 2020a; MoE, 2020b). The NGGP charts out a plan for Jordan to achieve an expanding yet sustainable and resilient economy that ensures the creation of green jobs for its citizens and increased investment in green projects. Four driving principles of green growth are identified and mainstreamed across the actions in the *NGGP*: transparent governance processes and enforcement of legislation, mechanisms to incentivize green growth, integrated planning processes that value societal impacts, behavior shifts and capacity building (MoE, 2020a).

For the energy policy within the *NGGP*, MoE and MEMR worked in partnership with the support of national stakeholders and the Global Green Growth Institute to identify 12 priority actions to achieve green growth through the energy sector. Key objectives (among others) in the energy sector are opening the market to competition, diversifying sources of natural gas imports, enhancing the safety of the electrical system while raising the availability and reliability of the system, encouraging investment in renewable energy, increasing the carrying capacity of the electrical grid, attracting private sector investment to the energy sector (MoE, 2020a, p. 27). Clearly, this touches indirectly on relevant components of the local nexus issue. For example, an improvement of the energy grid and the inset of renewable resources in the energy supply may not solve the high energy requirement of the water supply in households. It is declared that this measure can substantially contribute to a reduction of emissions in the water supply, wherefore a smaller nexus footprint may result.

For water, the *NGGP* likewise builds on stakeholder collaboration and addresses key challenges related to both supply and demand side management, through implementation of infrastructure and building community stewardship of resources. Moreover, it introduces incentives and financing mechanisms to reduce the overall cost burden of water resource management on public resources. Also, the policy aims for capacity building of public sector decision makers to use incentive structures, data and policy innovations in water sector management (MoE, 2020b, p. 41). Such incentives are, for example, the emphasis of stakeholder engagement and capacity building to enhance policy integration (IA1).

All governance experts interviewed also confirmed that this policy is an achievement regarding policy integration for the governance of the identified nexus issue, as they report that the policy itself emerged already in equal collaboration of various actors and with inclusion of key experts. It contains valuable pillars for the governance of the water-energy nexus issue.

Greater Amman Municipality (GAM)

Facing policies stemming directly from the urban level, further cross-sectoral policies are integral subjects. One of them is the *Climate Plan for Amman 2050*. It lays out an approach to creating a carbon neutral Amman, while expanding services and meeting the needs of the rapidly growing city (GAM, 2019). It orientates on SDGs and green growth principles (OECD, 2021).The policy refers to a model calculation that Amman currently fails to reach its 2050 near-zero emissions target. The policy states that land use strategies and carbon sequestration could be more effective in reducing emissions than some energy sector or transport actions. This document identifies important cross-sector and urban planning actions that are potentially necessary to help Amman achieve a carbon neutral Amman, which goes beyond simply reducing emissions. The policy aims, among other, more social tasks, to manage and fulfill climate change commitments, improve energy efficiency and energy security by including diversifying energy sources and improve the water management. It briefly identifies, without mentioning the word nexus, the water-energy problem, but without stating all related components. Concrete solutions are not proposed. Instead, vague goals are formulated. At least it clarifies that Amman does not have lead responsibility for these services, as they are provided through the national level government and national policies and regulations. The policy affirms the city to be, however, capable to take the lead in action areas related to municipal buildings, open spaces and the efficient use of water or water reuse in these areas. In other action areas, the city plans to act as an advocate for its residents and a partner in delivery (GAM, 2019, p. 46). Only two key experts have heard about this policy.

IA1, involved in nexus research and consultation on-site, reports that this policy has not been developed in inclusion of a broad range of experts and attached actors and ministries. Overall, the document has been poorly communicated and lacks action plans to implement the goals proposed in the paper. Therefore, it obviously obtains relevant attributes for a policy enhancing policy integration on the nexus topic. But even when looking at the document, these turn out to be rather hot air without relation to practical execution.

Amman's Green City Plan (AGCP) is a comparable document. It is result of a consulting order by the GAM (Limited, 2021). The document is an addition to the previous Amman climate plan (GAM, 2019). The *AGCP* for Amman has been developed over 18 months with input from 275 stakeholders. It proposes 37 short-term actions and 27 long-term actions to help achieve the vision for a green Amman. As one of four key environmental challenges, the document designates water scarcity while also setting emphasis on the energy sector. The document appoints concrete steps in both water and energy domains. Relating the nexus issue, the policy document appoints investments in renewable energy solar projects (Limited, 2021, p. 60) and upgrades and expanded access to water (Limited, 2021, p. 61). Still, the action domains of water and energy are discussed strictly distinct from each other. Therefore, there is less hint for a general integrated approach towards water and energy but strong evidence that water-energy nexus issue is known and addressed from different angles. Additionally, the relatively new policy is not known to many actors yet. Only one of the interviewees was familiar with the document and claimed that there is again a lack of clear implementation steps for stakeholders.

Eventually, there exists the *Amman Resilience Strategy* (Cities, 2017). The strategy was developed as part of the 100 Resilient City initiative (Network, 2021). The document is the result of a city-to-city exchange about similar urban challenges against disaster and violent conflict-protracted displacement. Eltinay, 2019 and IA1 indicate that the program has been useful in understanding the cities' urban risk profiles, promoting dialogue among local governments, and creating a culture of learning organizations for knowledge sharing on governance. The process of developing the policy and associated actions has included city leaders, communities, and the private sector which is why IA1 stresses the sustainability of the document. It is additionally the only city policy to stress the closeness of water and energy management domains while simultaneously providing practical measures within the pillar "an environmentally proactive City" (Cities, 2017). However, for most actions in the domain, the GAM or the MoE is listed. One can hardly detect a cooperation with the relevant water or energy actors, only Miyahuna is listed once as associated partner. This implies that there is ambition for integrated policy governance towards water-energy challenges however the integration is not fully conducted as key actors are not included.

Summary policy goals
The policy analysis reveals more nuanced patterns regarding the subject of policy integration in the case of Amman's water-energy nexus. According to the institutional structures in Jordan, the policies of relevance for urban Amman are mainly the national ones from the case-related ministries. In the case of energy, there are no policies detected directly referring to the water domain and considering the nexus issue, particularly not on the urban scale. In contrast to this, the MWI seems to be much more aware of the general water-energy nexus in the water supply. Above stated figures, but also the interviews, assured that the MWI has a much higher urge than the MEMR to deal with the issue due to exploding energy for water costs. But the ministry does not thematize fully the specific case of Amman where the general crucial water issue for Jordan come to a head due to high population density (Al-Masri et al., 2019; Mustafa and Talozi, 2018). The MoE builds with the *National Green Growth Plan* (MoE, 2020b; MoE, 2020a; MoE, 2017) chance for coordinated cooperation between the water and the energy sector to tackle energy challenges in the water supply.

However, the Amman case is again not considered explicitly. The concerning policies on the urban scale and related to GAM obtain other features that promote integrative governance between the water and energy sector to tackle the water-energy issue. Yet, they again only include MEMR and MWI as key actors for the nexus issue resolution to a limited extent and do only partly plan strategic implementation steps wherefore the plans are perceived rather as a pipe dream. In conclusion, there exists a broad range of policies from the local to the national scale issuing water and energy as well as interrelated topics. However, only the MWI thematizes the subject water-energy "nexus" as such, but also without clear relation to the urban case. When the urban case is in focus, the term nexus is not determined but at least relevant components of the nexus issue are approached. Therefore, one can say that the identified urban water-energy issue is found in various policies but only a few aspects of the topic are discussed in each policy. No policy depicts coherently the full scope of the issue in sense of policy integration (Candel, 2019).

Regardless, a rising awareness for the general nexus topic can be noted, especially when the interviews are considered. But structural inconsistencies across policies of different sectors (for example the renewable and nuclear energy plans or the IWRM approach) occur that illustrate the fragmented policy landscape and how differently various components of the concrete urban water-energy are perceived and approached by various actors and subsystems. In summary, only a low to medium degree of policy integration can be estimated based on the respective policies (Candel and Biesbroek, 2016).

5.2 Pune

For the second case, Pune, the general political system is shortly elaborated again. As key contribution of the analysis, the degree of policy integration regarding subsystem involvement, policy goals and policy frame towards the specific water-energy nexus in Pune is then assessed.

Holding more than 1.2 billion inhabitants, the Indian Union is the most populous democracy in the world. There are regular elections, competition among political parties and constitutionally guaranteed fundamental rights. The distribution of powers and responsibilities between the national state and the federal states is integrated into the political structure. The distribution of power is also intrinsic on the vertical axis and extends to the local level (Singh and Gaur, 2013). In the last decades, village councils, known as panchayats, gained control over parts of the education system, infrastructure, and police while this increase in local sovereignty has not been replicated in the cities, limiting their political and administrative opportunities for action (Kohli and Singh, 2013). Despite this seemingly strong federalism, India has been described as a "federation with a unitary bias" compared to other federal systems in the world (Kohli and Singh, 2013, p.233). This is reasoned central government has disproportionate power compared to the states in many affairs.

In summary, the state infrastructure can be described as rather complicated and even

convoluted democratic. Complex administrative infrastructures and offshoots of both national and state administrative systems affect the urban governance level.

5.2.1 Subsystem involvement

Due to the democratic structure of the Indian governmental system and the special nexus issue, which has less to do with the general circumstances of the country, the subsequent analysis evolves more around the institutional level of the city.

In contrast to most other Indian municipalities, Pune is appropriate example for strong urban governance (for Citizenship and Democracy, 2017). The government of the **Pune Municipal Corporation (PMC)** is headed by the Municipal Commissioner, who is designated by the Maharashtra state government and in charge of the executive branch. On the other side, there exists the deliberative branch that encloses the general body of 162 directly elected corporators that elect the mayor. The corporators and the mayor are elected every five years, the municipal commissioner is appointed for a maximum period of three years. Interviewees (IP2; IP3) claimed the municipal commissioner to have significantly more power resources and influence than mayors in Europe or the United States. The 39 urban departments of the PMC are core pieces of the PMC governance and allow Pune own public management across different sectors (PMC, 2021a). However, a department officer explained (IP1) in the interview that there is less cooperation across departments and that city governance is rather structured in silos. Based on research and conducted interviews (IP1; IP2; IP3) the two following departments of PMC are the key departments related to the nexus issue.

One the one side, the **Water Supply and Pumping Department** aims to provide adequate safe water for drinking, cooking and other basic needs in a sustainable manner. The department aims for water provision that meets minimum water quality standards and be readily and conveniently accessible continuously. The concrete tasks are the following: establishing an equitable distribution of water, identifying and minimizing water losses, promoting sustainable development, provide a fair way to allocate costs, improving system energy efficiency, improving the customer service level and implement best management practices (PMC, 2021c).

On the other side, there is the **Environment Department** to create environmental awareness, promote responsible citizenship and incentivize environmentally friendly attitudes among citizens. They achieve this by conducting workshops for different social groups and by developing collaboration with various schools, colleges, research institutes, NGO(s) and other related organizations working for environment and conducting programs for the environment as stated on the department's website (PMC, 2021b). They are also in charge of implementing sustainable development strategies (PMC, 2021b).

Nevertheless, drinking water supply is generally placed under state supervision, although there were repeated attempts to strengthen the local level. In fact, water governance is spread over all political levels with partly unclear division of responsibilities (Das, 2006). Generally, Maharashtra is considered as a national champion in water policy due to the variety of water institutions and policies (Misra and Kingdom, 2012). Among the state institutions, **Maharashtra Water Resource Regulatory Authority (MWRRA)** plays the key role according to all interviewees. The MWRRA supervises equitable distribution and pricing of water at various levels and sectors, as well as it monitors compliance and mediates in cases of conflict. However, the right to allocate water among the various sectors was taken back from the authority in 2011 (to the cabinet of ministers). Although the MWRRA is generally perceived as favorable in its role as an independent body in the highly contested water sector, it was also criticized for a lack of engagement and proactive regulation. Thus, limits to its independence were noted, as most of its members are former officials of the national water ministry (Misra and Kingdom, 2012).

The nexus issue is, in the Pune case, not so clearly linked to actors of the energy sector as in the Amman case because the issue develops successively on the household bases related to the public water supply. Thereof, the energy actors do not play an integral role in the governance of the nexus issue (accordingly to all interviewees). But for the sake of completeness, some integral energy actors should be stated after all. PMC itself does not manage

electricity supply in the city. Rather, bodies of the state and private entities are concerned with the energy supply. There is the **Maharashtra Energy Development Agency (MEDA)** to promote the use of alternative energy sources and energy conservation. The rapid expansion of renewable energy capacity in Maharashtra in recent years, as well as India's renewable energy targets, magnified MEDA's importance in this sector. Then, there is the **Maharashtra Electricity Regulatory Commission (MERC)**, which is the primary regulator of the sector. Otherwise, the sector is highly privatized and only marginally influenced by the state. Maharashtra State Power Generation Company Ltd., Maharashtra State Electricity Transmission Company Co. Ltd. and Maharashtra State Electricity Distribution Company Ltd. are the main private companies in charge (Heynen et al., 2019; Kale and Pohekar, 2014).

In the case of Pune, based on subsystem involvement, the second research question is not as easy to answer as in the case of the preceding case study. The nexus footprint analysis ultimately identified a challenge that had received little attention from both research and public bodies related to Pune. Nor can it be said that this subject is related equally to the two sectors of water and energy. On the contrary, it is primarily an issue that originates in water supply management and ultimately obtains consequences for energy consumption and resulting emissions. Therefore, it does not seem quite as clear as in the Amman case that basically the water and energy sectors must enhance joint governance. Nevertheless, it occurs as evident that some kind of integrative governance is needed to govern the resource challenge in a holistic and thus sustainable way (Joshi, 2017; IP2; IP3; IP4).

In practice, a high degree of departmental thinking shapes the structure of the governance system in Pune. This silo pattern continues on the state level and reaches eventually to the national level (Praharaj et al., 2018; IP2). In addition, the governance system consists of widely ramified departments and responsibilities, which can mean even internal staff hardly stay on top of things (IP1). Nevertheless, no dominant subsystem is found that overrides specific institutional structures. Indeed, there is the national, and more importantly, the state level that give general guidance in water provision. Yet, the PMC command over integral parts of Pune's resources governance. However, the structures remain horizontally organized on a departmental level, thus without awareness for cross-cutting nature of issues.

As a result, there are no institutional structures tracible that stimulates policy integration across policy subsystems towards the identified nexus issue (Candel and Biesbroek, 2016).

5.2.2 Policy frame

Generally, the term "nexus" is less known in respective sectors in Pune according to all respondents. The interviewees that are in exchange with academic institutions, such as the Gokhale Institute of Politics and Economics that conducts stakeholder workshops in the field together with foreign partners as the FUSE team, confirmed they have heard of the FEW nexus concept (IP2; IP3). How this concept can be implemented in urban management and governance seems to be still unknown. The specifically identified nexus issue for Pune was also not known to all (e.g. IP1), of all people, the PMC employee. IP3 clarifies that individuals' and actors' awareness of the problem greatly varies depending on their own water supply reality. The supply situation substantially depends on the specific neighborhood.

Moreover, there is less problem perception of the raised nexus issue as it lacks general integrated perception of the water sector by actors and citizens. This might explain why there is no framing for the identified nexus issue detected. IP4 reported that "India is just waking up for resource governance", the full comprehension for water and moreover integrated resource governance is still developing and it will take its time. As a result, only partial areas of the nexus are recognized by the institutional system, such as the general unreliability of the water supply sector (PMC, 2014). Yet, IP3 and IP4 claim that the institutional system has rather an eye for the supply side but neglects the demand side of water provision and associated issues. This is further confirmed by the subsequent review of policies in place which majorly focus on the supply side but do not take resource complexities occurring on the demand side into account. Although, there is no such thing as a policy frame for the issue, either explicit or implicit, in official documents, some interviewees were able to give

further background information on the topic to improve the general framing of the topic. It was IP2 and IP3 who first put the phenomenon of increased energy demand for water pumps into the context of "fight for water" in the city. As a result of the intermittent water provision, those who can afford it would install (more powerful) water pumps to make the water accessible, but also to pump out as much as possible when it is available in the public supply system. Others, often less endowed with assets, are consequently deprived of water, which is in most places already scarce. Later, this explanation was confirmed by the remaining interviewees. Kulkarni et al., 2019, Kulkarni and Shankar, 2014 and IP4 point to the additional aspect of the water-energy nexus that lies in the groundwater abstraction. The "fight for water" may be interpreted as factor that exacerbates groundwater abstraction which is in the long term environmentally critical (Kulkarni et al., 2019).

In sum, the degree of policy integration regarding the policy frame can be described as very low. The whole extent of the nexus issue is not reflected in any policies although it combines various cross-cutting challenges in the areas of water provision, groundwater governance and potentially further social, environmental and energy aspects.

5.2.3 Policy goals

Even though the analysis of the policy frame reveals less promising evidence for policy integration regarding the respective nexus issue, policy goals are reviewed in the following in more detail. This serves the purpose of mapping out policies in which the problem is at least partially embedded and to reflect on policy coherence.

The state level

As the research acknowledges various level of governance impacting urban realities, the *State Water Policy* was determined as fundamental for general water governance. It applies to all the line departments, semi-government agencies of the state government related to water, local bodies, bulk water users (domestic, industrial/commercial and others) and the citizens of the state (Department, 2019). The document ensures clean water and sanitation in the state. The policy acknowledges the challenge of depleting groundwater resources and uncertainty in water availability. To face water challenges in the state, the policy enhances the IWRM approach. Although the document contains rough guidelines for water governance, it is not able to provide precise instructions for the city of Pune and its resource challenges. It neither mentions associated actors that are somehow involved in the water provision or related subjects. IP1 explains that the policy is the guiding policy in place for water governance in the state, therefore also in Pune. IP3, IP4 and IP5 note that the ambitious goals and measures of the policy have little impact on actual resource governance at the urban level. This would be much more dependent on local factors, such as local plans, politicians, etc., they claim.

The urban level

In the urban regard, the *Water Supply System Project Policy for Pune* (PMC, 2014) appears as integral policy. The main objectives of the project are ensuring safe and equitable water supply to the entire population in Pune city for the next 30 years, ensuring the distribution of water during the entire day (24x7 modality), reducing the level of water losses and non-revenue water while ensuring the technical and economical sustainability of the water supply service (PMC, 2014). Therefore, the PMC introduces various activities to improve the public water supply system. The document lists key challenges for the water supply in Pune (PMC, 2014, p.10). Among those, there is "inequality in the distribution of water in various parts of the city" and the intermittent water supply stated. This demonstrates that some causing parts of the prior identified nexus issue are known to the PMC. Also, it is mentioned that various motor vehicles are used to pump water, however this is not issued for the case of private households. Groundwater abstractions is likewise mentioned in the sense that it is a persistent issue (PMC, 2014, p.174). Apart from increasing control measures, no actions are formulated to decrease groundwater abstraction. In sum, the policy acknowledges severe challenges in the city's water supply. But it does not approach the issue by holding an integrated perspective on further occurring issues that come with intermediate water supply.

Therefore, it does not recognize the nexus issue provoked through the city-internal "fight for water" (IP3). Furthermore, the document does not show any cross-linking with other departments or stakeholders to generally address issues listed in an integrated manner. As further enforcement of the 24x7 modality, PMC issued its *24x7 project* in 2017 (PMC, 2017), that came into force 2018 and is aimed to be finalized in 2021 (Khairnar, 2018). It strives to increase the pressure to water in the pipelines, and then to maintain the pressure on a 24-seven basis. In this sense, it directly approaches the key underlining problem of the present urban nexus issue. Yet, IP4 claims that this policy has been established in Pune like in other Indian cities at the incentive of the national government. The policy aims high but neglects specific urban circumstance like the actual water availability. The interviewee stresses that "this is a classic case of improving the supply side without understanding the demand side" (IP4). On the demand side, there is, among other factors, a steadily increasing population and disadvantageous water pipe system. Such factors would have to be taken into account when improving the water supply (IP3; IP4). Therefore, there exists no clear implementation path that enhances integrative governance on water.

In addition, *Pune's Smart City plan* is a policy plan motivated by the government of India. It was introduced as part of the "Smart Cities Mission", an initiative starting in 2015 (Praharaj et al., 2018; PMC, n.d.). Its aim is to drive economic growth and improve the quality of life for people in 100 selected cities across India, including Pune. These objectives are planned to be incentivized by support of urban innovation and the comprehensive integration of information and communication technology. In the concrete case of Pune, ensuring adequate water to all by reducing wastage is put on the agenda. Fighting supply leakage coupled with better monitoring of supply is a key point of the policy (PMC, n.d.). But it exists no further clarification how this objective is to be accomplished concretely. Regarding all actions, the policy aims stronger participation of stakeholders and a better interdepartmental coordination across sectors. But, again, no implementation plans for this target can be determined. Even if one finds references to integrative governance approaches in the document, they are very brief and seem to be nothing more than empty phrases. As it does not acknowledge existing policies in the field (as the other ones presented here for example), the *Smart City Plan* adds a new layer of plan and evolves an extra institutional instrument to the already complex governmental environment (Paskaleva, 2011; Praharaj et al., 2018), but it does not add value in facing the urban nexus issue (confirmed by all interviees exept for IP1).

Moreover, the *City Development Plan* plan encloses the most relevant fields for the city's future urban development and advises appropriate urban governance (PMC, 2012). It highlights the water sector in urban governance specifically. In this regards, it acknowledges the inequal distribution of water and the limited water supply that is additionally impeded by inadequate storage and water pressure (PMC, PMC, 2012, p.103). As part of improvements in the water supply, the system's energy efficiency is mentioned as well to promote sustainable development. Hence, this implies being receptive to integrative approaches. However, no concrete measures can be identified to make the approach applicable for governance structures in the future. By IP1, the development plan was considered as an integral policy for the city's future, however other interview partners state the policy to be less relevant for the concrete nexus issue. Following IP4, this is due to the lack of consideration of the demand-side complexities within the policy and missing implementation plans.

Eventually, the *Resilience Plan* strives to mainstream environmental thinking within the governments in the Pune metropolitan region (POR, 2019). It neither issues the complex nexus interdependencies that come along with the challenging water supply situation in Pune. But the plan points to important aspects of water and energy management that are related to the subject such as groundwater management and emissions due to energy mismanaging. The document does not only name objectives but declares defined strategies and action plans that incentivize various actors from different sectors to collaborate. IP2 explained that since start of the resilience plan implementation in 2018, 20 to 30% actions have been started already. The implementation of the plan is in close cooperation with the PMC and other stakeholders like NGOs. For "Indian conditions" there would be fair progress. In contrast,

IP3 claims the policy to be still unknown across concerning departments. The remaining interviewees confirm largely the existence of the policy but do not see their relevance yet for ongoing political processes including facing the discussed nexus issue.

Summary policy goals

Overall, there are not many policies that are directly related to water governance, as there are key policies like the *State Water Policy* (Department, 2019) and the *24x7 plan* (PMC, 2017), that aim to regulate the general water situation (IP1). Among all policies, there is no problem perception to the raised nexus challenge determinable. Only partial areas of the nexus are recognized, such as the general unreliability of the water supply system in Pune. Generally, there is neither the nexus term itself know to the documents. This also helps to understand that the policies hardly show any integrative governance approaches. However, some mention integrative water management or even IWRM. But the way of integration is not clearly defined nor are suggestions made on how these concepts can be implemented, nor are other stakeholders (potentially from other sectors) included in policy implementation plans. Therefore, the analysis of interviews reveals a general sceptic among non-officials towards the implementation of ambitious goals in the water supply of the city. Yet, IP1 reports that still slowly but steady development towards more complex resource governance happens, initiated by the acknowledgement of SDGS. Policies like the *Resilience Plan* (POR, 2019) could be classified under this *integrative turn* in urban governance of Pune as it has an eye for actor integration and capacity building to implement cross-sectoral goals. Still, the current state of such integrative approaches do not seem sufficient to inherently approach the elaborated nexus issue. Hence, only a low degree of policy integration regarding the range of policies is to be found as the nexus is not sufficiently addressed in any policy (Candel and Biesbroek, 2016). Nevertheless, there are no inconsistencies occurring across polices of different origins, like state and urban level, wherefore one can speak of some degree of policy coherence simultaneously. This is however not highly astonishing since only policies related to water but no from a completely different sector, as energy for example, was analyzed. Therefore, this factor should not be considered too important in this context.

5.2.4 Summarizing results on degree of policy integration in both cases

In sum, both cases demonstrate a relatively low degree of policy integration towards the revealed water-energy nexus issues. A graphical summary of the condition can be found in the following figures. Based on the outcome of the case studies in accordance to Candel and Biesbroek, 2016, it is estimated that Amman's governance holds a low to medium degree in policy integration.

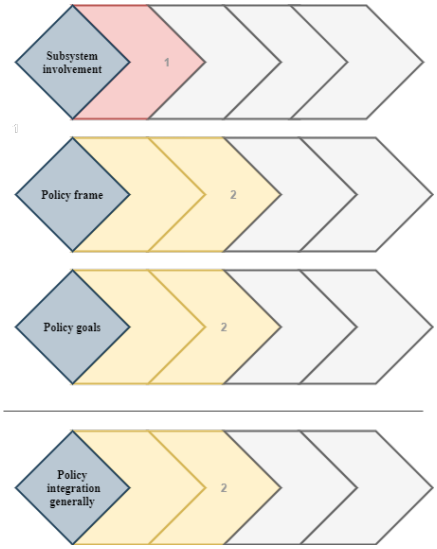


FIGURE 5.1: Degrees of policy integration Amman.

In contrast, in Pune's governance system, there is nearly no policy integration detectable wherefore it yields the lowest score. Hence, silo approaches to resources issues seem to dominate local governance in both cases.

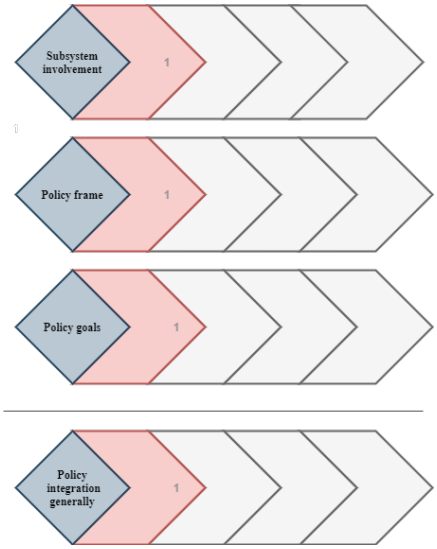


FIGURE 5.2: Degrees of policy integration Pune.

With a view to further literature, these results match the experience of previous scholars. Following Simpson and Jewitt, 2019, an integrative or even holistic approach to resources governance is still primarily unknown in governance systems of the global south. Yet, the prior research simultaneously reveals a slow awakening towards the matter. Hereafter, it is

elaborated how these insights in policy integration can yield conclusions on nexus governance in the specific cases.

Chapter 6

Contribution of a mixed-methods approach

In the previous section, the degree of policy integration was analyzed as a reflection of the nexus challenges in the institutional system of both cases. Based on this, it is now derived which strengths and weaknesses exist in governance regarding the nexus in the respective cases. In concrete terms, this means that the chapter reassesses the alignment of governance with the respective urban water-energy nexus issue. To this end, it is evaluated to what extent the institutional system, as analyzed in chapter 5, matches the material perspective on the nexus in chapter 4. Strengths are detected in aspects, where governance displays or even faces challenges of the material nexus. Weaknesses are to be comprehended as aspects of governance that do not reflect the material nexus issue and its challenges. Then, the contribution of a mixed-methods derivation for strength and weaknesses in nexus governance as in this work is discussed.

6.1 Strengths and weaknesses of nexus governance in Amman

From the institutional analysis, it appears that the specific nexus issue is commonly known among governance stakeholders, indicating a general strength of urban nexus governance in this case. The only aspect of the issue that is not directly associated as part of a holistic perception is the one of tanker trucks. However, these are also significant contributors to increased emissions in the water supply, apart from public water pumping. Nevertheless, this phenomenon of tanker trucks is also widely known, even if it is not always perceived as an ecological problem calling for governance action (IA1). Moreover, as a result of the increasing awareness of the cross-cutting nature of water supply, it is recognized by various actors in the water and environmental sector that governance should encompass different areas related to the nexus issue. However, the nexus issue is generally not referred to as "nexus" but is described in broader terms such as integrated management, etc. This is not necessarily a weakness since there is a general cross-cutting issue understanding, while a consistent nexus perspective is still developing (IA1; IA2; IA4; IA5). Based on policies striving for integrated and sustainable solutions and the interviews, one can report capacity building towards increased nexus governance to cope with the occurring challenges that are revealed in chapter four (Candel, 2019).

On the contrary, one must acknowledge that governance in the Amman case does not fully reflect the nexus in its institutional structures. Even though the water-energy issue is acknowledged highly in the water sector, the nexus is not yet reflected as integrated governance task of the whole system. There is a primary lack of recognition of an integrative approach on the side of the energy sector, given that energy system stakeholders perceive the issue mainly within the boundaries of the water sector (reported by all interviewees). In cases where some integrative actions from the energy sector with the water sector take place, they are limited to practice-oriented commissions, e.g., among engineers, which have no governmental relevance. This is also evidence that capacity building for understanding interrelationships in the energy sector hardly falls on fertile ground and thus does not reach

the entire governance system. But the energy sector is an integral part of the governance of the specific nexus issue in this case. Without the intrinsic motivation of actors from the energy sector to develop sustainable solutions with further actors, particularly from the water sector, policy integration for reducing energy consumption and emissions for water supply in Amman seems dubious (Candel and Biesbroek, 2016; IA1).

Furthermore, the way in which actors of the water and associated sectors, as the environmental one, apply integrated approaches under keywords like nexus for the issue are rather operationalized through sector-specific approaches as IWRM. This indicates that the nexus approach is not fully implemented in governance practice because concepts do obtain an integrative access to occurring issues but still demonstrate a sector-centered approach. The IWRM approach can be seen as precursor of the nexus approach since it does not fully reflect the holistic character of the nexus concept (Benson et al., 2015; Hagemann and Kirschke, 2017). This water-centered perspective might enhance path-dependencies in governance structures (Romero-Lankao et al., 2017), as indicated by IA1 and IA2, which in turn prevent the consideration of the full nexus issue as in local governance. Also, the lack of strategic development of the nexus indicates a strong technologized, application-based understanding of the nexus. Nevertheless, the nexus calls for its own governance strategies (Gondhalekar and Ramsauer, 2017, Märker et al., 2018).

Besides that, the urban aspect of the material water-energy issue of Amman is hardly captured on the institutional side. Indeed, the high energy consumption for water supply is recognized as an almost nationwide problem. But the severeness of the topic in this highly populated city is not acknowledged by the key actors in the field, such as the MWI and the MEMR. Therefore, the system fails to coherently address the issue in relation to its own geographical challenges and local demand-side struggles like the tanker trucks (Sigel et al., 2017b). Certainly, there exist valuable policies at least indirectly facing the nexus challenges on the urban scale. However, these policies remain powerless without the inherent inclusion of the key actors such as MWI and MEMR.

TABLE 6.1: Strengths and weaknesses of nexus governance in Amman.

Strengths	Weaknesses
General recognition of nexus phenomenon	Less political recognition for the specific nexus issue
Occasional cross-sectoral cooperation	Energy sector does not regard itself as part of the challenge
Capacity building for nexus comprehension	Nexus is operationalized in a sector-centered way (IWRM)
	Nexus approach remains technological and not governance-strategic
	Urban options for nexus action are limited

6.2 Strengths and weaknesses of nexus governance in Pune

In this case, the mixed-methods analysis reveals a great gap between the material resources nexus issue and the institutional structures in charge. The institutional side does not seem to replicate severe nexus resource struggles on a household basis within the city of Pune. Moreover, as proven by all interviews as well as the considered documents, there is generally less comprehension for cross-cutting nature of governance objects in Pune's urban governance. Especially as the resource governance is poorly understood as something that requires an integrative approach. Thus, it is not recognized that the consumption patterns of water and energy are severely entangled.

Therefore, Pune's governance fails to inherently thematize the water issue and associated resource nexus that occur on the demand-side. Instead, the institutional system focuses on the supply side - to be more precise, on the supply side of water provision (along the provision of further public services). In return, the institutional system cannot cover the revealed nexus challenge. Still, policies like the *Resilience Plan* indicate the fact that, at least gradually, integrated approaches to urban governance are being developed with the help of capable stakeholders in place like the Gokahle Institute and ACWADAM. However, this appears as a complex mission since the institutional system is ruled by a tangle of policy levels and structures.

Moreover, by analyzing the material side and the subsequent institutional side, it can be concluded that the institutional side does not sufficiently cover the urban character of the identified nexus problem. The increased energy consumption for water is a problem specific to the geographically defined area. The phenomenon is based on the general water scarcity and irregular water supply in the city as reported by interviewees. Further population growth, as is foreseen (Kantakumar et al., 2020), is likely to aggravate the problem in future (Butsch et al., 2017, IP4). In contrast, existing related policies do not issue this urban component of water and associated stresses. Even though some are aimed at the urban space directly and developed by the PMC, they carry mostly superficial urban character. This can be explained by the fact that policies in place are often incited from programs at the state or national level even though PMC obtains a comparably high freedom in urban governances (IP3; IP4). In consequence, the urban policies do not appear to draw extensively from local experience. Seemingly, the city's governance system is not realizing its potential towards specific urban resources governance. This may partly explain the fact that the specific water-energy nexus issue does not manifest itself directly at all on the institutional side.

TABLE 6.2: Strengths and weaknesses of nexus governance in Pune.

Strengths	Weaknesses
Building capabilities towards nexus through policies	No political recognition for the specific nexus issue No general nexus comprehension in the institutional system Strong focus on supply side while turning a blind eye to demand side struggles

6.3 Methodological contribution of the mixed-methods approach operationalizing nexus footprints to conclude on strengths and weaknesses of nexus governance

An integral insight of the case study is the fact that a nexus footprint incentivizes to give equal attention to two or three nexus dimensions. In reality, the nexus approach is often translated in a water-centered way in practice due to its origin in the water sector as a redevelopment of existing integrative approaches, such as IWRM (cf. Märker et al., 2018). In the case of Amman, this pitfall was strongly proven by the review of policies. Without the interdisciplinary perspective that provides resource management background knowledge and nexus footprint analysis, one might tend to settle for finding an IWRM approach in policy plans that is tasked with making the nexus approach a reality. However, the look from a preceding empirical nexus analysis provides an equal perspective on occurring issues and a greater understanding of resources challenges. This, in turn, may help to approach resources interrelations in a holistic manner. Yet, approaches as the IWRM have been holding a dominant position in water governance in many governance contexts across the world. In opposite to the nexus, IWRM has at least twice as long a history and has had time to become a well-known part of governance systems in terms of resource management (Agarwal et al., 2000; Benson et al., 2015). The application of a mixed-methods analysis opens the view for the identification of the focal points of the concrete nexus phenomenon. In this way, the analysis of institutional structures focuses more on the concrete design of the strategies facing the nexus. In this way, strategies that do not fit the resource challenge are more easily identified and facilitate governance analysis.

The nexus footprint approach can broaden the horizon to the extent that path dependencies (as described by IA1 and IP4) are broken in analysis by an orientation towards concrete problems that need to be solved holistically. The pure empirical issue analysis, independently from the governance analysis in the second step, is key to thinking beyond perceived systemic structures. However, it must be mentioned that there is a difference in the analysis and the implementation process of the nexus perspective towards nexus governance. The mixed-methods perspective majorly contributes to the awareness of the nexus subject, but it does not necessarily enhance the systemic optimization of resource governance in the short-term (Zhang et al., 2019). It can draw attention to issues for improvement that are not yet covered by public awareness, literature or other sources (see Pune case). Simultaneously,

the nexus footprint concept is a first step of approaching the nexus in order to broadly understand it. The nexus footprint obtains thus the ability to reveal important characteristics of a nexus issue and sets intriguing incentives for policy integration process going beyond accustomed governance paths in the regarded urban system (Romero-Lankao et al., 2017).

Finally, another clear advantage of the interdisciplinary approach operationalizing nexus footprints for nexus governance analysis arises with respect to the object of integration. Candel, 2019 as well as Jordan and Halpin, 2006 state that it still remains unclear what is to be integrated exactly when aiming for policy integration. Nexus footprinting can address this ambiguity in governance theory. As stated above, the nexus footprint approach provides guidance in nexus issue definition. From there, one derives valuable insights on which objects exactly must be integrated into the governance process. Therefore, nexus analysis benefits from a clearer definition of an overarching goal, as requested in Weitz et al., 2017a and Weitz et al., 2017b, to evaluate strengths and weaknesses of a governance system facing a nexus issue. In turn, this may prevent further policy fragmentation. Additionally, the base of setting an objective to integrate can promote a universal comprehension of the nexus, not only within governance analysis, but amongst various actors. Again, this can facilitate policy integration process towards the nexus since there exist a common understanding from which joint objectives can be established. Usually, the perception of the nexus varies across different disciplines and stakeholders, therefore common paths for collaboration and policy integration remain challenging (Weitz et al., 2017a;Weitz et al., 2017b).

In sum, the methodological contribution of the thesis targets on a sharper recognition of nexus issues in urban spaces. Through the mixed-methods concept, the thesis approach enhances resource nexus characterization as policy-making conceptual tool supporting sustainable development (FAO, 2014; Hoff, 2011).

Chapter 7

Discussion

After application of the study design, this discussion section reevaluates the theoretical-methodological contributions and outcomes of the thesis. Special attention is paid to the discussion part, as the thesis obtains an exploratory approach. Therefore, it is highly relevant to dedicate a broad discussion to the thesis. In this way, it can be judged to what extent the study design can be transferred to future nexus work.

7.1 Theoretical-methodological reflections on the study

This section incentivizes the reconsideration of the general case study design, being inspired by SES and taking a range of data acquisition opportunities, the nexus footprint approach and the operationalization of policy integration theory into account.

7.1.1 Case study design

The case study approach was selected to enrich the comparably small landscape of urban nexus studies. The design of the case studies can be described as advantageous in two ways.

Conceptually, the structure of this thesis inspired by a complex systems approach through SES may set an innovative example for future mixed-methods work in the field of systemic research on nexus issues. Certainly, in contrast to nexus footprint and policy integration theory, the SES approach appears only in the margins of the work explicitly. The fact that SES was introduced as an integral part of this thesis at the beginning of the work may seem exaggerated. For the essential part of the analysis, SES has not been mentioned any further. Critiques might claim that this is a result by the lack of theorization, especially of the components of the SES concept (Fabinyi et al., 2014; Stojanovic et al., 2016). Nevertheless, the concept has done a fundamental service to this thesis as a theory-neutral framework. By grounding the work with a SES perspective, the general structure and perspective on nexus issues of this thesis has been established. As formulated by Ostrom et al., 1994, the SES gives organizational guidance to the explorative inquiry. The general structure of the thesis develops in the logic of SES by diagnosing the object of interest – the nexus – as a complex systemic matter and approaching the research in a material and institutional analysis that is accompanied by each theoretical conceptualization. This interdisciplinary method derived from SES perspective, has not been adopted so far extensively in formal publications. Indeed, an axiomatically similar approach to conceptualize socio-material interconnections for FEW research in cities has been proposed by Covarrubias, 2018 before. However, the thesis progresses one step further as it determines two theoretical approaches, that complete the lack of theorization which the SES concept leaves. Still, each theoretical approach obtains a specific connection to the matter of nexus and can stand as nexus analysis on its own. The present work proves that both the nexus footprint concept and policy integration theory can be ideally used to identify the nexus in its broad shades of comprehension from a pure material understanding to an understanding as governance subject. The overarching SES approach to the topic then logically makes it possible to link and weight the results from both sides of the analysis. Hence, it facilitates both a review of the interactions between material resources and of the interaction between institutions in charge towards the nexus as demanded by literature (Bizikova et al., 2013).

The other aspect in which the design of the case studies can be described as advantageous is that the methods reach beyond generic data acquisition. The variety of theoretical concepts integrated and entangled within the thesis, enhances a mix of qualitative data sets, while acknowledging even quantitative insights from footprint studies. Hence, the thesis offers literature review, policy document analysis and key expert interview analysis. Obviously, partly, the quantity of analysis subjects, such as the number of interviews, could have been extended, as described in the methodologies part. Yet, the variety and linking of methods by the concept of analysis appears unique. Furthermore, the methods compilation aims to inspire a template for future research on urban nexus complexities. This is mainly due to the fact that urban nexuses is treated stepmotherly until today, in the sense that they are mostly a reductionist version of national nexus considerations (Artioli et al., 2017, 2017; Newell et al., 2019; Zhang et al., 2019). The broad variety of methods to approach nexus issues obtains the power to reveal case specific nexus complexities on-site. For this purpose, the interviews with meaningful partners are essential. But the nexus footprint approach, that was firstly introduced in this shape in this paper, can also deliver meaningful insights in the case-specific urban nexus conditions as elaborated in the respective chapter.

7.1.2 Nexus footprints

Certainly, due to the limited extent of this thesis, the application of the nexus footprint approach is only foreshadowed by utilizing further literature. Yet, promising tendencies in the use of urban footprint methodology is determinable within the thesis. The analysis is able to reveal fields of tension between two or three nexus resources on the micro level through the bottom-up approach of the nexus footprint concept utilizing household data (cf. Mguni and van Vliet, 2020). This is particularly for studies of places in developing countries, such as Amman and Pune, of interest. Significant research gaps regarding nexus complexities remain in the global south, among those there are especially gaps in urban research (Fan et al., 2019). Though, accelerated urbanization resulting in severe resource challenges particularly take place in cities of the global south. Therefore, focus in scholarship on these areas is required. In the meantime, growing cities offer the chance to realize integrated nexus solutions from scratch (Kumar and Saroj, 2014). For doing so, systematic characterization of urban nexus resource issues are and will be needed to match policy infrastructure and the emerging challenges, particularly in fast-expanding cities of developing countries (Zhang et al., 2019). The urban nexus study including a nexus footprint, as shown above, can provide such valuable features for characterization of urban nexus challenges.

Considering future research utilizing nexus footprints, the approach can be complemented by distinguishing between different social attributes, such as income classes or neighborhoods. By doing so, the analysis can detect even more specific nexus problems that may be unique to marginalized groups which are contested by "intertwined social practices predicated upon particularly volatile, variegated and non-discretionary configurations of consumption, lifestyles and systems of provisioning" (Mguni and van Vliet, 2020, p.8). Urban places in developing countries need special attention for volatile conditions (Adger, 2006). In this regard, the nexus footprint approach is particularly of interest since such occurring vulnerable circumstances caused by resource mismanagement are hardly traceable from macro-perspective. Yet, these approaches are mostly conducted in material urban research (among others Lombardi et al., 2017; Paterson et al., 2015). Ultimately, the nexus footprint helps to identify structural challenges at the local level so that pathways towards resilience can be defined more coherently. The disclosure of demand-side resource interactions in conjunction with user practices and policy instruments supports the process of urban resilience (Mguni and van Vliet, 2020).

7.1.3 Policy integration

The preceding point lead directly to the contribution of the application of policy integration theory in addition to the nexus footprint. Policy integration enriches the thesis study as it is complementary to the nexus footprint analysis. The policy integration theory application locates the nexus issues in a specific institutional setting. Thereby, the theory enhances the

comprehension of two different subjects: the institutional system itself, where the resources challenges are embedded in, and the fact of how the institutional system reflects a specific nexus issue towards governance. Yet, by applying the theory in the thesis, three discussable challenges in the application of policy integration theory occur.

First, the approach of the work does neglect the practical design of policy integration. It seems occasionally ambiguous to assess the reality of policy integration in the respective case studies. This is especially the case when some kind of cooperation between sectors is detected but the cooperation seems too superficial to be characterized as a degree of policy integration (as for example appearing through policy document analysis in the Amman case). Building on this experience, the policy integration approach for this kind of analysis requires further operationalization of policy integration practice. McNamara, 2012 proposes clear distinguishing criteria to differentiate between cooperation, coordination, and collaboration in institutional practice. These may be used in future research to substantially argue on the quality of policy integration when adapting the theoretical approach of this work. Only collaboration across actors with shared power arrangements can facilitate real policy integration within the system.

Second, the present work demonstrates a complementary conceptual gap between the material and the institutional nexus. In the Amman case, the material nexus can be transferred to the institutional side fairly directly as the material nexus issue appears to be nearly equally related to the water and energy sectors. However, in the Pune case, a water-energy nexus issue must be acknowledged as stronger related to the institutional water sector. Energy is obviously a strong component in the case, but the issue arises nearly entirely through mismanagement in the water sector, as indicated by the footprint and elaborated on through the interviews and relevant documents. The interpretation of this work is that the nexus problem should also be considered at the institutional level. However, it would then make sense not to simply prioritize policy integration between water and energy domains. Instead, the policy integration ambitions of the water domain towards other institutional domains contributing (indirectly) to the material water-energy nexus on a household basis deserves attention. These can include the energy sector but the health or social sector may also appear to be relevant. Hence, one of the implicit hypotheses of the thesis, that the material nexus matches the institutional nexus, can only limitedly be confirmed. To put it in a nutshell, this work thus establishes that the material nexus and the notion of nexus in governance may differ in some cases. This might be of relevance for further mix-methods nexus studies but also for general nexus governance debate as such findings was not yet determined in literature. Regardless, this recognition does not diminish the value of the mixed-methods approach. The general value of mixed-methods analysis is that the nexus footprint study can shed light on critical resource challenges, which are then tangible for governance analysis in light of specific local institutional structures.

Third, utilizing the insights gained from a combination of nexus footprint and policy integration theory to draw conclusions on strengths and weaknesses of nexus governance, can seem curtailed. The policy integration analysis displays a broad range of discoveries. Yet, deriving the strength and weaknesses from a comparison of the two methodological distinct approaches results in a rather small selection of findings. Accordingly, the usefulness of the broad, preceding policy integration analysis can therefore be debated. However, the broad policy analysis is considered fundamental, as it is necessary to understand the degree of policy integration, hence nexus governance. Only with the help of these substantial results can overall conclusions be drawn and the strengths and weaknesses of nexus governance argued about. The shortness of concluding results may be related to how stark one summarizes the findings from the policy integration analysis. The overall procedure to conclude on the strengths and weaknesses of nexus governance therefore assures to be substantial and inherent which builds a basis for further nexus scholarship.

7.2 Reflection on results of study

The research explores nexus challenges for two specific urban places and the governance they are facing. Therefore, the contribution of this work is two-fold: on the one side the thesis contributes to the methodological discussion on how to identify and analyze nexus issues

and on the other side the thesis delivers valuable case-specific knowledge on the specific nexus governance.

7.2.1 Selection of the nexus issue

The research reveals two tangible water-energy nexus issues for the cases of Amman and Pune. Certainly, further nexus issues might have been detectable. However, based on household-centered data and literature for both cases, the identified nexuses have been the most significant ones in the area of water-energy interactions. Additionally, the nexuses as challenges for the respective urban places have been confirmed by all interviews conducted.

7.2.2 Pursuits for policy integration

Next, the thesis translates the nexuses identified into objects of integration that are to be represented on the institutional side. Therefore, it establishes a governance-structure independent view on "what has to be integrated" to analyze to what extent, or if at all, the nexus issue is reflected in the regarded governance system. On this point, the thesis might set a controversial implicitness of *the more policy integration the better*. The analysis discusses policy integration as the ultimate goal and judges gaps in policy integration as weaknesses of nexus governance. Candel and Biesbroek, 2016 highlight that not recognizing the need for policy integration can be harmful and risky when governing potentially destructive problems. Also, this work concludes that neglecting issue interrelations in the concerning governance system can lead to long-term resource exploitation (particularly in the case of Amman) and additional costs for residents (particularly for the case of Pune) (Weitz et al., 2017a).

However, the work mutually reveals a discrepancy between the idealized nexus concept and practical nexus governance ambitions, wherefore it can be reasoned that policy integration along the nexus requires avowal for frequent fragmentation in policy integration. Such a process depends upon political weighing and judgments of the desirability of pursuing strengthened policy integration (Candel, 2019). This recognition appears as a more realistic perspective on nexus governance and leaves space for different perspectives on a specific nexus subject (Weitz et al., 2017a). Instead of aiming for the highest degree possible of policy integration as the ultimate goal, it is instead important to determine the right mix of policy strategies to govern nexus issues (Keast et al., 2007; McNamara, 2012). This would also prevent additional costs through logistical expenses for extensive policy integration processes, as argued by critics (Peters, 2018). Additionally, adjusted and moderate policy integration are easier to coordinate along with other political ambitions such as decentralization (Peters, 2018; Underdal, 1980). Hence, capabilities and capacities are required to understand different options and strategies to cope with the specific nexus challenge (Runhaar et al., 2018). Future research may discuss and test how a revealed nexus can be used as a steering direction of governance analysis utilizing various options of policy integration.

7.2.3 Ambiguity in stakeholder selection

Moreover, this thesis proves specific local governance structures, but also inter-dependencies of further policy levels are to be acknowledged as impacts on urban nexus governance. Yet, the inclusion of various institutions and the exclusion of others may seem somewhat arbitrary, although the selection of regional or national institutions dealing with urban issues was based on literature and interview research. Also, interviewees implied that non-governmental organizations (NGOs) and further non-institutional stakeholders are crucial to the policy integration process facing the specific nexus issues. The present work acknowledges the contribution of these actors only marginally, as it assesses the governmental policy integration performance. If the approach of this thesis is adopted in future, it may be advantageous to establish a broader set and a more elaborated selection process of actors and institutions to be analyzed. Candel and Biesbroek, 2016 certainly leave room for such an enlargement of actor perspectives. Even among citizens and non-governmental structures, there are relatively stable groups determinable as objects of study (Koppenjan et al., 2004). If the range of actors would have been expanded, the results of this study would have surely slightly shifted.

7.2.4 Consideration of political conditions

As a consequence of a broader field of actor consideration, the political conditions of a nexus case could gain importance. For example, Amman, that was in comparison to Pune relatively strong in facing the nexus issue institutionally, might be evaluated somewhat differently. In the analysis results, the dictatorship ruling Amman plays nearly no role since the focus of study was only on the functioning of intra-systemic integration of institutions. Policy integration, thus nexus governance, requires a high amount of political and organizational orchestration (Runhaar et al., 2018). Surely, institutional features in dictatorship facilitate such orchestration to a certain degree due to inner unity (Cheibub et al., 2010). Therefore, the results on the degree of policy integration must acknowledge in future the general political conditions in an improved way in order to achieve an integrated picture on nexus governance. Additionally, it might be interesting to conduct research as to what extent nexus governance is indeed hindered or stimulated by different political regime circumstances.

7.2.5 Transferability of study

Finally, the work attempts to draw generalizable conclusions on how a mixed-methods approach can contribute to determining strength and weaknesses of urban nexus governance based on the two case studies. This small number of case studies could lead to irritation about how the conclusions concerning the methods are adoptable in further studies. Barnes et al., 2012 and Merriam and Tisdell, 2015 emphasize that the results of any research method can be utilized in other situations, but transferability is most relevant to qualitative research methods such as case studies. Thus, while the findings of this thesis are on the first stage context-related, the work presents on the second stage an overarching approach that provides potential for transferability due to several reasons. The thesis provides detailed and substantial description about the subjects of research, the limits of research and data collection strategies. Therefore, it provides a comprehensive overview as to how and to what extent the concept of this thesis is applicable to further cases (Lincoln and Guba, 1985; Shenton, 2004). Apart from this, the structure of the thesis intends to be understood as a basic framework for further nexus studies. Therefore, the work incentivizes a specific mixed-methods approach that combines two theoretical approaches which each reflect a specific comprehension of the nexus, as explained further above. This specific structure is easily applicable to other urban places that are scene of interrelated resource challenges. As a result, the thesis argues the ability to draw generalizable conclusions on the contributions of this mixed-methods analysis.

7.3 Summary discussion

In the end, the range of results and discussion impulses proves the mixed-methods approach to be a valuable concept for nexus scholarship. Therefore, an innovative contribution of this work to be noted is that which emerges through the two-fold methodological approach and the in-detail study of two the urban cases. The first one opens new and more specifically integrated perspectives on a (water-energy) nexus, the second one enhances actionable findings through applied nexus comprehension on urban cases.

Chapter 8

Conclusion

In conclusion, the subsequent answers to the research questions can be given, followed by some final remarks.

1. How can a nexus footprint contribute to an advanced understanding of a water-energy nexus issue?

By determining water-energy interrelations with concrete figures, the nexus footprint achieves to deliver a precise nexus characterization. In this way, resource problems that occur in a particular place, such as a city, can be made visible. Thus, the approach provides the tangibility of the nexus concept for governance comprehension.

2. How are nexus issues governed institutionally in the cases of Amman and Pune?

In Amman, a fragmented policy landscape neglecting the urban character of the revealed nexus challenge is present. Yet, meanwhile it develops, at least sector-related, acknowledgment for nexus governance.
In Pune, commonly no political recognition of the nexus issue appears wherefore no nexus reflection in the institutional system is determinable.

3. How can a mixed-methods approach contribute to determining strengths and weaknesses of urban nexus governance?

The mixed-methods approach is proven to reveal all dimension of an appearing nexus on the local scale. Moreover, it bases governance analysis on neutral ground, independently from previous path-dependencies and defines a clear object for urban governance which can be seen as objective for nexus governance in the regarded system.

Practically, the mixed-methods approach is to be applied in evaluating to what extent the institutional system matches the material perspective on the nexus. Strength is detected in aspects, where governance displays or even faces challenges of the material nexus. Weakness is to be comprehended as aspects of governance that do not reflect the material nexus issue and its challenges.

This results in the subsequent answer regarding the main research question:

What are the strengths and weaknesses of nexus governance in Amman and Pune and how can a mixed-methods approach operationalizing nexus footprints contribute to it?

Regarding Amman, strength is detected in the recognition for the nexus topic. Simultaneously, inconsistent use and operationalization of the nexus term in governance appear, no acknowledgement from one inherently involved sector (energy sector) is revealed while a water-centered perspective on the nexus is demonstrated and the urban aspect of nexus issue and influence of tanker trucks on the issue are commonly neglected.

Regarding Pune, nearly no strengths regarding nexus governance is identifiable. Yet, a slow awakening to the general nexus concept is perceived. The main weaknesses in nexus governance in this place is that it fails to address the nexus issue universally, while the specific urban background factors on the issue are also not acknowledged.

The mixed-methods approach operationalizing nexus footprints contributes to this elaboration by a confrontation of the institutional system with the concrete nexus challenge. The

preceding nexus footprint application facilitates a reveal of a specific urban nexus and its tangibility for further study.

Conclusively, the thesis is a suitable approach on the urban nexus subject by acknowledging both material and institutional perspective on the matter. This enables an integrative perspective on urban nexuses. Simultaneously, facilitated by bottom-up designed nexus footprints, the nexuses discussed are specifically derived from their urban microenvironment. Thus, the operationalization of nexus footprints contribute a local grounding of the studies. Though, nexus footprints do not eliminate challenging urban data acquisition, yet they offer a template on how to structure and interpret present local data. Therefore, the concept enhances local perspective on resource interrelations and may stress the awareness of the urban level regarding resources challenges.

In turn, this awareness of the urban material challenges enforces the perspective on urban governance. Facing persisting negligence of urban nexus issues and its governance, the thesis exemplifies the feasibility and attraction of urban perspective in nexus research. Utilizing conceptual tools as policy integration theory to analyze nexus governance in the face of a resource challenge is proven to be advantageous to set a horizon for institutional comprehension of the nexus. As a result, this may shape the basis for an applied improvement of resource governance in urban settings. Specifically, this would be of interest in the global south as urban places there are increasingly facing resource challenges while being commonly neglected by research and politics. Accordingly, future research may enhance the attention of those places while adopting a similar approach as proposed by this thesis.

Additionally, of interest to future research might be the combination of the mixed-methods urban nexus approach and SDGs. SDGs are one of the only international contexts for environmental resources concerns, where the urban scale is stressed and prioritized. However, SDGs do not yet sufficiently consider the interrelation across objectives (Simpson and Jewitt, 2019). The mixed-methods approach might build the chance to detect nexus issues and to put it into the context of the accomplishment of SDGs when considering the governance perspective on it. Hereby, the SDGs focusing on water and energy could be combined and bridged into the urban development context, which is the subject of another SDG objective.

Lastly, it might be of value to consider further resources in such a mixed-methods way as introduced in this work. Water and energy are however crucial but not the only resources that are significantly interrelated on the urban scale. For example, the proposed nexus footprint framework enables the inclusion of food in the urban nexus study. Evolving a perspective for food consumption patterns that are interrelated with water, energy or both opens even broader horizons for crucial local nexuses and its governance.

In closing, the thesis aims to highlight the promising nature of resource nexus comprehension for academia and beyond which the thesis innovatively applied to the urban scale. It is hoped that many urban studies facing integral resource challenges will be built on the nexus concept in the future, since *"Ours is a world of looming challenges and increasingly limited resources"*.

(Ban Ki-moon, former Secretary-General of the United Nations)

Bibliography

Adams, W. C. (2015). Conducting semi-structured interviews [Publisher: Wiley Hoboken]. *Handbook of practical program evaluation*, *4*, 492–505.

Adelle, C., Jordan, A., & Benson, D. (2015). The role of policy networks in the coordination of the European Union's economic and environmental interests: The case of EU mercury policy [Publisher: Taylor & Francis]. *Journal of European Integration*, *37*(4), 471–489.

Adelle, C., Pallemaerts, M., & Chiavari, J. (2009). Climate change and energy security in Europe. *Policy Integration and its Limits, Report*, *4*.

Adelle, C., & Russel, D. (2013). Climate policy integration: A case of déjà vu? [Publisher: Wiley Online Library]. *Environmental Policy and Governance*, *23*(1), 1–12.

Adger, W. N. (2006). Vulnerability [Publisher: Elsevier]. *Global environmental change*, *16*(3), 268–281.

Agarwal, A., delos Angeles, M. S., Bhatia, R., Chéret, I., Davila-Poblete, S., Falkenmark, M., Villarreal, F. G., Jønch-Clausen, T., Kadi, M. A., & Kindler, J. (2000). *Integrated water resources management*. Global water partnership Stockholm.

Ahmad, S., Jia, H., Chen, Z., Li, Q., & Xu, C. (2020). Water-energy nexus and energy efficiency: A systematic analysis of urban water systems. *Renewable and Sustainable Energy Reviews*, *134*, 110381. https://doi.org/10.1016/j.rser.2020.110381

Al-Bakri, J. T., Salahat, M., Suleiman, A., Suifan, M., Hamdan, M. R., Khresat, S., & Kandakji, T. (2013). Impact of climate and land use changes on water and food security in Jordan: Implications for transcending "the tragedy of the commons" [Publisher: Multidisciplinary Digital Publishing Institute]. *Sustainability*, *5*(2), 724–748.

Albrecht, T. R., Crootof, A., & Scott, C. A. (2018). The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment [Publisher: IOP Publishing]. *Environmental Research Letters*, *13*(4), 043002.

Allan, T., Keulertz, M., & Woertz, E. (2015). *The water–food–energy nexus: An introduction to nexus concepts and some conceptual and operational problems*. Routledge.

Al-Masri, R. A., Chenoweth, J., & Murphy, R. J. (2019). Exploring the Status Quo of Water-Energy Nexus Policies and Governance in Jordan [Publisher: Elsevier]. *Environmental Science & Policy*, *100*, 192–204.

Almuhtady, A., Alshwawra, A., Alfaouri, M., Al-Kouz, W., & Al-Hinti, I. (2019). Investigation of the trends of electricity demands in Jordan and its susceptibility to the ambient air temperature towards sustainable electricity generation. *Energy, Sustainability and Society*, *9*(1), 39. https://doi.org/10.1186/s13705-019-0224-1

Al-Saidi, M., & Elagib, N. A. (2017). Towards understanding the integrative approach of the water, energy and food nexus. *Science of The Total Environment*, *574*, 1131–1139. https://doi.org/10.1016/j.scitotenv.2016.09.046

Al-Zu'bi, M. (2017). Water–Energy–Food–Climate Change Nexus in The Arab Cities: The Case of Amman City, Jordan. https://doi.org/10.11575/PRISM/28672

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective [Publisher: JSTOR]. *Ecology and society*, *9*(1).

Arifin, S. R. M. (2018). Ethical considerations in qualitative study. *International Journal of Care Scholars*, *1*(2), 30–33.

Arrow, K. J. (1969). The organization of economic activity: Issues pertinent to the choice of market versus nonmarket allocation. *The analysis and evaluation of public expenditure: the PPB system*, *1*, 59–73.

Artioli, F., Acuto, M., & McArthur, J. (2017). The water-energy-food nexus: An integration agenda and implications for urban governance. *Political Geography*, *61*, 215–223. https://doi.org/10.1016/j.polgeo.2017.08.009

Ascione, M., Campanella, L., Cherubini, F., Bargigli, S., & Ulgiati, S. (2008). The Material and Energy Basis of Rome: An Investigation of Direct and Indirect Resource Use through Material Flow, Energy and Footprint Methods [Publisher: John Wiley & Sons, Ltd]. *ChemSusChem*, *1*(5), 450–462. https://doi.org/10.1002/cssc.200700017

Astleithner, F., & Hamedinger, A. (2003). Urban sustainability as a new form of governance: Obstacles and potentials in the case of Vienna. *Innovation*, *16*(1), 51–75. https://doi.org/10.1080/13511610304510

Athauda, N. (2021). FUSE Discussion Paper (in preparation).

Bank, W. (2010). Cities and climate change: An urgent agenda.

Barcelo, L., Kline, J., Walenta, G., & Gartner, E. (2014). Cement and carbon emissions. *Materials and Structures*, *47*(6), 1055–1065. https://doi.org/10.1617/s11527-013-0114-5

Barnes, J., Conrad, K., Demont-Heinrich, C., Graziano, M., Kowalski, D., Neufeld, J., Zamora, J., & Palmquist, M. (2012). Generalizability and transferability. Retrieved March 8, 2021, from http://writing.colostate.edu/guides/pdfs/guide65.pdf

Bauer, D., Philbrick, M., Vallario, B., Battey, H., Clement, Z., & Fields, F. (2014). The water-energy nexus: Challenges and opportunities. *US Department of Energy*.

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., & Tol, R. S. (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach [Publisher: Elsevier]. *Energy policy*, *39*(12), 7896–7906.

Benson, D., Gain, A. K., & Rouillard, J. J. (2015). Water governance in a comparative perspective: From IWRM to a'nexus' approach? *Water Alternatives*, *8*(1), 756–773.

Biggs, E. M., Bruce, E., Boruff, B., Duncan, J. M., Horsley, J., Pauli, N., McNeill, K., Neef, A., Van Ogtrop, F., & Curnow, J. (2015). Sustainable development and the water–energy–food nexus: A perspective on livelihoods [Publisher: Elsevier]. *Environmental Science & Policy*, *54*, 389–397.

Bizikova, L., Roy, D., Swanson, D., Venema, H. D., & McCandless, M. (2013). *The water-energy-food security nexus: Towards a practical planning and decision-support framework for landscape investment and risk management*. Citeseer.

Bolleyer, N. (2011). The influence of political parties on policy coordination [Publisher: Wiley Online Library]. *Governance*, *24*(3), 469–494.

Bonn, T. (2013a). On the political sideline? The institutional isolation of donor organizations in Jordanian hydropolitics. *Water Policy*, *15*(5), 728–737. https://doi.org/10.2166/wp.2013.007

Bonn, T. (2013b). *Wasserpolitik in Jordanien* [Google-Books-ID: 1M57GMdPhfEC]. LIT Verlag Münster.

Bosworth, T. (1993). Local authorities and sustainable development [Publisher: Wiley Online Library]. *European Environment*, *3*(1), 13–17.

Briassoulis, H. (2004). Policy integration for complex policy problems: What, why and how. *Greening of Policies: Interlinkages and Policy Integration, Berlin*, 3–4.

Briassoulis, H. (2011). Governing desertification in Mediterranean Europe: The challenge of environmental policy integration in multi-level governance contexts [Publisher: Wiley Online Library]. *Land Degradation & Development*, *22*(3), 313–325.

Butsch, C., Kumar, S., Wagner, P. D., Kroll, M., Kantakumar, L. N., Bharucha, E., Schneider, K., & Kraas, F. (2017). Growing 'smart'? Urbanization processes in the Pune urban agglomeration [Publisher: Multidisciplinary Digital Publishing Institute]. *Sustainability*, *9*(12), 2335.

Cairns, R., & Krzywoszynska, A. (2016). Anatomy of a buzzword: The emergence of 'the water-energy-food nexus' in UK natural resource debates [Publisher: Elsevier]. *Environmental Science & Policy*, *64*, 164–170.

Candel, J. J. L. (2019). The expediency of policy integration. *Policy Studies*, 1–16. https://doi.org/10.1080/01442872.2019.1634191

Candel, J. J. L., & Biesbroek, R. (2016). Toward a processual understanding of policy integration. *Policy Sciences*, *49*(3), 211–231. https://doi.org/10.1007/s11077-016-9248-y

Chang, Y., Li, G., Yao, Y., Zhang, L., & Yu, C. (2016). Quantifying the water-energy-food nexus: Current status and trends [Publisher: Multidisciplinary Digital Publishing Institute]. *Energies*, *9*(2), 65.

Chavez, A., Ramaswami, A., Nath, D., Guru, R., & Kumar, E. (2012). Implementing Trans-Boundary Infrastructure-Based Greenhouse Gas Accounting for Delhi, India. *Journal of Industrial Ecology*, *16*(6), 814–828. https://doi.org/https://doi.org/10.1111/j.1530-9290.2012.00546.x

Cheibub, J. A., Gandhi, J., & Vreeland, J. R. (2010). Democracy and dictatorship revisited [Publisher: Springer]. *Public choice*, *143*(1), 67–101.

Chen, S., Tan, Y., & Liu, Z. (2019). Direct and embodied energy-water-carbon nexus at an inter-regional scale. *Applied Energy*, *251*. https://doi.org/10.1016/j.apenergy.2019.113401

Chini, C. M., Schreiber, K. L., Barker, Z. A., & Stillwell, A. S. (2016). Quantifying Energy and Water Savings in the U.S. Residential Sector [Publisher: American Chemical Society]. *Environmental Science & Technology*, *50*(17), 9003–9012. https://doi.org/10.1021/acs.est.6b01559

Chini, C. M., & Stillwell, A. S. (2020). Envisioning Blue Cities: Urban Water Governance and Water Footprinting [Publisher: American Society of Civil Engineers]. *Journal of Water Resources Planning and Management*, *146*(3), 04020001.

Cities, 1. R. (2017). Amman Resilience Strategy. Retrieved July 6, 2021, from https://resilientcitiesnetwork.org/downloadable_resources/Network/Amman-Resilience-Strategy-English.pdf

Clark, W. C., Van Kerkhoff, L., Lebel, L., & Gallopin, G. C. (2016). Crafting usable knowledge for sustainable development [Publisher: National Acad Sciences]. *Proceedings of the National Academy of Sciences*, *113*(17), 4570–4578.

Covarrubias, M. (2018). The nexus between water, energy and food in cities: Towards conceptualizing socio-material interconnections. *Sustainability Science*, *14*(2), 277–287. https://doi.org/10.1007/s11625-018-0591-0

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry [Publisher: Taylor & Francis]. *Theory into practice*, *39*(3), 124–130.

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. *Applied Energy*, *210*, 393–408. https://doi.org/10.1016/j.apenergy.2017.08.243

Das, K. (2006). Drinking Water and Sanitation in Rural Maharashtra: A Review of Policy Initiatives. *Gujarat Institute of Development Research. Ahmedabad September*.

Dayyeh, A. A. (2020). Energy strategy 2020 — 2030. *Jordan Times*. Retrieved August 4, 2021, from http://www.jordantimes.com/opinion/ayoub-abu-dayyeh/energy-strategy-2020-%E2%80%94%C2%A02030

De Stercke, S., Chaturvedi, V., Buytaert, W., & Mijic, A. (2020). Water-energy nexus-based scenario analysis for sustainable development of Mumbai [Publisher: Elsevier]. *Environmental Modelling & Software*, *134*, 104854.

DeBenedictis, A., Haley, B., Woo, C. K., & Cutter, E. (2013). Operational energy-efficiency improvement of municipal water pumping in California. *Energy*, *53*, 237–243. https://doi.org/10.1016/j.energy.2013.02.012

de Boer, J., de Witt, A., & Aiking, H. (2016). Help the climate, change your diet: A cross-sectional study on how to involve consumers in a transition to a low-carbon society [Publisher: Elsevier]. *Appetite*, *98*, 19–27.

DeNooyer, T. A., Peschel, J. M., Zhang, Z., & Stillwell, A. S. (2016). Integrating water resources and power generation: The energy–water nexus in Illinois [Publisher: Elsevier]. *Applied energy*, *162*, 363–371.

Department, W. R. (2019). Maharashtra State Water Policy. Retrieved July 1, 2021, from https://wrd.maharashtra.gov.in/Site/Upload/PDF/State%20Water%20Policy%2005092019-pages-32-55.pdf

Doiron, R., & Asselin, M. (2015). Ethical dilemmas for researchers working in international contexts. *IASL Annual Conference Proceedings*, 112–122.

Dupont, C., & Oberthür, S. (2012). Insufficient climate policy integration in EU energy policy: The importance of the long-term perspective. *Journal of Contemporary European Research*, *8*(2).

Eltinay, N. (2019). City-to-city exchange: Redefining "resilience" in the Arab region [Publisher: Emerald Publishing Limited]. *International Journal of Disaster Resilience in the Built Environment*.

Eriksson, O., Reich, M. C., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., Baky, A., & Thyselius, L. (2005). Municipal solid waste management from a systems perspective [Publisher: Elsevier]. *Journal of cleaner production*, *13*(3), 241–252.

Fabinyi, M., Evans, L., & Foale, S. J. (2014). Social-ecological systems, social diversity, and power: Insights from anthropology and political ecology [Publisher: JSTOR]. *Ecology and society*, *19*(4).

Fan, J.-L., Kong, L.-S., Wang, H., & Zhang, X. (2019). A water-energy nexus review from the perspective of urban metabolism. *Ecological Modelling*, *392*, 128–136. https://doi.org/10.1016/j.ecolmodel.2018.11.019

FAO. (2014). *The water-energy-food nexus: A new approach in support of food security and sustainable agriculture*. FAO Rome.

for Citizenship and Democracy, J. C. (2017). Annual survey of India's city-systems (AsICS). Retrieved July 10, 2021, from https://janaagraha.org/asics/report/ASICS-report-2017-fin.pdf

Franco, S., Mandla, V. R., & Ram Mohan Rao, K. (2017). Urbanization, energy consumption and emissions in the Indian context A review. *Renewable and Sustainable Energy Reviews*, *71*, 898–907. https://doi.org/10.1016/j.rser.2016.12.117

Frank, B., Delano, D., & Caniglia, B. S. (2017). Urban systems: A socio-ecological system perspective. *Sociol. Int. J*, *1*(1), 1–8.

FUSE. (2020). Pune Household Survey. unpublished

FUSE. (2021). Food Water Energy for Urban Sustainable Environments (FUSE). Retrieved March 9, 2021, from https://fuse.stanford.edu/

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating ecological, carbon and water footprint into a "footprint family" of indicators: Definition and role in tracking human pressure on the planet [Publisher: Elsevier]. *Ecological indicators*, *16*, 100–112.

GAM. (2019). The Amman Climate Plan. A Vision for 2050 Amman. Retrieved June 16, 2021, from https://bit.ly/3zcCNA3

Gao, H., Scherson, Y. D., & Wells, G. F. (2014). Towards energy neutral wastewater treatment: Methodology and state of the art [Publisher: Royal Society of Chemistry]. *Environmental science: Processes & impacts*, *16*(6), 1223–1246.

Gerbens-Leenes, P. W., Hoekstra, A. Y., & Bosman, R. (2018). The blue and grey water footprint of construction materials: Steel, cement and glass [Publisher: Elsevier]. *Water resources and industry*, *19*, 1–12.

Ghodsvali, M., Krishnamurthy, S., & de Vries, B. (2019). Review of transdisciplinary approaches to food-water-energy nexus: A guide towards sustainable development. *Environmental Science and Policy*, *101*, 266–278. https://doi.org/10.1016/j.envsci.2019.09.003

Gibbs, G. R. (2007). Thematic coding and categorizing [Publisher: Sage Thousand Oaks, CA]. *Analyzing qualitative data*, *703*, 38–56.

Gleick, P. H. (1994). Water and energy [Publisher: Annual Reviews 4139 El Camino Way, PO Box 10139, Palo Alto, CA 94303-0139, USA]. *Annual Review of Energy and the environment*, *19*(1), 267–299.

Gondhalekar, D., & Ramsauer, T. (2017). Nexus city: Operationalizing the urban water-energy-food nexus for climate change adaptation in Munich, Germany [Publisher: Elsevier]. *Urban Climate*, *19*, 28–40.

Government, J. (2021a). Ministry of Water and Irrigation. Retrieved July 24, 2021, from https://bit.ly/3y3q417

Government, J. (2021b). Municipality of Greater Amman. Retrieved July 24, 2021, from https://bit.ly/3sySTl4

Grove, J. M., Pickett, S. T. A., Whitmer, A., & Cadenasso, M. L. (2013). Building an Urban LTSER: The Case of the Baltimore Ecosystem Study and the D.C./B.C. ULTRA-Ex Project. In S. J. Singh, H. Haberl, M. Chertow, M. Mirtl, & M. Schmid (Eds.), *Long Term Socio-Ecological Research: Studies in Society-Nature Interactions Across Spatial and Temporal Scales* (pp. 369–408). Springer Netherlands. https://doi.org/10.1007/978-94-007-1177-8_16

Hagemann, N., & Kirschke, S. (2017). Key issues of interdisciplinary NEXUS governance analyses: Lessons learned from research on integrated water resources management [Publisher: Multidisciplinary Digital Publishing Institute]. *Resources*, *6*(1), 9.

Halbe, J., Pahl-Wostl, C., A. Lange, M., & Velonis, C. (2015). Governance of transitions towards sustainable development – the water–energy–food nexus in Cyprus. *Water International*, *40*(5-6), 877–894. https://doi.org/10.1080/02508060.2015.1070328

Hamiche, A. M., Stambouli, A. B., & Flazi, S. (2016). A review of the water-energy nexus [Publisher: Elsevier]. *Renewable and Sustainable Energy Reviews*, *65*, 319–331.

Hartley, J. (1994). *Case studies in organizational research: Qualitative methods in organizational research, a practical guide*. London, UK: Sage.

Heard, B. R., Miller, S. A., Liang, S., & Xu, M. (2017). Emerging challenges and opportunities for the food–energy–water nexus in urban systems [Publisher: Elsevier]. *Current Opinion in Chemical Engineering*, *17*, 48–53.

Heynen, A. P., Lant, P. A., Sridharan, S., Smart, S., & Greig, C. (2019). The role of private sector off-grid actors in addressing India's energy poverty: An analysis of selected exemplar firms delivering household energy [Publisher: Elsevier]. *Energy and Buildings*, *191*, 95–103.

Hoekstra, A. Y., Chapagain, A. K., Mekonnen, M. M., & Aldaya, M. M. (2011). *The water footprint assessment manual: Setting the global standard*. Routledge.

Hoekstra, A. Y. (2012). The hidden water resource use behind meat and dairy [Publisher: Oxford University Press]. *Animal frontiers*, *2*(2), 3–8.

Hoekstra, A. Y. (2016). A critique on the water-scarcity weighted water footprint in LCA [Publisher: Elsevier]. *Ecological indicators*, *66*, 564–573.

Hoekstra, A., Chapagain, A., & van Oel, P. (2019). Progress in water footprint assessment: Towards collective action in water governance. *Water (Switzerland)*, *11*(5). https://doi.org/10.3390/w11051070

Hoff, H. (2011). Understanding the Nexus. Background paper for the Bonn2011 Nexus conference: The Water, Energy and Food Security Nexus. Retrieved February 16, 2021, from https://mediamanager.sei.org/documents/Publications/SEI-Paper-Hoff-UnderstandingTheNexus-2011.pdf

Hussein, H. (2018). Tomatoes, tribes, bananas, and businessmen: An analysis of the shadow state and of the politics of water in Jordan [Publisher: Elsevier]. *Environmental Science & Policy*, *84*, 170–176.

Hussien, W. A., Memon, F. A., & Savic, D. A. (2018). A risk-based assessment of the household water-energy-food nexus under the impact of seasonal variability. *Journal of Cleaner Production*, *171*, 1275–1289. https://doi.org/10.1016/j.jclepro.2017.10.094

Içduygu, A., & Nimer, M. (2020). The politics of return: Exploring the future of Syrian refugees in Jordan, Lebanon and Turkey [Publisher: Taylor & Francis]. *Third World Quarterly*, *41*(3), 415–433.

IPCC. (2006a). IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 - Energy. Retrieved June 14, 2021, from https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html

IPCC. (2006b). IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5 - Waste. Retrieved June 14, 2021, from https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

IPCC. (2019). Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — IPCC. Retrieved June 14, 2021, from https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

Jadhav, A. (2018). Environment Report has bad news for Pune: In 6 years, greenhouse gas emissions increase by 29%. https://indianexpress.com/article/cities/pune/environment-report-has-bad-news-for-pune-in-six-years-greenhouse-gas-emissions-increase-by-29-pc-5276578/

Jochim, A. E., & May, P. J. (2010). Beyond subsystems: Policy regimes and governance [Publisher: Wiley Online Library]. *Policy Studies Journal*, *38*(2), 303–327.

Jordan, A., & Lenschow, A. (2010). Environmental policy integration: A state of the art review [Publisher: Wiley Online Library]. *Environmental policy and governance*, *20*(3), 147–158.

Jordan, G., & Halpin, D. (2006). The political costs of policy coherence: Constructing a rural policy for Scotland [Publisher: Cambridge University Press]. *Journal of public policy*, *26*(1), 21–41.

Joshi, S. (2017). Politics of Water and Development: Case of Pune. *Understanding Built Environment* (pp. 161–169). Springer
footprint contained.

JWA. (2015). Water Distribution Program: Summer 2015.

Kale, R. V., & Pohekar, S. D. (2014). Electricity demand and supply scenarios for Maharashtra (India) for 2030: An application of long range energy alternatives planning. *Energy Policy*, *72*, 1–13. https://doi.org/10.1016/j.enpol.2014.05.007

Kantakumar, L. N., Kumar, S., & Schneider, K. (2020). What drives urban growth in Pune? A logistic regression and relative importance analysis perspective [Publisher: Elsevier]. *Sustainable Cities and Society*, *60*, 102269.

Karandish, F., & Hoekstra, Y., Arjen. (2017). Informing national food and water security policy through water footprint assessment: The case of Iran [Publisher: Multidisciplinary Digital Publishing Institute]. *Water*, *9*(11), 831.

Keast, R., Brown, K., & Mandell, M. (2007). Getting the right mix: Unpacking integration meanings and strategies [Publisher: Taylor & Francis]. *International Public Management Journal*, *10*(1), 9–33.

Khairnar, A. (2018). Finally, PMC's 24x7 water supply project gets nod, L&T bags contract. Retrieved August 5, 2021, from https://www.hindustantimes.com/pune-news/finally-pmc-s-24x7-water-supply-project-gets-nod-l-t-bags-contract/story-BP0MaV8ru5S74AHsjzQL5L.html

Klassert, C., Gawel, E., Sigel, K., & Klauer, B. (2018). Sustainable Transformation of Urban Water Infrastructure in Amman, Jordan – Meeting Residential Water Demand in the Face of Deficient Public Supply and Alternative Private Water Markets. In S. Kabisch, F. Koch, E. Gawel, A. Haase, S. Knapp, K. Krellenberg, J. Nivala, & A. Zehnsdorf (Eds.), *Urban Transformations: Sustainable Urban Development Through Resource Efficiency, Quality of Life and Resilience* (pp. 93–115). Springer International Publishing. https://doi.org/10.1007/978-3-319-59324-1_6

Kohli, A., & Singh, P. (2013). *Routledge handbook of Indian politics*. Routledge.

Koppenjan, J. F. M., Koppenjan, J., & Klijn, E.-H. (2004). *Managing uncertainties in networks: A network approach to problem solving and decision making*. Psychology Press.

Koteswara Rao, D., & Chandrasekharam, D. (2019). Quantifying the water footprint of an urban agglomeration in developing economy. *Sustainable Cities and Society*, *50*, 101686. https://doi.org/10.1016/j.scs.2019.101686

Kounina, A., Margni, M., Bayart, J.-B., Boulay, A.-M., Berger, M., Bulle, C., Frischknecht, R., Koehler, A., i Canals, L. M., & Motoshita, M. (2013). Review of methods addressing freshwater use in life cycle inventory and impact assessment [Publisher: Springer]. *The International Journal of Life Cycle Assessment*, *18*(3), 707–721.

Kulkarni, H., Bhagwat, M., Kale, V., & Aslekar, U. (2019). *PUNE'S AQUIFERS Some Early Insights From A Strategic Hydrogeological Appraisal*. https://doi.org/10.13140/RG.2.2.11362.48326

Kulkarni, H., & Shankar, P. V. (2014). Groundwater resources in India: An arena for diverse competition. *Local Environment*, *19*(9), 990–1011. https://doi.org/10.1080/13549839.2014.964192

Kumar, P., & Saroj, D. P. (2014). Water–energy–pollution nexus for growing cities [Publisher: Elsevier]. *Urban Climate*, *10*, 846–853.

Kurian, M. (2017). The water-energy-food nexus: Trade-offs, thresholds and transdisciplinary approaches to sustainable development [Publisher: Elsevier]. *Environmental Science & Policy*, *68*, 97–106.

Kurian, M., Scott, C., Reddy, V. R., Alabaster, G., Nardocci, A., Portney, K., Boer, R., & Hannibal, B. (2019). One swallow does not make a summer: Siloes, trade-offs and synergies in the water-energy-food nexus [Publisher: Frontiers]. *frontiers in Environmental Science*, *7*, 32.

Lafferty, W., & Hovden, E. (2003). Environmental policy integration: Towards an analytical framework [Publisher: Frank Cass]. *Environmental politics*, *12*(3), 1–22.

Laffont, J.-J. (2008). Externalities [Publisher: Palgrave Macmillan]. *New Palgrave Dictionary of Economics*.

Lahn, G., Grafham, O., & Sparr, A. E. (2016). Refugees and energy resilience in Jordan. Research Paper. https://www.chathamhouse.org/sites/default/files/publications/research/2016-08-03-refugees-energy-jordan-lahn-grafham-sparr.pdf

Leach, G. (1976). *Energy and food production.* IPC Science; Technology Press.

Leck, H., Conway, D., Bradshaw, M., & Rees, J. (2015). Tracing the water–energy–food nexus: Description, theory and practice [Publisher: Wiley Online Library]. *Geography Compass*, *9*(8), 445–460.

Leonard-Barton, D. (1990). A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites [Publisher: INFORMS]. *Organization science*, *1*(3), 248–266.

Limited, A. (2021). Amman Green City Action Plan.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. sage.

Lombardi, M., Laiola, E., Tricase, C., & Rana, R. (2017). Assessing the urban carbon footprint: An overview. *Environmental Impact Assessment Review*, *66*, 43–52. https://doi.org/10.1016/j.eiar.2017.06.005

Longhurst, R. (2003). Semi-structured interviews and focus groups. *Key methods in geography*, *3*(2), 143–156.

Loubet, P., Roux, P., Loiseau, E., & Bellon-Maurel, V. (2014). Life cycle assessments of urban water systems: A comparative analysis of selected peer-reviewed literature [Publisher: Elsevier]. *water research*, *67*, 187–202.

Lyytimäki, J., Salo, H., Lepenies, R., Büttner, L., & Mustajoki, J. (2020). Risks of producing and using indicators of sustainable development goals [_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/sd.2102]. *Sustainable Development*, *28*(6), 1528–1538. https://doi.org/https://doi.org/10.1002/sd.2102

Macknick, J., Newmark, R., Heath, G., & Hallett, K. C. (2012). Operational water consumption and withdrawal factors for electricity generating technologies: A review of existing literature [Publisher: IOP Publishing]. *Environmental Research Letters*, *7*(4), 045802.

Madurai Elavarasan, R., Selvamanohar, L., Raju, K., Vijayaraghavan, R. R., Subburaj, R., Nurunnabi, M., Khan, I. A., Afridhis, S., Hariharan, A., & Pugazhendhi,

R. (2020). A holistic review of the present and future drivers of the renewable energy mix in Maharashtra, state of India [Publisher: Multidisciplinary Digital Publishing Institute]. *Sustainability*, *12*(16), 6596.

Mahatransco. (2017). Energy Mix Maharashtra. https://www.mahatransco.in/

Malik, R. P. S. (2002). Water-Energy Nexus in Resource-poor Economies: The Indian Experience. *International Journal of Water Resources Development*, *18*(1), 47–58. https://doi.org/10.1080/07900620220121648

Märker, C., Venghaus, S., & Hake, J.-F. (2018). Integrated governance for the food–energy–water nexus–The scope of action for institutional change [Publisher: Elsevier]. *Renewable and Sustainable Energy Reviews*, *97*, 290–300.

May, P. J., Sapotichne, J., & Workman, S. (2006). Policy coherence and policy domains [Publisher: Wiley Online Library]. *Policy Studies Journal*, *34*(3), 381–403.

McCurdy, D. B., & Fitchett, G. (2011). Ethical Issues in Case Study Publication: Making Our Case(s)" Ethically. *Journal of Health Care Chaplaincy*, *17*(1-2), 55–74. https://doi.org/10.1080/08854726.2011.559855

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges [Publisher: JSTOR]. *Ecology and society*, *19*(2).

McNamara, M. (2012). Starting to untangle the web of cooperation, coordination, and collaboration: A framework for public managers [Publisher: Taylor & Francis]. *International Journal of Public Administration*, *35*(6), 389–401.

Mekonnen, M. M., & Hoekstra, A. Y. (2012a). The blue water footprint of electricity from hydropower [Publisher: Copernicus GmbH]. *Hydrology and earth system sciences*, *16*(1), 179–187.

Mekonnen, M. M., & Hoekstra, A. Y. (2011). National water Footprint accounts: The green, blue and grey water Footprint of production and consumption. Volume 1: Main Report.

Mekonnen, M. M., & Hoekstra, A. Y. (2012b). A global assessment of the water footprint of farm animal products [Publisher: Springer]. *Ecosystems*, *15*(3), 401–415.

MEMR. (2017). Annual Report 2017. Retrieved June 30, 2021, from https://www.memr.gov.jo/ebv4.0/root_storage/en/eb_list_page/annual_report_2017.pdf

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research: A guide to design and implementation*. John Wiley & Sons.

Meyer, C. B. (2001). A case in case study methodology [Publisher: Sage Publications Sage CA: Thousand Oaks, CA]. *Field methods*, *13*(4), 329–352.

Mguni, P., & van Vliet, B. J. (2020). Rethinking the urban Nexus-Resilience and vulnerability at the urban Nexus of Water, Energy and Food (WEF). An introduction to the special issue.

Misra, S., & Kingdom, W. (2012). Improving Urban Water Supply & Sanitation Services. Retrieved July 10, 2021, from https://bit.ly/2XOilru

Miyahuna. (2019). *Annual Report 2019* (tech. rep.). Retrieved June 17, 2021, from https://www.miyahuna.com.jo/uploads/pdf_files/annual_reports/2019_en.pdf

Miyahuna. (2021). Miyahuna. Retrieved July 24, 2021, from https://miyahuna.com.jo/en

MoE. (2017). A National Green Growth Plan for Jordan. Retrieved June 30, 2021, from https://www.greengrowthknowledge.org/sites/default/files/A%20National%20Green%20Growth%20Plan%20for%20Jordan.pdf

MoE. (2020a). Green Growth National Action Plan 2021-2025, Energy Sector. Retrieved July 1, 2021, from https://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/20022_Jordan_Energy_v04_HL_Web.pdf

MoE. (2020b). Green Growth National Action Plan 2021-2025, Water Sector. Retrieved July 1, 2021, from https://www.greengrowthknowledge.org/sites/default/files/downloads/policy-database/20022_Jordan_Water_v03_HL_Web.pdf

MPIC. (2020). Jordan Response Plan for the Syria Crisis 2018-2020: Executive Summary (Jordan Response Platform). Amman. http://www.jrpsc.org/

Muller, M. (2015). The'nexus' as a step back towards a more coherent water resource management paradigm. *Water Alternatives*, *8*(1).

Mustafa, D., & Talozi, S. (2018). Tankers, Wells, Pipes and Pumps: Agents and Mediators of Water Geographies in Amman, Jordan. *Water Alternatives*, *11*, 916.

MWI. (2016a). Energy efficiency and renewable energy policy for the Jordanian water sector. Retrieved June 30, 2021, from http://extwprlegs1.fao.org/docs/pdf/jor167028.pdf

MWI. (2016b). National Water Strategy 2016-2025. Retrieved June 30, 2021, from https://www.liportal.de/fileadmin/user_upload/oeffentlich/Jordanien/10_ueberblick/National_Water_Strategy__2016-2025_-25.2.2016.pdf

NEPCO. (2019). Annual Report 2019. Retrieved July 2, 2021, from https://www.nepco.com.jo/store/DOCS/web/2019_en.pdf

Network, R. C. (2021). Our story. Retrieved July 7, 2021, from https://bit.ly/3kj9pC3

Newell, J., Goldstein, B., & Foster, A. (2019). A 40-year review of food-energy-water nexus literature and its application to the urban scale. *Environmental Research Letters*, *14*(7). https://doi.org/10.1088/1748-9326/ab0767

Nilsson, M., & Nilsson, L. J. (2005). Towards climate policy integration in the EU: Evolving dilemmas and opportunities [Publisher: Taylor & Francis]. *Climate Policy*, *5*(3), 363–376.

Nolan, L. B. (2015). Slum definitions in urban India: Implications for the measurement of health inequalities [Publisher: Wiley Online Library]. *Population and Development Review*, *41*(1), 59–84.

OECD. (2021). Green growth and sustainable development. Retrieved July 6, 2021, from https://www-oecd-org.proxy.library.uu.nl/greengrowth/

Olsson, G. (2015). *Water and energy: Threats and opportunities*. IWA publishing.

Ostrom, E., Gardner, R., Walker, J., Walker, J. M., & Walker, J. (1994). *Rules, games, and common-pool resources*. University of Michigan Press.

Parnell, S. (2016). Defining a global urban development agenda [Publisher: Elsevier]. *World Development*, *78*, 529–540.

Paskaleva, K. A. (2011). The smart city: A nexus for open innovation? *Intelligent Buildings International*, *3*(3), 153–171. https://doi.org/10.1080/17508975.2011.586672

Paterson, W., Rushforth, R., Ruddell, B. L., Konar, M., Ahams, I. C., Gironás, J., Mijic, A., & Mejia, A. (2015). Water footprint of cities: A review and suggestions for future research [Publisher: Multidisciplinary Digital Publishing Institute]. *Sustainability*, *7*(7), 8461–8490.

Peters, B. G. (2005). The search for coordination and coherence in public policy: Return to the center. *Unpublished paper. Department of Political Science. University of Pittsburgh*.

Peters, B. G. (2015). *Pursuing horizontal management: The politics of public sector coordination*. University Press of Kansas.

Peters, B. G. (2018). The challenge of policy coordination [Publisher: Taylor & Francis]. *Policy Design and Practice*, *1*(1), 1–11.

PMC. (n.d.). Reimagining Pune: Mission Smart City Detailed plan to transform Pune into a world-class Smart City. Retrieved July 17, 2021, from https://pmc.gov.in/informpdf/Smart_City/SPC_Part_1.pdf

PMC. (2012). City Development Plan of Pune City -2041 (revised). https://www.pmc.gov.in/sites/default/files/project-glimpses/Draft_City_Development_Plan_for_Pune_City_2041_Vol-1.pdf

PMC. (2014). Water Supply System For Pune City - Detailed Project Report February. Retrieved July 17, 2021, from https://www.pmc.gov.in/en/water-supply-system-for-pune-city-dpr14-02-14

PMC. (2017). Pune 24x7. Retrieved May 8, 2021, from https://www.pmc.gov.in/en/municipal-bond-program

PMC. (2020). Water Supply and Pumping Department: Overview and Functioning. Retrieved November 9, 2020, from http://www.pmc.gov.in/en/water?qt-water_supply_overview_and_functi=0

PMC. (2021a). All Departments. Retrieved July 10, 2021, from https://www.pmc.gov.in/en/all-departments

PMC. (2021b). Environment Department. Retrieved July 17, 2021, from https://pmc.gov.in/en/environment

PMC. (2021c). Water Supply and Pumping Department. Retrieved July 17, 2021, from https://pmc.gov.in/en/water

PMRDA. (2018). About PMRDA. Retrieved November 9, 2020, from http://www.pmrda.gov.in/background.html

POR. (2019). Resilience Strategy Pune (Draft). Retrieved July 17, 2021, from https://resilientpunehome.files.wordpress.com/2019/03/resilient-pune-draft-strategy_view.pdf

Praharaj, S., Han, J. H., & Hawken, S. (2018). Urban innovation through policy integration: Critical perspectives from 100 smart cities mission in India [Publisher: Elsevier]. *City, culture and society*, *12*, 35–43.

Ramaswami, A., Boyer, D., Nagpure, A. S., Fang, A., Bogra, S., Bakshi, B., Cohen, E., & Rao-Ghorpade, A. (2017). An urban systems framework to assess the trans-boundary food-energy-water nexus: Implementation in Delhi, India [Publisher: IOP Publishing]. *Environmental Research Letters*, *12*(2), 025008.

Ramaswami, A., Chavez, A., Ewing-Thiel, J., & Reeve, K. E. (2011). Two Approaches to Greenhouse Gas Emissions Foot-Printing at the City Scale. *Environmental Science & Technology*, *45*(10), 4205–4206. https://doi.org/10.1021/es201166n

Ramesh, M. (2003). *Studying public policy: Policy cycles and policy subsystems*. Don Mills, Ont.: Oxford University Press.

Rayner, J., & Howlett, M. (2009). Introduction: Understanding integrated policy strategies and their evolution [Publisher: Elsevier]. *Policy and Society*, *28*(2), 99–109.

Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leaves out [Publisher: IIED 3 Endsleigh Street, London WC1H ODD, United Kingdom]. *Environment and urbanization*, *4*(2), 121–130.

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning [Publisher: Springer]. *Policy sciences*, *4*(2), 155–169.

RIVM. (2021). National institute for public health and the environment. Retrieved March 14, 2021, from https://www.rivm.nl/en

RKI. (2021). COVID-19. Retrieved August 11, 2021, from https://www.rki.de/EN/Content/infections/epidemiology/outbreaks/COVID-19/COVID19.html

Rode, S. (2009). Sustainable drinking water supply in Pune metropolitan region: Alternative policies [Publisher: JSTOR]. *Theoretical and Empirical Researches in Urban Management*, *4*(1S), 48–59.

Romero-Lankao, P., McPhearson, T., & Davidson, D. J. (2017). The food-energy-water nexus and urban complexity [Publisher: Nature Publishing Group]. *Nature Climate Change*, *7*(4), 233–235.

Runhaar, H., Driessen, P., & Uittenbroek, C. (2014). Towards a systematic framework for the analysis of environmental policy integration [Publisher: Wiley Online Library]. *Environmental Policy and Governance*, *24*(4), 233–246.

Runhaar, H., Wilk, B., Persson, A., Uittenbroek, C., & Wamsler, C. (2018). Mainstreaming climate adaptation: Taking stock about "what works" from empirical research worldwide [Publisher: Springer]. *Regional environmental change*, *18*(4), 1201–1210.

Sabatier, P. A., & Jenkins-Smith, H. C. (1993). *Policy change and learning: An advocacy coalition approach*. Westview press.

Sanders, K. T. (2015). Critical review: Uncharted waters? The future of the electricity-water nexus [Publisher: ACS Publications]. *Environmental science & technology*, *49*(1), 51–66.

Scherer, L., & Pfister, S. (2016). Global water footprint assessment of hydropower. *Renewable Energy*, *99*, 711–720. https://doi.org/10.1016/j.renene.2016.07.021

Scott, C. A., Pierce, S. A., Pasqualetti, M. J., Jones, A. L., Montz, B. E., & Hoover, J. H. (2011). Policy and institutional dimensions of the water–energy nexus [Publisher: Elsevier]. *Energy Policy*, *39*(10), 6622–6630.

Seo, J., Park, J., Oh, Y., & Park, S. (2016). Estimation of total transport CO2 emissions generated by medium-and heavy-duty vehicles (MHDVs) in a sector of Korea [Publisher: Multidisciplinary Digital Publishing Institute]. *Energies*, *9*(8), 638.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects [Publisher: IOS press]. *Education for information*, *22*(2), 63–75.

Sigel, K., Klassert, C., Zozmann, H., Talozi, S., Klauer, B., & Gawel, E. (2017a). *Socioeconomic surveys on private tanker water markets in Jordan: Objectives, design and methodology* (tech. rep.). UFZ Discussion Paper.

Sigel, K., Klassert, C., Zozmann, H., Talozi, S., Klauer, B., & Gawel, E. (2017b). Urban water supply through private tanker water markets: An empirical market analysis of Amman, Jordan. Retrieved March 18, 2021, from https://www.ufz.de/index.php?de=20939&pub_id=24004

Simpson, G. B., & Jewitt, G. P. W. (2019). The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review. *Frontiers in Environmental Science*, *7*, 8. https://doi.org/10.3389/fenvs.2019.00008

Singh, D. A., & Gaur, A. S. (2013). Governance structure, innovation and internationalization: Evidence from India [Publisher: Elsevier]. *Journal of International Management*, *19*(3), 300–309.

Smajgl, A., Ward, J., & Pluschke, L. (2016). The water–food–energy Nexus–Realising a new paradigm [Publisher: Elsevier]. *Journal of Hydrology*, *533*, 533–540.

SOFRECO. (2010). Building development capacities of Jordanian Municipalities Baladiaty: The quest for decentralizing government in the Hashemite Kingdom of Jordan: Some preliminary findings of a situation analysis. Retrieved June 19, 2021, from https://bit.ly/3zaG5DR

Soltani, A., Sadiq, R., & Hewage, K. (2016). Selecting sustainable waste-to-energy technologies for municipal solid waste treatment: A game theory approach

for group decision-making [Publisher: Elsevier]. *Journal of Cleaner Production*, *113*, 388–399.

Stillwell, A. S., Clayton, M. E., & Webber, M. E. (2011). Technical analysis of a river basin-based model of advanced power plant cooling technologies for mitigating water management challenges [Publisher: IOP Publishing]. *Environmental Research Letters*, *6*(3), 034015.

Stojanovic, T., McNae, H. M., Tett, P., Potts, T. W., Reis, J., Smith, H. D., & Dillingham, I. (2016). The "social" aspect of social-ecological systems: A critique of analytical frameworks and findings from a multisite study of coastal sustainability [Publisher: JSTOR]. *Ecology and Society*, *21*(3).

Swilling, M., & Hajer, M. (2017). Governance of urban transitions: Towards sustainable resource efficient urban infrastructures [Publisher: IOP Publishing]. *Environmental Research Letters*, *12*(12), 125007.

Szerszynski, B., & Galarraga, M. (2013). Geoengineering knowledge: Interdisciplinarity and the shaping of climate engineering research [Publisher: SAGE Publications Sage UK: London, England]. *Environment and Planning A*, *45*(12), 2817–2824.

Talozi, S., Al Sakaji, Y., & Altz-Stamm, A. (2015). Towards a water–energy–food nexus policy: Realizing the blue and green virtual water of agriculture in Jordan [Publisher: Routledge]. *International Journal of Water Resources Development*, *31*(3), 461–482.

Thomas, G. (2021). *How to do your case study*. Sage.

Tosun, J., & Lang, A. (2017). Policy integration: Mapping the different concepts [Publisher: Routledge]. *Policy Studies*, *38*(6), 553–570.

Turner, J. (2014). Counting Carbon: The Politics of Carbon Footprints and Climate Governance from the Individual to the Global. *Global Environmental Politics*, *14*(1), 59–78. https://doi.org/10.1162/GLEP_a_00214

UCLG. (2013). *Municipalities on the frontline: The effects of the Syrian Crisis on local government in bordering countries (Turkey, Jordan, Lebanon)* (Mission report and recommendations). United Cities and Local Governments. Retrieved June 19, 2021, from https://bit.ly/3mp6Tgi

UFZ. (2021). FUSE: Nahrung Wasser Energie für eine nachhaltige urbane Umwelt. Retrieved July 30, 2021, from https://www.ufz.de/index.php?de=44339

UN. (2011). Cities and Climate Change Global Report on Human Settlements. Retrieved July 30, 2021, from https://unhabitat.org/sites/default/files/download-manager-files/Cities%20and%20Climate%20Change%20Global%20Report%20on%20Human%20Settlements%202011.pdf

UN. (2020). IAEG-SDGs. Inter-agency and Expert Group on SDG Indicators. Retrieved May 21, 2021, from https://unstats.un.org/sdgs/iaeg-sdgs/

Underdal, A. (1980). Integrated marine policy: What? why? how? [Publisher: Elsevier]. *Marine Policy*, *4*(3), 159–169.

Urbaniec, K., Mikulčić, H., Rosen, M. A., & Duić, N. (2017). A holistic approach to sustainable development of energy, water and environment systems [Publisher: Elsevier]. *Journal of cleaner production*, *155*, 1–11.

Urbinatti, A., Benites-Lazaro, L., Carvalho, C., & Giatti, L. (2020). The conceptual basis of water-energy-food nexus governance: Systematic literature review using network and discourse analysis. *Journal of Integrative Environmental Sciences*, *17*(2), 21–43. https://doi.org/10.1080/1943815X.2020.1749086

Vanham, D. (2016). Does the water footprint concept provide relevant information to address the water–food–energy–ecosystem nexus? [Publisher: Elsevier]. *Ecosystem services*, *17*, 298–307.

Vanham, D., Leip, A., Galli, A., Kastner, T., Bruckner, M., Uwizeye, A., Van Dijk, K., Ercin, E., Dalin, C., & Brandão, M. (2019). Environmental footprint family to address local to planetary sustainability and deliver on the SDGs [Publisher: Elsevier]. *Science of the Total Environment*, *693*, 133642.

Varone, F., Nahrath, S., Aubin, D., & Gerber, J.-D. (2013). Functional regulatory spaces [Publisher: Springer]. *Policy Sciences*, *46*(4), 311–333.

Venghaus, S., Märker, C., Dieken, S., & Siekmann, F. (2019). Linking environmental policy integration and the water-energy-land-(food-) nexus: A review of the European Union's energy, water, and agricultural policies [Publisher: Multidisciplinary Digital Publishing Institute]. *Energies*, *12*(23), 4446.

Villamayor-Tomas, S., Grundmann, P., Epstein, G., Evans, T., & Kimmich, C. (2015). The water-energy-food security nexus through the lenses of the value chain and the institutional analysis and development frameworks [Publisher: Water Alternatives Association]. *Water Alternatives*, *8*(1), 735–755.

Visseren-Hamakers, I. J. (2015). Integrative environmental governance: Enhancing governance in the era of synergies. *Current Opinion in Environmental Sustainability*, *14*, 136–143. https://doi.org/10.1016/j.cosust.2015.05.008

Voigt, P., & Von dem Bussche, A. (2017). The eu general data protection regulation (gdpr) [Publisher: Springer]. *A Practical Guide, 1st Ed., Cham: Springer International Publishing*, *10*, 3152676.

Wackernagel, M., Onisto, L., Bello, P., Linares, A. C., Falfán, I. S. L., Garcıa, J. M., Guerrero, A. I. S., & Guerrero, M. G. S. (1999). National natural capital accounting with the ecological footprint concept [Publisher: Elsevier]. *Ecological economics*, *29*(3), 375–390.

Weitz, N., Strambo, C., Kemp-Benedict, E., & Nilsson, M. (2017a). Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance. *Global Environmental Change*, *45*, 165–173. https://doi.org/10.1016/j.gloenvcha.2017.06.006

Weitz, N., Strambo, C., Kemp-Benedict, E., & Nilsson, M. (2017b). *Governance in the water-energy-food nexus: Gaps and future research needs*. Stockholm Environment Institute.

WHO. (2020). Healthy diet. Retrieved June 23, 2021, from https://www.who.int/news-room/fact-sheets/detail/healthy-diet

Wiedmann, T., & Minx, J. (2008). A definition of 'carbon footprint' [Publisher: Nova Science Publishers: Hauppauge, NY, USA]. *Ecological economics research trends*, *1*, 1–11.

Wright, L. A., Kemp, S., & Williams, I. (2011). Carbon footprinting': Towards a universally accepted definition [Publisher: Taylor & Francis]. *Carbon management*, *2*(1), 61–72.

Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

Yorke, V. (2013). Politics matter: Jordan's path to water security lies through political reforms and regional cooperation. *NCRR Trade Regulation, University of Bern, Bern*.

Yue, Q., & Guo, P. (2021). Managing agricultural water-energy-food-environment nexus considering water footprint and carbon footprint under uncertainty. *Agricultural Water Management*, *252*, 106899. https://doi.org/10.1016/j.agwat.2021.106899

Zafonte, M., & Sabatier, P. (1998). Shared beliefs and imposed interdependencies as determinants of ally networks in overlapping subsystems [Publisher: Sage Publications 6 Bonhill Street, London EC2A 4PU, UK]. *Journal of theoretical politics*, *10*(4), 473–505.

Zawaydeh, S., & Al-Ghandoor, A. (2017). *Decomposition analysis of CO2 emisssions of electricity generation in Jordan: Toward zero emissions. conference paper*.

Zhang, P., Zhang, L., Chang, Y., Xu, M., Hao, Y., Liang, S., Liu, G., Yang, Z., & Wang, C. (2019). Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resources, Conservation and Recycling*, *142*, 215–224. https://doi.org/10.1016/j.resconrec.2018.11.018

Zozmann, H., Klassert, C., Sigel, K., Gawel, E., & Klauer, B. (2019). Commercial Tanker Water Demand in Amman, Jordan—A Spatial Simulation Model of Water Consumption Decisions under Intermittent Network Supply [Publisher: Multidisciplinary Digital Publishing Institute]. *Water*, *11*(2), 254.

Appendix A

Interview guides

Interview guide Amman

Interviewee Code:

Interview Date:

Background interviewee:

- What is your current professional position?
- In which category would you group your organization (national/ regional/ local government, private, NGO, academic)?
- How are you professionally attached to the topics water and energy in Amman?

Nexus Awareness:

- Are you familiar with the term "nexus"?
- How is the term nexus commonly known and operationalized in Amman's politics?
- Are you aware of the identified water-energy nexus in Amman? - *(stating the figures/findings of material research)*
- Can you confirm the specific water-energy nexus issue in Amman?
- Are you professionally concerned with the specific nexus issue?

Background nexus issue:

- Which factors enhance the identified nexus (institutionally, materially, politically, …)?
- Is there another information in this regard you would like to share?

Institutional coverage of the nexus:

- How independent from the national level can the municipality govern its resource issues?
- Is there an institutional awareness for the specific water-energy issue?
- Which institutions are in charge of the specific components of the identified nexus (for example water and energy)?
- Do these institutions have a nexus awareness (generally/ for the specific one)?
- To what extent do they collaborate (for tackling the nexus)?
- Do they strive for policy integration towards the nexus?
- What hinders their collaboration?

Nexus policies:

- Which policies in place are relevant for governing the identified nexus?
- As how important for the identified nexus issue would you rate the following policies? – *(stating already examined policies)*

Interview guide Pune

Interviewee Code:

Interview Date:

Background interviewee:

- What is your current professional position?
- In which category would you group your organization (national/ regional/ local government, private, NGO, academic)?
- How are you professionally attached to the topics water and energy in Pune?

Nexus Awareness:

- Are you familiar with the term "nexus"?
- How is the term nexus commonly known and operationalized in Pune's politics?
- Are you aware of the identified water-energy nexus Pune? - *(stating the figures/findings of material research)*
- Can you confirm the specific water-energy nexus issue in Pune?
- Are you professionally concerned with the specific nexus issue?

Background nexus issue:

- Which factors enhance the identified nexus (institutionally, materially, politically, …)?
- Is there another information in this regard you would like to share?

Institutional coverage of the nexus:

- How independent from the national level can the municipality govern its resource issues?
- Is there an institutional awareness for the specific water-energy issue?
- Which institutions are in charge of the specific components of the identified nexus (for example water and energy)?
- Do these institutions have a nexus awareness (generally/ for the specific one)?
- To what extent do they collaborate (for tackling the nexus)?
- Do they strive for policy integration towards the nexus?
- What hinders their collaboration?

Nexus policies:

- Which policies in place are relevant for governing the identified nexus?
- As how important for the identified nexus issue would you rate the following policies? – *(stating already examined policies)*

Appendix B

Codebook

Code System Amman

1 energy
2 SDG
3 object, goal
4 water
4.1 tanker, tanker trucks
4.2 water supply, water provision
5 Challenge, issue, problem
6 nexus
6.1 policy coherence
6.2 policy integration
6.3 collaboration
6.4 water-energy
7 stakeholder, actor, engagement, partner
7.1 Ministry of Energy and Mineral Resources
7.2 Ministry of Water and Irrigation
7.3 GAM; Greater Amman Municipality

Code System Pune

1 energy
2 SDG
3 object, goal
4 water
4.1 unreliable, intermittent
4.2 water supply, water provision
4.3 demand
4.3 pumps, pumping
4.3 groundwater
5 Challenge, issue, problem
6 nexus
6.1 policy coherence
6.2 policy integration
6.3 collaboration
6.4 water-energy
7 stakeholder, actor, engagement, partner

Appendix C

FUSE Discussion Paper

FUSE Discussion Paper [Draft]

By Nelsha Athauda

The Urban Nexus Footprint Model: An Early Application

I. Background

The 1992 United Nations Conference on Environment and Development made the first call for the creation of sustainability indicators to measure the changes in the social, economic, political, and physical factors of sustainability. Since the summit, hundreds of indicators have been developed and aggregated (e.g. Ultra-fine particulate matter exposure, greenhouse gas emissions, etc.). However, interdisciplinary indicators are particularly valuable as they can reveal interdependencies between human resource use and long-term sustainability.

Different concepts of carbon (Rees, 1992) and water footprints (Hoekstra, 2011) have emerged as indicators that provide stakeholders with easily understandable information on the environmental effects of their resource consumption. However, the footprints model is generally focused on measuring the extent to which a single resource is used which can provide limited information of interdependencies between intertwined resource systems. Resources are vastly integrated and dependent on each other, especially within the nexus between food, water, and energy (Daher & Mohtar, 2012). For example, increasing electricity tariffs can decrease water pumping for irrigation, which can in turn affect the availability of certain food crops. These interdependencies have not received sufficient attention in research so far, despite their importance for finding pathways towards sustainable resource use.

The Nexus Footprint is an emerging indicator (Maiwald, 2021, *in preparation*) (Shu et al., 2021) (Wahl et al., 2021) that aims to quantify the intersections within the highly interconnected web of food, water, and energy systems of a given region. The purpose of the Nexus Footprint model is to provide values allowing stakeholders to visualize trends in urban resource consumption as well as to provide a scientific basis for objective comparison (Wahl et al., 2021).

2.1 Objective of the paper and description of case study areas

The purpose of this discussion paper is to test how a Nexus footprint could be operationalized empirically. To test whether such a method is applicable across different settings, three case study cities with unique resource management situations were selected:

1. The first case study examines Pune, India, a large urban city in the state of Maharashtra. Pune is shaped by water access disparities due to wealth inequality which results in disparities for rural populations as well as resource constraints due to the city's rapid urbanization (Butsch et al., 2017).

2. The second case study examines Amman, the capital city of Jordan, which faces an ongoing water shortage and is considered one of the most water-scarce countries in the world (Ray et al., 2012). Amman's water scarcity is impounded by rapid population growth and is further exacerbated by the effects of climate change. Jordan has a negative virtual water balance (Talozi et al., 2015), meaning that it exports more water than it imports which adds further stress on water sustainability.

3. The final case study city is Vienna, Austra which exhibits patterns of high water and carbon-intensive consumption. However, the majority of its electrical energy comes from renewable sources, there is innate access to high-quality drinking water supply, and relatively high self-sufficiency rates for food products (Leidwein et al., 2013).

	Pune, India	**Jordan, Amman**	**Vienna, Austria**
Population	3,124,458 (*Pune City Population Census 2011-2021 | Maharashtra*, n.d.)	4,000,000	1,945,000 (*Statistics Austria*, n.d.)
Average household size	4 (FUSE Survey)	5 (HEIS)	2.041 (*Statistics Austria*, n.d.)
Median Income	100000 rupees per capita per year (FUSE Survey)	900 JOD per capita per year (HEIS)	50,349 USD per capita per year in Austria (*OECD Better Life Index*, n.d.)
Climate	Hot semi-arid climate (BSh) bordering a tropical wet and dry (Aw)	Hot semi-arid (BSh)	Oceanic climate (Cfb)

Table 1: Case Study City Descriptions

II. Methods

2.1 The Nexus Footprint Concept

To assess food, water, and energy (FWE) resource consumption across our three case studies, we analyzed data on household consumption of various consumer goods and services as part of a bottom-up approach. The main concept of the Nexus footprint is the linkages between FWE resources. Basic indicators are derived from these resources as products for the bottom-up footprint assessment (as shown in Table 2). The indicators are based on consumption in the residential sector to provide a more accurate representation of average resource consumption per capita. The aim of compiling these indicators is to not only determine product consumption but to use them as a foundation to quantify the interactions within the FWE nexus, expressed with the involvement of at least two of the FWE components. The goal is to illustrate how resource consumption in one component can result in a nexus issue (Maiwald, 2021, *in preparation*).

There are numerous interrelations embedded between the dimensions of the FWE nexus. But these interrelations are only traceable during consideration of not only direct but also indirect resource consumption. In the case of water, indirect resource effects may be factors like energy consumption for water pumping, filtration, etc. Considering a carbon footprint, indirect resources are adopted that contribute to carbon consumption. One of such resources is often water (Koteswara Rao & Chandrasekharam, 2019; Lombardi et al., 2017). The fact that energy appears to be an indirect resource effect involved in water resource consumption and the other way around, as proven by previous research (see, among others, DeNooyer et al., 2016; Macknick et al., 2012; Sanders, 2015), is the starting point for a nexus footprint methodology. Additionally, food production compiles both a great amount of water and energy consumption (Mekonnen & Hoekstra 2011, 2012; Leach 1976) (Maiwald, 2021, *in preparation*).

Indirect interactions across FWE resource consumption are highlighted as an integral part of the urban nexus footprint concept. While the urban nexus footprint is oriented on goods that are discussed in many footprint studies, the nexus study is focused on finding relevant interactions within resource consumption in contrast to conventional footprints accumulating the total amount of water or energy consumed. A single footprint is unable to reveal nexus tensions (Chang et al., 2016). The nexus footprint approach demonstrates resource overuse or mismanagement that results from the consumption of the other nexus resources as it sets resource use into context. The reasons for the overuse or mismanagement may not be detected without analyzing the second resource that indirectly shapes the consumption of the first resource. In theory, the urban nexus footprint model will be able to capture these interactions (Maiwald, 2021, *in preparation*).

2.2 Operationalizing the Nexus Footprint concept

Various equations were used to calculate the nexus footprints values. Generally, the approach was to find data that quantifies the direct and indirect consumption on a city level and determine population averages. The first nexus footprint calculated was the green, blue, and grey water used to produce and process food in the average diet for each case study city (W_{FP}).

$$W_{FP} = \sum_{i=1}^{14} \quad F_i \cdot \omega_i \tag{1}$$

F_i: average consumption of food from category i ∈ $\{1,2,\ldots,14\}$ in kg per year. Annex X lists all 14 categories used as well as the data sources for each food item.
ω_i: global average water footprint per ton of F_i

Equation (1) displays the equation used to calculate the water footprint of selected food categories. The water footprint of each food item was calculated by applying the derived quantities per capita to global average water footprints (M^3 ton^{-1}) of 14 different food categories (Mekonnen & Hoekstra, 2011). The 14 food categories were selected based on the data availability and food item standardization across the three case study cities. The amount of food consumed by each case study city as well as the data source used to obtain each value is shown in Table S1 of the supplementary information. Different sources were utilized for standardization and data quality purposes.

$$C_{FP} = \sum_{i=1}^{14} \quad F_i \cdot c_i \tag{2}$$

F_i: average consumption of food from category i ∈ $\{1,2,\ldots,14\}$ in tons per year. Annex X lists all 14 categories used as well as the data sources for each food item.
c_i: greenhouse gas emissions per ton of F_i

The Carbon footprint for food (C_{FP}) in equation 2 multiplied each food quantity by their greenhouse gas emissions (Poore & Nemecek, 2018). These emissions were reported in carbon dioxide equivalents and thus include non-CO_2 greenhouse gases as well.

$$C_{Elec} = \sum_{i=1}^{n} \quad E_i \cdot \alpha_i \cdot \delta_i$$
(3)

E_i: Average electricity used for residential purposes per capita
α_i: Proportion of electricity generated by each energy source, i (oil, natural gas, coal, etc.)
δ_i: Direct carbon dioxide emissions factor for each type of fuel (i) based on IPCC reports

Carbon emissions from select energy sources (electricity, LPG, and kerosene) were calculated using global averages for CO2 emission factors for each fuel type (Gómez et al., 2006), as reported by the Intergovernmental Panel on Climate Change. Equation (3) shows the equation

used to calculate the carbon emissions of electricity. The proportion of electricity generated by each source was determined from state or national level data and the global averages for carbon dioxide emissions by electricity generation source were also reported by the IPCC.

$$C_W = \sum_{i=1}^{n} \quad W_w \cdot \alpha_i \cdot \delta_i$$
(4)

C_W: Carbon emissions for either piped public water supply or well water sources
W_w: Average electricity used to transport either piped public water supply or well water for residential purposes per capita
α_i: Proportion of electricity generated by each energy source, i (oil, natural gas, coal, etc.)
δ_i: Direct carbon dioxide emissions factor for each type of fuel (i) based on IPCC reports

Carbon emissions by water sources were calculated using averages of residential water consumption by source and multiplying the energy value by the carbon emissions factors for each case study by the carbon dioxide emitted through each electricity generation source. For example, equation 5 below shows the carbon dioxide emissions in Amman, Jordan from the piped public water supply. The amount of energy used to pump piped water was multiplied by the proportion of electricity generated from natural gas multiplied by the carbon dioxide emissions of natural gas in energy units. This number was added to the amount of energy used to pump piped water, multiplied by the proportion of electricity generated from oil multiplied by the carbon dioxide emissions of oil per energy unit. For Pune, India, households commonly operated electric pumps to increase the amount of water delivered through the pipes. The carbon emissions of this pumping were included in the value reported below.

$$C_{Tanker} = \frac{2 \cdot \beta \cdot \gamma}{WTanker} \qquad (5)$$

$CTanker$: Carbon emissions for water transported by tanker trucks
β: Average distance traveled by tanker trucks transporting water for residential consumers from water source to residential neighborhoods
γ: Carbon dioxide emitted per unit of distance travelled
$WTanker$: Amount of water transported by tanker trucks on average

The carbon emissions of tanker water were calculated by multiplying the average distance tanker trucks (Zozmann et al., 2019) traveled by two to obtain a round-trip distance, then by multiplying the emissions of a middle-duty vehicle truck (Seo et al., 2016) and dividing by the average weight of water carried by the truck.

Table S2 displays the data sources used to calculate values for each case study city. Variable names or ‘signs’ have been assigned to each variable to create clearer equations. F=kg, W=cubic meters of water, C=kg of CO2e, E=kwh

2.2.1 Direct Water Consumption

The overall water consumption W_{total} is calculated according to the following equation:

$W_{total} = W_{piped} + W_{tanker} + W_{well}$

W_{piped} : Average amount of water consumed from the public water supply delivered through pipes
W_{well} : Average amount of water consumed from the operation of public or private wells or borewells
W_{Tanker} : Average amount of water consumed from the services of a tanker truck delivery

2.2.2 Carbon footprint of direct energy consumption

To calculate the carbon footprint of direct energy consumption, we first establish the direct consumption of electricity and energy products:

Then, we calculate a carbon footprint:
$C_{total} = C_{Electric} + C_{fuel} + ...$

With

$C_{Electric} = \sum E * alpha * epsilon$

$C_{fuel} = \sum E * alpha * epsilon$

And so forth

2.3 Data Sources

The urban nexus footprint model provides a more specialized approach in detecting nexus issues. This model may reveal that two resources, in a specific geographic area, are strongly connected, allowing for a stronger understanding of resource interactions.

Municipal-level data was utilized whenever available to ensure a bottom-up perspective of the footprints and to accurately depict day-to-day urban resource consumption. The accuracy of results relates to the quality and quantity of data available (Koteswara Rao & Chandrasekharam, 2019). To examine the nexus footprint of an urban city, commodity data is to find average resource consumption values. However, at the city level (a small spatial scale), such data is not always readily available.

While utilizing data from the household level was prioritized, national-level data was used to supplement where household data was not available Values from peer-reviewed journals and grey literature reports were also utilized to fill information gaps.rehis ultinged a depiction of consumption patterns that is not able to characterize the exact peculiarities of smaller regions. Urban and related regional data can deliver valuable data that more accurately depicts urban complexities.

To calculate the water footprint for Pune, India, Household Consumer Expenditure information from the National Sample Survey Office (NSSO) was used to identify consumption quantities of food items. The energy calculations primarily utilized data from a household survey (Zhu et al. 2021, *in preparation*) conducted by the Helmholtz Centre for Environmental Research (UFZ) to obtain information on water and energy consumption.

For Amman, Jordan, expenditures for food were identified from the 2013 Household Expenditure and Income Survey (HEIS) (*Household Expenditure and Income Survey*, 2013). To convert expenditures (Jordan Dinar) to consumption quantities (Kilograms), market prices for food were averaged from the United Nations World Food Programme (World Food Programme, 2021).

Food consumption quantities from the exact municipalities were prioritized, however, some values were substituted by national-level data if the conversion from expenditure was unreliable or if the food category was unavailable at the municipal level. Substitutions were made using national-level data from FAOSTAT or in the case of Amman- the Jordan Department of Statistics. For Vienna, Austria, all food consumption data was sourced from FAOSTAT as municipal level consumption data was not available.

The FUSE survey is a household survey whose results will be published next year (Zhu et al. 2021, *in preparation*). The survey was conducted in 2020 and the data included data from 1,872 participants in Pune, India. Outliers beyond the 95th percentile were removed for standardized averages.

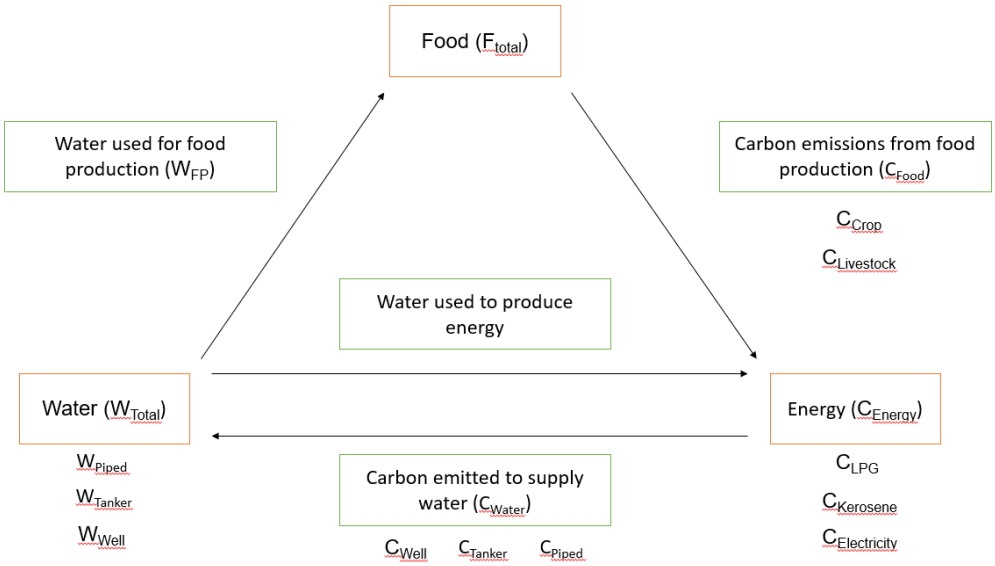


Figure 3: Nexus Footprints Conceptualization

III. Results

In the following, we present the outcome of this first application of a nexus footprint methodology before proceeding to discuss relevant findings for each case study in Section 4.

Food

Table 2 indicates the results of our footprint estimation for the water and carbon footprints of food consumption. The lowest water and carbon footprints for food consumption were in Pune, India, estimated at 634.4 m^3 per year per capita and 729.9 kg CO2e, respectively. The highest water and carbon footprints for food consumption were in Vienna, Austria, estimated at 1358.8 m^3 per year per capita and 2515.835 kg CO2e.

Vienna's footprints were higher than values in Amman or Pune due to the higher consumption of animal products. The food items contributing to Vienna's higher footprints were beef, pigmeat, milk, and butter. The amount of food consumed by each case study city is shown in Table S1 of the supplementary information.

Variable	Pune, India		Amman, Jordan		Vienna, Austria	
	Value	**Year**	**Value**	**Year**	**Value**	**Year**
Direct food consumption per capita for selected food categories	454.7 kg	2012	553.1 kg	2013	547.65 kg	2018
Water footprint of food consumption	634.4 m^3	2012	998.3m^3	2013	1358.814 m^3	2018
Carbon footprint of food consumption	729.9 kg CO2e	2012	1804.089 kg CO2e	2013	2515.835 kg CO2e	2018

Table 2: Food-related Nexus Footprint data

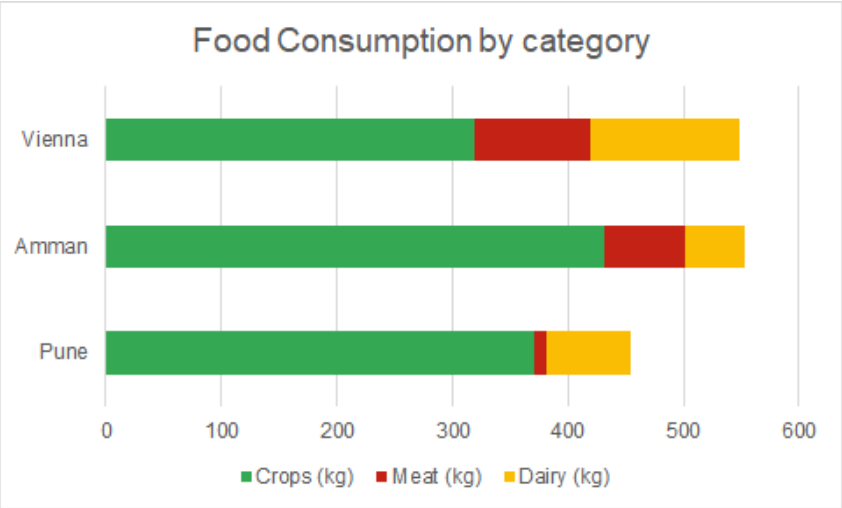
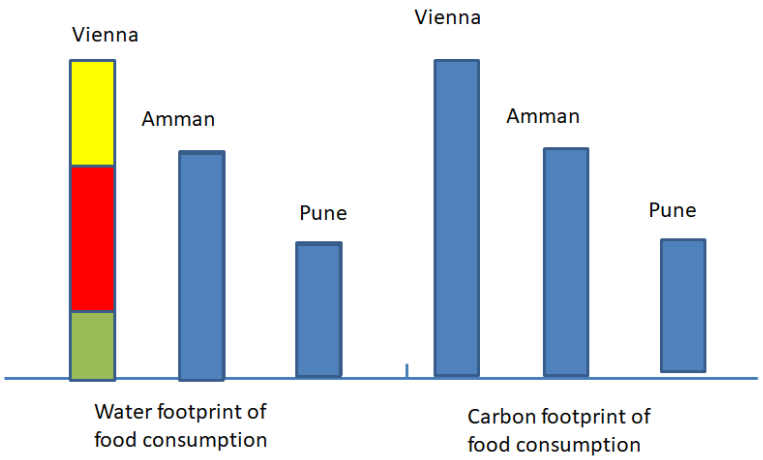
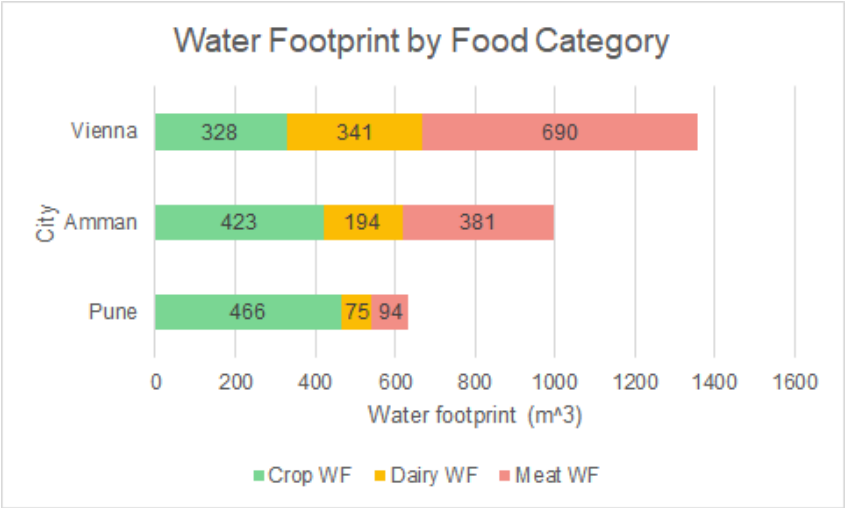
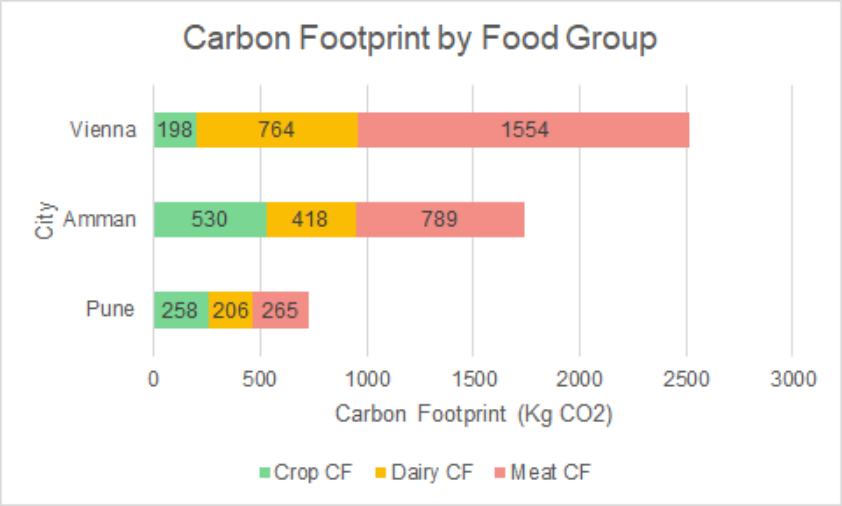


Figure 1: Food consumption quantities (kg) by crop, meat, and dairy categories


Vienna
Amman
Pune
Vienna
Amman
Pune
Water footprint of food consumption
Carbon footprint of food consumption


Water Footprint by Food Category
City
Vienna
Amman
Pune
328
341
690
423
194
381
466
75
94
0
200
400
600
800
1000
1200
1400
1600
Water footprint (m^3)
Crop WF
Dairy WF
Meat WF



Water

The average residential water consumption per capita per year of the public network water, tanker truck water, and well water was calculated for each case study city. Pune utilized all three water sources. Amman utilized network and tanker truck water only as the drilling and pumping of new wells is illegal in Jordan (Molle et al., 2017). In Vienna, tanker trucks are not utilized as the public network water is accessible and safe for consumption. While about 3% of the public water supply is pumped from groundwater during maintenance or emergency use, electricity is generated from the water's natural gravity flow resulting in a net gain of electricity (Vienna Water, n.d.).

Variable	Pune, India		Amman, Jordan		Vienna, Austria	
	Value	Year	Value	Year	Value	Year
Direct network/piped water consumption per capita	37.75 m^3	2020	45.9 m^3	2013	51.1 m^3	2012
Direct tanker water consumption per capita	0.01037 m^3	2020	3.89 m^3	2015	0 m^3	NA
Direct well water consumption per capita	0.06674 m^3	2020	NA	NA	NA	NA

Direct total water consumption per capita	37.83 m^3		49.79 m^3		51.1 m^3	

Table 3: Direct water source consumption per capita

Energy

Electricity generation sources for Vienna and Amman came from national-level IEA data which revealed that 79% of Austria's electricity came from renewable sources (mostly hydroelectric). The remaining sources were mostly natural gas, coal, and biofuels. Jordan's electricity generation sources changed drastically every year, however, for 2018, the majority was sourced from natural gas and oil with only 11% from renewable sources. Pune's electricity generation source data came from the Maharashtra State Power Generation Company, a state-level source which revealed a 75% proportion of electricity generated from the burning of coal which emits the most carbon dioxide out of the sources used by the three case studies (94,600 kg of CO2 per TJ). Graphs depicting these electricity generation sources are in Figure S1 of the supplementary information.

Variable	**Pune, India**		**Amman, Jordan**		**Vienna, Austria**	
	Value	**Year**	**Value**	**Year**	**Value**	**Year**
Carbon emissions of average residential electricity generation per capita per year (kg CO2)	111.4 kg of CO2**	2019	146.2726 kg of CO2*	2015	94.3 kg of CO2*	2015
Carbon emissions of average residential kerosene consumption per capita per year	22.87209 kg of CO2	2019	23.18167 kg of CO2	2019	0 kg of CO2	NA
Carbon emissions of average residential LPG consumption	120.7429 kg of CO2	2019	135.91 kg of CO2	2018	0 kg of CO2	NA

per capita per year						
Carbon emissions of average residential energy consumption for selected sources per capita (kg of CO2)	254.9 kg of CO2		305.4 kg of CO2		94.3 kg of CO2	
*Indicates data provided by national-level data **Electricity generation sources and proportions were calculated from data provided on the state-level						

Table 4: Carbon emissions of electricity, kerosene, and LPG

Table 5 displays the carbon dioxide emissions of water from selected sources (public water supply, tanker trucks, and wells) which provided a diverse set of results. Vienna had at least 0 kg of CO2 emissions from its water supply as 97% water is transported down the Lower Austrian-Styrian Alps without the need for pumps and is used to generate electricity.

89.7% of Amman's carbon emissions from its water supply came from the electricity-intensive aquifer pumping conveyance system. The remaining emissions came from public and private water tanker trucks which sell directly to consumers.

Pune had the highest carbon emissions from water due to the energy-intensive operation of pumps used to obtain well water. The 10.42 kg of carbon dioxide emissions for private water pumping included the pumping to extract water from wells as well as the pumping used to extract piped public water at a higher pressure.

Variable	**Pune, India**		**Amman, Jordan**		**Vienna, Austria**	
	Value	**Year**	**Value**	**Year**	**Value**	**Year**
Carbon emissions for public network water pumping (kg CO2/capita/year)	3.6 kg of CO2	2020	36.49067 kg of CO2	2014 & 2013 data	0 kg of CO2	2017

Carbon emissions used for tanker water consumption (kg CO2/capita/year)	0.0088 kg of CO2	2020	4.24 kg of CO2	2019	0 kg of CO2	NA
Carbon emissions for private water pumping from wells and for residential augmentation of public supply (kg CO2/capita/year)	7.06 kg of CO2	2020	NA	NA	NA	NA
Carbon emissions for selected residential water sources (kg CO2/capita/year)	10,66 kg of CO2		40.7 kg of CO2		0 kg of CO2	

Table 5: Carbon emissions from selected energy sources

IV. Discussion

Before addressing the limitations, we first have to highlight our most relevant results and contextualize them.

A few, first ideas:

- Pune & Amman: An insufficient public water supply system leads to the use of carbon-intensive alternatives among households
- Vienna: Meat and dairy heavy diets almost make up for having a lot of renewables and not requiring energy to pump water
    - Highlighting why food matters
- All studies: Differences in income lead to ...

Relevance

- Our analysis showed that even through a relatively simple analysis, nexus interdependencies can be revealed and quantified
- This rather “inexpensive” indicator can thus be a good complement for the in-depth studies of water or carbon footprint, as it sketches how individual resources systems interact

- We can identify vulnerable groups by differentiating income and other factors
- We demonstrated how through mostly publicly available data, supplemented by household surveys whereever possible, we can get a indication for nexus governance action field
- Governance should overcome silo thinking for sustainability policies, e.g. by improving water supplies, substantial carbon emission reductions can be accomplished
-

Limitations and potentials for future applications of the framework

This early operationalization of the FWE nexus model has several limitations and is meant to serve as an exploration of the model's potential capabilities. The data quality could have been vastly improved through the publication of further household-level data in Austria and more regional energy consumption data across all three case studies. Both the carbon and water footprint calculation relied on global averages for carbon emissions factors which severely impacted accuracy. Jordan imports up to 95% of its food (Vasquez & Khraishy, 2015) and would likely have much higher greenhouse gas emissions for food than India or Vienna which have higher agricultural capabilities and rely far less on food imports. Another major limitation was the lack of both recent and consistent data. Several calculations were required to rely on data from different years or data from 2012 without more recent data points to use.

The selected energy sources omitted fuels used to heat residences, which is likely to be substantial in Vienna. Finally, we cannot get a system-wide picture of sustainability through the bottom-up approach. Analyses such as this one should be complemented by top-down input-output material flow analyses

V. Conclusion

The early operationalization of the FWE Nexus model showed that the nexus model is a useful sustainability capability as it is capable of providing a focused perspective on resource interdependencies within the food, water, and energy resource nexus.

Future FWE nexus models should work on the bottom-up approach to study the urban resource consumption patterns. This model is useful in identifying mismanaged resources and inequalities in resource access which provides it with the potential to affect resource management policy.

VI. Supplementary Information

Table S3 displays the source of the quantity of each food item used to calculate the food water footprint for each case study cite. Pune, India primarily relied on city-level data from the NSSO Survey (National Sample Survey Office, 2013). Amman, Jordan used city-level food item expenditure data from the HEIS Survey (*Household Expenditure and Income Survey*, 2013). Vienna almost entirely relied on nation-level FAOSTAT data (Food and Agriculture Association of the United Nations, 2021). FAOSTAT data was also used to supplement quantities in Pune and Amman when it was required for standardization purposes. Data from JDOS (Jordan Department of Statistics, 2019) and Statistics Austria (*Statistics Austria*, n.d.) were used for the same purposes.

	Pune		**Amman**		**Vienna**	
	Food (kg)	**Data Source**	**Food (kg)**	**Data Source**	**Food (kg)**	**Data Source**
Vegetables	89.1	FAOSTAT	137.4	HEIS	87.7	FAOSTAT
Fruit	59.9	NSSO	65.9	HEIS	100.8	FAOSTAT
Cereals	182.9	FAOSTAT	119.9	JDOS	114.4	FAOSTAT
Pulses	12.6	NSSO	7.3	JDOS	0.7	FAOSTAT
Oil	3.0	NSSO	22.1	HEIS	0.0	FAOSTAT
Sugar	21.2	FAOSTAT	77.1	HEIS	14.0	FAOSTAT
Nuts	1.6	FAOSTAT	2.3	JDOS	1.0	FAOSTAT
Beef	2.8	NSSO	6.8	HEIS	16.7	FAOSTAT
Mutton	3.0	NSSO	5.3	HEIS	1.1	FAOSTAT
Pig	1.6	NSSO	0.0	FAOSTAT	49.0	FAOSTAT
Chicken	2.2	NSSO	41.8	HEIS	18.5	FAOSTAT

Eggs	1.6	NSSO	15.1	HEIS	15.3	FAOSTAT
Milk	73.3	NSSO	20.8	HEIS	82.2	Statistics Austria
Butter	0.1	FAOSTAT	31.2	JDOS	46.3	FAOSTAT
Total (kg)	454.7		553.1		547.7	
HEIS and NSSO data provided city-level data. JDOS and FAOSTAT data provided national-level data						

Table S1: Food quantities and data sources used to calculate water and carbon footprints for each case study city

			Data Sources		
	Sign	**Equations**	**Pune, India**	**Amman, Jordan**	**Vienna, Austria**
Average network (piped) water consumption per capita (m^3)	W_{Piped}	W_{Piped}	FUSE Survey	HEIS Survey	(*Water and Wastewater Services in the Danube Region*, 2015)
Average tanker water consumption per capita (m^3)	W_{Tanker}	W_{Tanker}	FUSE Survey	(Zozmann et al., 2019)	NA

Average well water consumption per capita (m^3)	W_{Well}	W_{Well}	FUSE Survey	NA	NA
Total average water consumption per capita for selected sources (m^3)	W_{Total}	$W_{total} = W_{piped} + W_{tanker} + W_{well}$			
Water footprint of food production (m^3)	W_{FP}	$W_{FP} = \sum$ (Cereals (kg) * Global average water footprint per ton of cereals ($m^3 ton^{-1}$)) + (Fruits (kg) * Global average water footprint per ton of fruits (m3ton-1) +…)	NSSO Survey; FAOSTAT, Mekonnen & Hoekstra, 2011	HEIS Survey; FAOSTAT; JDOS; World Food Programme; Mekonnen & Hoekstra, 2011	FAOSTAT; Mekonnen & Hoekstra, 2011
Carbon footprint of food production (kg CO2)	C_{Food}	$C_{FP} = \sum$ ((Cereals (kg) * CO2 for Cereals + Pulses (kg) * CO2 for Pulses ...)	Poore & Nemecek, 2018	Poore & Nemecek, 2018	Poore & Nemecek, 2018
Average residential electricity consumption per capita	$E_{Electric}$	$E_{Electric}$	FUSE Survey	Dar-Mousa & Markhamreh, 2019; Almuhtady et al, 2019; IEA	(*Statistics Austria*, n.d.)

Carbon emissions of average residential electricity generation per capita per year (kg CO2)	$C_{Electric}$	$C_{Electric}$ = ∑ (proportion of $E_{Electric}$ from Oil * CO2 emissions of Oil) +(proportion of $E_{Electric}$ from Natural Gas * CO2 emissions of Natural Gas + …			
Average residential kerosene consumption per capita per year	$E_{Kerosene}$	$E_{Kerosene}$	FUSE Survey	(*Ministry of Energy and Mineral Resources Annual Report*, 2017)	(*Statistics Austria*, n.d.)
Carbon emissions of average residential kerosene consumption per capita per year (kg CO2)	$C_{Kerosene}$				
Average residential LPG consumption per capita per year	E_{LPG}	E_{LPG}	FUSE Survey	(Al-Ghandoor, 2013)	(*Statistics Austria*, n.d.)
Carbon emissions of Average residential LPG consumption per capita per year	C_{LPG}				

Total average residential energy consumption for selected sources per capita	E_{Total}	$E_{total} = E_{Electric} + E_{Kerosene} + E_{LPG}$			
Carbon emissions of average residential energy consumption for selected sources per capita (kg of CO2)	C_{Energy}	Sources are for electricity	(*Carbon Inventory of Pune City*, 2012)	(Alkurd et al., 2018)	(Vienna City Administration, 2017)
Carbon emissions for network (piped) water consumption (kg CO2/capita/year)	C_{piped}	C_{piped} = CO2 from public water supply + CO2 from pumping piped water into households	FUSE Survey (Kumar et al., 2017)		(Vienna Water, n.d.)
Carbon emissions used for tanker water consumption (kg CO2/capita/year)	C_{tanker}	C_{Tanker} = (2 * Average distance * kg CO2 per km) / avg kg of water carried	FUSE Survey, Heinrich tanker survey	(Zozmann et al., 2019) (Seo et al., 2016)	
Carbon emissions for well water consumption (kg CO2/capita/year)	C_{well}		FUSE Survey		
Carbon emissions for selected residential water sources (kg CO2/capita/year)	C_{Water}	$C_{Water} = E_{piped} + E_{tanker} + E_{Well}$	FUSE Survey		

Table S2: Methodology and data sources for indicator calculation

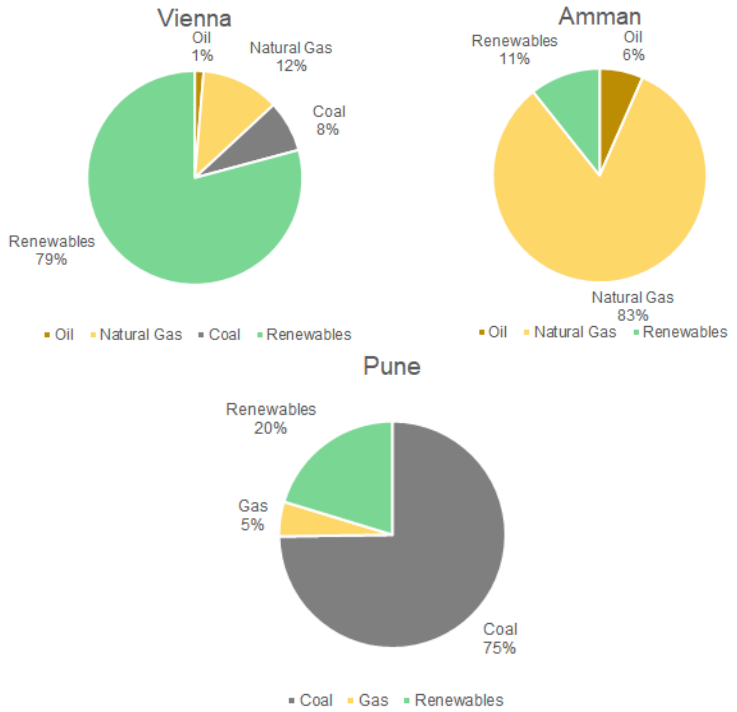


Figure S1: Electricity Generation Sources in Austria, Jordan, and Maharashtra State

Al-Ghandoor, A. (2013). Evaluation of energy use in Jordan using energy and exergy analyses. *Energy and Buildings*, *59*, 1–10. https://doi.org/10.1016/j.enbuild.2012.12.035

Alkurd, R., Takruri, H. R., & Amr, A. M. (2018). Trends of Energy and Macronutrients Intakes in Jordan as Obtained by Household Expenditure and Income Surveys. *Journal of Agricultural Science*, *11*(1), p191. https://doi.org/10.5539/jas.v11n1p191

Butsch, C., Kumar, S., Wagner, P. D., Kroll, M., Kantakumar, L. N., Bharucha, E., Schneider, K., & Kraas, F. (2017). Growing 'Smart'? Urbanization Processes in the Pune Urban Agglomeration. *Sustainability*, *9*(12), 2335. https://doi.org/10.3390/su9122335

Carbon Inventory of Pune City. (2012). The Energy and Resources Institute. https://www.pmc.gov.in/sites/default/files/miscellaneous/Carbon_Inventory_of_Pune_City_2012.pdf

Daher, B., & Mohtar, R. (2012). *Water, energy, and food: The Ultimate Nexus*. https://doi.org/10.1081/E-EAFE2-120048376

Food and Agriculture Association of the United Nations. (2021). *Food Balances*. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/FBS

Gómez, D., Watterson, J., Americano, B., Ha, C., Marland, G., Matsika, E., Nenge Namayanga, L., Osman-Elasha, B., Kalenga Saka, J., & Treanton, K. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. *2*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

Hoekstra, A. Y. (2011). *The water footprint assessment manual: Setting the global standard*. Earthscan.

Household Expenditure and Income Survey. (2013). Jordan Economic Research Forum. http://www.erfdataportal.com/index.php/catalog/128/study-description

Jordan Department of Statistics. (2019). *Agricultural Food Balance Sheet*. http://jorinfo.dos.gov.jo/Databank/pxweb/en/FoodBalanceSheet/

Kumar, P., Matto, M., & Sharda, C. (2017). *Mainstreaming Energy Efficiency in Unrabn Water and Wastewater Management in the Wake of Climate Change*. Centre for Science and Environment. https://cdn.cseindia.org/attachments/0.73120800_1505297784_Policy-Paper-Mainstreaming-Energy-Efficiency-in-Urban-Water.pdf

Leidwein, A., Kolar, V., Mechtler, K., Baumgarten, A., Berthold, H., Strauss, G., Steinwider, J., Maria Krachler, M., Weigl, M., Eitzinger, J., Formayer, H., Schlatzer, M., Rohrer, G., Längauer, M., Steinhäusler, F., Pichelstorfer, L., Vas, J., Teixeira, A. da S., Tribl, C., … Ortner, K. (2013). *Food security risks for Austria caused by climate change*. 664.

Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, *15*(5), 1577–1600. https://doi.org/10.5194/hess-15-1577-2011

Ministry of Energy and Mineral Resources Annual Report. (2017). Ministry of Energy and Mineral Resources. http://images.mofcom.gov.cn/jo/201807/20180729161644462.pdf

Molle, F., Al Karablieh, E., Al Naber, M., Closas, A., & Salman, A. (2017). *Groundwater Governance in Jordan The case of Azraq Basin*. https://ageconsearch.umn.edu/record/273350/files/H048395.pdf

National Sample Survey Office. (2013). *India—Household Consumer Expenditure, NSS 68th Round Sch1.0 Type 2: July 2011—June 2012, Type—2—Overview*. Ministry of Statistics & Programme Implementation. http://microdata.gov.in/nada43/index.php/catalog/126/study-description

OECD Better Life Index. (n.d.). Retrieved August 5, 2021, from https://www.oecdbetterlifeindex.org/countries/austria/

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Pune City Population Census 2011-2021 | Maharashtra. (n.d.). Retrieved August 5, 2021, from

https://www.census2011.co.in/census/city/375-pune.html

Ray, P. A., Kirshen, P. H., Rosenberg, D. E., & Hagan, R. E. (2012). *An Overview of the Water Situation in Amman, Jordan*. 1980–1989. https://doi.org/10.1061/41114(371)207

Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: What urban economics leaves out. *Environment and Urbanization*, *4*(2), 121–130. https://doi.org/10.1177/095624789200400212

Seo, J., Park, J., Oh, Y., & Park, S. (2016). Estimation of Total Transport CO2 Emissions Generated by Medium- and Heavy-Duty Vehicles (MHDVs) in a Sector of Korea. *Energies*, *9*, 638. https://doi.org/10.3390/en9080638

Shu, Q., Scott, M., Todman, L., & McGrane, S. J. (2021). Development of a prototype composite index for resilience and security of water-energy-food (WEF) systems in industrialised nations. *Environmental and Sustainability Indicators*, *11*, 100124. https://doi.org/10.1016/j.indic.2021.100124

Statistics Austria. (n.d.). Retrieved August 5, 2021, from http://www.statistik.at/web_en/statistics/PeopleSociety/social_statistics/index.html

Vasquez, O., & Khraishy, M. (2015). *Market Overview and Guide to Jordanian Market Requirements*. 22.

Vienna City Administration. (2017). *Energy! Ahead Energy Report of the City of Vienna*. Municipal Department 20 – Energy Planning. https://www.wien.gv.at/stadtentwicklung/energie/pdf/energiebericht2017-en.pdf

Vienna Water. (n.d.). *The Journey of Vienna's Drinking Water*. City of Vienna. Retrieved July 23, 2021, from https://www.wien.gv.at/english/environment/watersupply/supply/way.html

Wahl, D., Ness, B., & Wamsler, C. (2021). Implementing the urban food–water–energy nexus through urban laboratories: A systematic literature review. *Sustainability Science*, *16*(2), 663–676. https://doi.org/10.1007/s11625-020-00893-9