sustainability

MDPI

Article

Stakeholder Workshops Informing System Modeling—Analyzing the Urban Food–Water–Energy Nexus in Amman, Jordan

Bernd Klauer [1,*], Karin Küblböck [2], Ines Omann [2], Raphael Karutz [1], Christian Klassert [1], Yuanzao Zhu [1], Heinrich Zozmann [1], Mikhail Smilovic [3], Samer Talozi [4], Anjuli Jain Figueroa [5,6], Hannes Grohs [2], Jasmin Heilemann [1] and Steven Gorelick [5]

1 Helmholtz Centre for Environmental Research—UFZ, D-04318 Leipzig, Germany
2 Austrian Foundation for Development Research—ÖFSE, A-1090 Wien, Austria
3 International Institute for Applied Systems Analysis—IIASA, A-2361 Laxenburg, Austria
4 Methods for Irrigation and Agriculture (MIRRA), Amman 11194, Jordan
5 Woods Institute for the Environment, Stanford University, Stanford, CA 94305, USA
6 U.S. Department of Energy, Washington, DC 20585, USA
* Correspondence: bernd.klauer@ufz.de; Tel.: +49-341-235-1702

check for updates

Citation: Klauer, B.; Küblböck, K.; Omann, I.; Karutz, R.; Klassert, C.; Zhu, Y.; Zozmann, H.; Smilovic, M.; Talozi, S.; Figueroa, A.J.; et al. Stakeholder Workshops Informing System Modeling—Analyzing the Urban Food–Water–Energy Nexus in Amman, Jordan. *Sustainability* **2022**, *14*, 11984. https://doi.org/10.3390/su141911984

Academic Editor: Hossein Bonakdari

Received: 1 July 2022
Accepted: 18 September 2022
Published: 22 September 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: Large cities worldwide are increasingly suffering from a nexus of food, water, and energy supply challenges. This complex nexus can be analyzed with modern physico-economic system models. Only when practical knowledge from those affected, experts, and decision makers is incorporated alongside various other data sources, however, are the analyses suitable for policy advice. Here, we present a concept for "Sustainability Nexus Workshops" suitable for extracting and preparing relevant practical knowledge for nexus modeling and apply it to the case of Amman, Jordan. The experiences of the workshop participants show that, although water scarcity is the predominant resource problem in Jordan, there is a close connection between food, water, and energy as well as between resource supply and urbanization. To prevent the foreseeable significant degradation of water supply security, actions are needed across all nexus dimensions. The stakeholders demonstrate an awareness of this and suggest a variety of technical measures, policy solutions, and individual behavioral changes—often in combination. Improving the supply of food, water, and energy requires political and institutional reforms. In developing these, it must be borne in mind that the prevalent informal structures and illegal activities are both strategies for coping with nexus challenges and causes of them.

Keywords: food-water-energy nexus; nexus challenges; policy interventions; sustainable use of resources; stakeholder participation; sustainability nexus workshops; physico-economic system model; mega city; Amman

1. Introduction

The provision of food, water, and energy (FWE) is crucial for human well-being. Population growth, rising consumption, and growing urban agglomerations—typical dynamics in the Global South—increase the demand for the resources land, water, and energy [1–3] and bring about the danger of overexploitation of resources and degradation of the environment. There is ample evidence that addressing the FWE nexus requires realizing that these subsystems are intertwined and interdependent [4–6]. Pumping water needs energy; growing food needs irrigation water; land on which energy crops are grown or infrastructure is built cannot be used for food production. The planning, design, and implementation of long-term strategies for sustainable use of the resources land, water, and energy need to take these interdependencies into account and call for an integrated assessment approach that considers human decisions under different biophysical and economic constraints [7]. However, in political and economic practice, a tendency towards "silo thinking" has been detected [8].

In a systematic literature review on analyzing and solving urban food–water–energy nexus problems, Wahl et al. [9] emphasize the importance of stakeholder participation and found that research should not simply look at material flows, but should systematically analyze behaviors, habits, and social patterns. Promising tools for such an integrated assessment are physico-economic models, where model components representing the agricultural system, the water cycle, and the energy-production system are linked and combined with a multi-agent approach representing consumers, producers, administration, and political decision makers [10]. Such integrated systems models of the FWE nexus could be used to analyze the effects of alternative policy interventions under different scenarios with respect to a variety of evaluation metrics. However, if the FWE model aims at practically guiding policy makers and other stakeholders, its design is demanding. The model must be sufficiently detailed, precise, and fed with enough data from monitoring, statistics, and other empirical sources to represent the complexity of the natural and engineered hydrological system, the agro-ecological system as well as the economic system. However, to develop a comprehensive system understanding for the design of an auspicious FWE model, problem-specific practical and action knowledge is necessary [11]. Proper and effective methods for gaining such practical knowledge in early stages of a planning process are stakeholder workshops, where participants are confronted with problems and try to identify goals and alternative solutions [12].

Wahl et al. [9] also explore in their literature review the role that participatory approaches can have in analyzing and solving FWE nexus problems. They conclude that even short-term participatory approaches, such as the stakeholder workshop conducted by Treemore-Spears et al. [13], can support actions that lead to a more equitable and sustainable society [14]. However, Wahl et al. [9] identified only two approaches in which participation extends over a longer period of time [15,16]. This paper aims to present a further contribution in this regard.

Linking integrated systems modeling and long-term stakeholder participation to assess potential solutions to FWE problems is the focus of the FUSE project (https://fuse.stanford.edu/, accessed on 21 June 2022), which includes the work presented in this paper. FUSE addresses FWE nexus challenges particularly in urban agglomerations. More than half of the world's population lives in cities—and the trend is rising. In cities, FWE problems are particularly prominent due to the high density of users. FUSE stands for Food-Water-Energy for Urban Sustainable Environments and aims at implementable solutions to meet the urban-FWE challenge with a development path that is sustainable and adapted to local needs. We develop a concept for stakeholder workshops organized in two stages, called "Sustainability Nexus Workshops" (SNW) [17]) that link stakeholder participation with state-of-the-art integrated systems modeling in a co-creative process. The two stages extend over a period of ~3.5 years and include as essential elements phases with intensive stakeholder participation in the form of workshops in the first year (1st Stage) and last year (2nd Stage).

This paper focuses on the 1st Stage of the SNW and describes how the practical and action knowledge of stakeholders, i.e., specific information of their situation, but also their wishes, ideas, and visions about the future, could be gathered, processed, and turned into inputs for the design of an integrated physico-economic model of the FWE nexus in urban and peri-urban environments. Such a framing of a model is a creative act that—if it is to succeed—needs judgment and uses heuristics [18]. In this paper, a heuristic approach, i.e., a systematic way of processing the information collected at the stakeholder workshops during the 1st Stage, is offered. We will demonstrate how important model inputs, namely, a list of potential policy interventions, can be selected. More specifically, we will explain how the stakeholder workshops can be designed and organized to obtain a systematic overview over the FWE challenges in urban and peri-urban environments, and how, on this basis, a list of possible technical measures and policy interventions can be derived.

Knowledge gained in the 1st Stage about stakeholders' perception of FWE nexus challenges and solutions, and of the institutional structures in which both are embedded, can also help structure model analyses and prepare the 2nd Stage of nexus workshops in a way that enhances their relevance to stakeholders. The degree to which stakeholders are aware of nexus linkages, for example, provides an initial evaluation of the degree to which they might be open to consider policy interventions that account for several nexus dimensions simultaneously and overcome silo thinking.

To test the SNW concept for cities in the Global South, where resource scarcity and nexus challenges are particularly pressing, Amman, the capital of Jordan, and Pune, a mega city in south-west India, have been selected as case studies in the FUSE project. In this paper we concentrate on Amman and its greater metropolitan region that have been growing rapidly over the past two decades (for the results in Pune see [19]).

This paper pursues two closely related goals. First, it documents the empirical results of an analysis of the nexus challenges in Amman based on the 1st Stage Sustainability Nexus Workshops there. Second, it demonstrates conceptually how the Two-Stage Sustainability Nexus Workshop (SNW) approach developed in the FUSE project is used as a heuristic for the design of a complex integrated systems model for analyzing the FWE nexus.

After giving some basic facts about the FEW-nexus situation in Amman as well as the FUSE modeling approach there, Section 2 describes the concept of the SNW concept and explains how the stakeholder interaction in the workshops at the 1st Stage helped deepen the problem understanding. It guides the process of gathering and filtering the relevant information for the model development. Section 3 summarizes the results of the analysis for Greater Amman and gives an overview of the identified nexus challenges, potential solutions, and policy interventions that were brought up by the workshop participants. Section 4 discusses causes for nexus challenges in Amman and possible courses of action, looks at the role of informal institutions as causes of nexus challenges as well as leverage points for their solution, and discusses the merits and limitations of the nexus workshop approach as a heuristic for model development. Section 5 concludes with an outlook on fusing system modeling and stakeholder involvement.

2. Concepts of the Sustainability Nexus Workshops

2.1. Case Study Greater Amman Municipality

More than 4.5 million people currently live in Greater Amman Municipality [20] and expectantly the number will grow further in the future. Extreme water scarcity exacerbated by climate change and population growth characterizes Jordan [21,22]. In 2015, agriculture accounted for 51% of Jordan's total water use [23] but contributed below 4.4% to its GDP [24]. Despite this water scarcity, Jordan is likely to have a negative virtual water balance, since it is a net exporter of fruit and vegetables [25]. Regarding energy, Amman (as well as Jordan as a whole) has historically been highly dependent on imports from its neighboring countries, since it is only endowed with few fossil energy resources. In 2014, Jordan imported 97% of its energy (https://data.worldbank.org/indicator/EG.IMP.CONS.ZS?locations=JO, accessed on 21 June 2022). However, the significant potential of solar energy has not been realized yet [26]. On average, Jordan uses 14% of its electricity for water service provision (mostly pumping) [27].

Understanding the nexus between food, water, and energy production and consumption for Jordan with a focus on Amman is key to evaluating different paths and promoting those that target sustainability while avoiding those that are headed toward crisis. This is what the FUSE project aims for by developing an integrated systems model of the urban FWE nexus embedded in the nexus workshops. The FWE model of the FUSE team is a slight extension of the so-called Jordan Water Model [28,29], a country-wide, modular multi-agent model for evaluating water policy measures under different scenarios. It comprises the entire natural and man-made water cycle as well as household, commercial, industrial, and agriculture water users. In the FUSE project, the Jordan Water Model is being expanded to incorporate more explicitly the nexus dimensions of energy, food, and urbanization (see Appendix A).

2.2. Overview over the Five Phases of the Sustainability Nexus Workshop Approach

The Sustainability Nexus Workshop (SNW) approach is a process for systematic stakeholder engagement aimed at strengthening the judgment of decision makers as well as scientists involved in problem analysis. The role of judgment and heuristics in model development is explained in more detail in Appendix B. The SNW approach comprises five phases with two series of workshops, at the beginning (1st Stage) and the end (2nd Stage) of our 3.5-year project period, respectively, as explained in Figure 1. A more detailed description of the workshop concept, logistics, and the composition of the participants can be found in Appendix C (see also [17]).

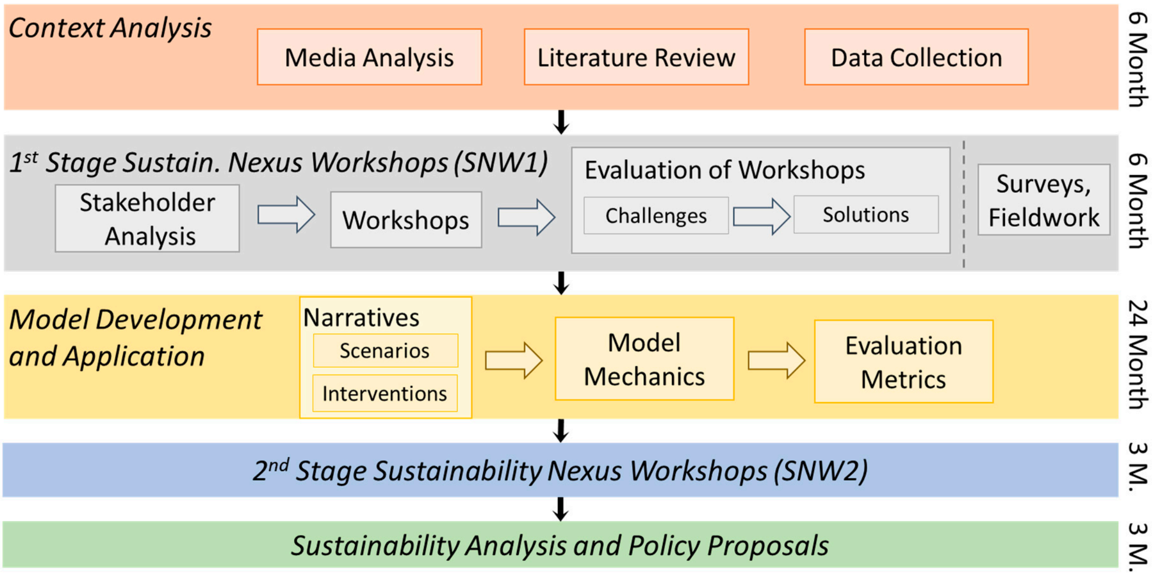

Figure 1. The five phases and approximate timeline of the nexus analysis. *Phase 1 "Context analysis":* Available information on the nexus between water, energy, and food production and consumption as well as relationship between the urban agglomeration and its hinterland is collected and the scope of the analysis is defined. *Phase 2 "1st Stage Sustainability Nexus Workshops (SNW1)":* Stakeholders share challenges, coping strategies, and co-create visions, and potential infrastructural and policy solutions involving limited land, water, and energy resources. In parallel, surveys and further fieldwork are conducted to round off data collection. *Phase 3 "Model Development and Application":* The information gathered is being processed and integrated into the system model to explore the potential benefits of these solutions. To this purpose, the proposed solutions are formalized to "policy interventions" that then will be analyzed under different scenarios by the model using a variety of evaluation metrics. *Phase 4 "2nd Stage Sustainability Nexus Workshops (SNW2)":* The modeling results are presented to the participants of the first workshops, and feedback is elicited. *Phase 5 "Sustainability Analysis and Policy Proposals":* Modeling results as well as stakeholder responses are evaluated, and policy proposals are derived.

The first series of workshops held in Amman in March 2019 consisted of three workshops: one for stakeholders affected by FWE problems (or more precisely: representatives of those affected stakeholders), a second one for experts from academia, government, and NGOs, and the last one for Jordanian modeling experts. The process of these 1st Stage Sustainability Nexus Workshops is described in Figure 2 and explained in more detail in the following subsections. For logistical reasons, the workshops were condensed to one week while pre- and post-processing was spread over several months.

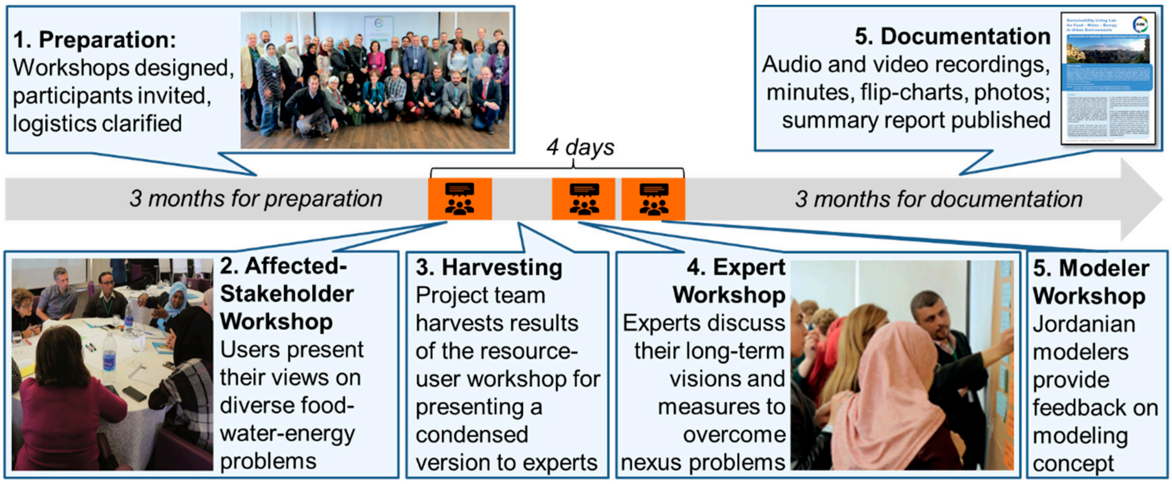

Figure 2. Process of the 1st Stage Sustainability Nexus Workshops.

2.3. Affected-Stakeholder Workshop

The overall purpose of the affected-stakeholder workshop was to share and discuss FWE challenges that those affected by nexus-problems face, to learn about their coping strategies, and to initiate a brainstorming process about ideas and solutions for the future. Based on a stakeholder analysis, participants from diverse NGOs in the areas of water, food, energy, urban matters, environmental protection, social issues, as well as farmers, youth group representatives, and small companies were invited and 35 representatives actually attended the workshop (for more details see Appendix C).

After an introduction to the project, participants formed small groups and debated current FWE challenges and coping strategies. The questions "How has the situation regarding food, water, or energy changed in the last two decades? How have you reacted to those changes?" were discussed in five different groups (Urban and social development/Water and infrastructure/Agriculture and food security/Environment/Energy). The minutes taken include changes and corresponding challenges observed by the participants as well as their coping strategies, wishes, and demands. The group work was presented and discussed in a plenary session.

The afternoon shifted the attention from the present to the future. The basis for the analysis of future scenarios are the Shared Socioeconomic Pathways (SSP) [30], which were also used for the preparation of the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC). The SSPs are projections of global socioeconomic changes in different countries of the world until the year 2100 (population development, economic development, the level of education, urbanization). There are five scenarios, of which the SSP2 (Middle of the Road) was designed as a reference scenario. In our workshop, four different perspectives on future developments were presented that are all based on SSP2 (Table 1).

Table 1. Four perspectives on future developments under SSP2 [17].

ID: Short Title	Description
PI: Climate change and water scarcity	Climate change will have severe impacts on the average temperatures in Jordan: By 2100, temperatures may increase between 2 °C and 6 °C compared to the baseline (1980–2010). Climate change will also reduce water availability in the region. Already being among the most water-scarce countries in the world, the situation is expected to worsen over the next decades [21,22,28].

Table 1. *Cont.*

ID: Short Title	Description
PII: Amman—growing metropolis	Between 2004 and 2014, Amman's population almost doubled. The city's rapid and erratic growth has been driven mainly by migration, both domestic and cross-border. The expected continuous growth of Amman will entail strong increases in resource and land use and pose stress on infrastructure.
PIII: Highland agriculture under pressure	Falling groundwater levels and increasing water pollution and salinization in Jordan's highland have made irrigation more difficult. Between 1995 and 2017, water levels in the A7/B2 aquifer were lowered by up to 60 m. The situation is expected to worsen in the future. Many highland farmers will need to change their agricultural practices to stay profitable.
PIV: Energy independence	Jordan's energy demand has been rising in the recent decades and it is projected that electricity demand will threefold by 2050. Currently, almost all energy resources are imported. Increasing energy independence is a goal to which renewable energy, especially wind and solar, could contribute, if a well-coordinated scaling up starts soon.

Participants then discussed in four groups, each based on one of the perspectives, how they would deal with the challenges, what policy solutions would be possible, what actions are needed, and what opportunities might arise. This was done in a world café style, where participants could change tables twice. Again, the groups presented their findings in the plenary session followed by a general discussion.

2.4. Critical Reflection of Results

The following day, the FUSE team critically reflected and systematized the results of the affected-stakeholder workshop to stimulate discussion at the expert workshop the next day. The stakeholder statements were checked for plausibility by the FUSE team and freed from evaluations. Afterwards, they were sorted according to nexus dimensions but also examined to see whether facts were presented, grievances denounced or wishes expressed, and goals formulated.

2.5. Expert Workshop

After a presentation of basic ideas and facts of the FUSE project to the 42 experts from academia, government, NGOs, and civil society (see Appendix C), experts were then asked to form groups and dream about "the future they want". They were asked to imagine the year 2050 with all the FWE challenges, of which they have heard about, having been overcome by then. The group task was to discuss the essentials of such a sustainable future for the Greater Amman Municipality. The minutes taken represent a summary of these visions.

The afternoon started with the presentation of the results of the affected-stakeholder workshop, particularly the overview over the perceived challenges and possible policy solutions. After this, the FUSE team again presented the four different perspectives on future developments within SSP2 (Table 1). The participants discussed in four groups—each taking one of the perspectives as a starting point—how their visions of a sustainable future (formulated in the morning session) could be reached, even though FWE systems are put under pressure in the perspectives. Each group came up with up to five policy solutions they deemed as most important. The day ended with a feedback round and presentation of the project's next steps.

2.6. Modelers Workshop

In a half-day workshop, Jordanian modeling experts—most of them working at universities—were presented with the initial ideas of the integrated model and critically discussed them. From this, the FUSE team sought to learn from their experience and incorporate their assessments into our model development process.

2.7. Documentation and Processing of the Workshop Results

During the summer of 2019, the team produced documentation of the affected-stakeholder and expert workshops in Amman [17] and made it available to workshop participants and the public. Additionally, more extensive internal documentation was developed on the basis of the written minutes, the audio recordings, the presentations, the flip charts prepared during the group work, and recollections of the team members.

2.8. Use of the Workshop Results for Model Development

To compile the workshop results into a manageable list of policy interventions to be analyzed based on the model, the team distilled a short list from the wealth of proposed measures in a discussion process guided by the following principles:

- *Feasibility*: The interventions should be—in principle—technically and administratively feasible.
- *Suitability*: The interventions should be suitable for mitigating or solving nexus challenges.
- *Comprehensiveness*: The selection of interventions reflects the range of nexus challenges and the diversity of possible policy measures.
- *Policy relevance*: The selection of interventions takes into consideration governmental plans.
- *Capability*: The model [28] should be capable of estimating the main and side effects of the interventions.

3. Results

3.1. Stakeholders' Challenges, Coping Strategies, and Solutions

The participants of the affected-stakeholder workshop named many different challenges, which refer to all four nexus dimensions of food, water, energy, and urbanization. The challenges were clustered into 20 topics (Figure 3 and Table A2 in Appendix D). The number of mentions alone reflects the obvious fact that water scarcity in Amman (as well as Jordan as a whole) is the dominant resource problem. Challenges from the other nexus dimensions, however, also have been mentioned frequently by the participants. In addition to the nexus challenges, the participants also refer to three driving forces that have a significant impact on resource use: (1) climate change; (2) population growth and refugee immigration; (3) growing informality of the process of resource allocation and low law enforcement. The FWE nexus in Amman is made visible in Figure 3 by explicitly showing the links between the different challenges mentioned explicitly by the stakeholders (see Table A2) as lines.

Although the large number of connections between the various challenges makes it difficult to identify clusters, two of them can be identified: First, we can see that the driving forces are linked to many challenges from all nexus dimensions underlining their importance in overcoming the challenges. Secondly, it can be seen that more connections originate from water-related challenges than from the other nexus dimensions. This is consistent with the general finding that water is the most severe resource issue in Jordan.

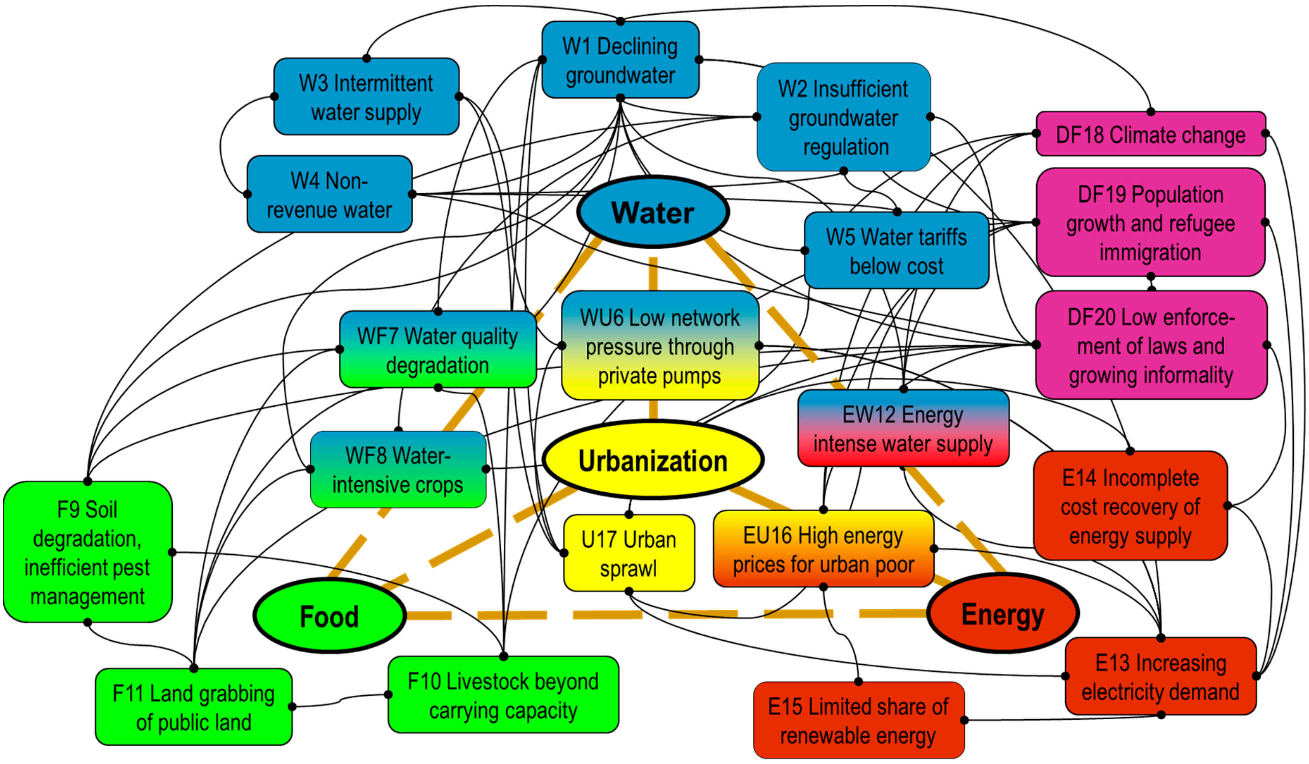

Figure 3. Triangle of FWE nexus challenges; intermediate outcome of stakeholder discussion. Challenges from Table 1 are located according to their proximity to one of the nexus dimensions of food, water, energy, and urbanization. The magenta boxes indicate governance challenges of the FWE nexus. The interdependencies and influences between the different challenges listed in Table A2 are shown as connecting lines.

3.2. Experts' Visions

In the expert workshop, visions of an ideal future were proposed. Figure 4a shows two examples of flipcharts illustrating the visions of the groups and Figure 4b summarizes the different visions elaborated in four groups. Though the visions looked different, there were many similarities: there was a consensus that Jordan has a unique cultural heritage and that it is imperative to maintain it. However, in addition to maintaining traditions, social and technological innovations are seen as important to achieve a sustainable FWE future. In each of the common visions for 2050, a sustainable Amman region has solved its water and energy problems by better management and planning, use of the latest technology and changes in (individual) behavior, and open, transparent governance, and implementation of new as well as existing regulations. Affordable and accessible resources are available for all. Jobs are being created by the transition from traditional and agricultural industries to a service-based economy, in which tourism and information technology (IT) play a central role and Jordan is becoming a major trade hub in the Middle East. Urbanization has been tamed and Amman is a livable, green city.

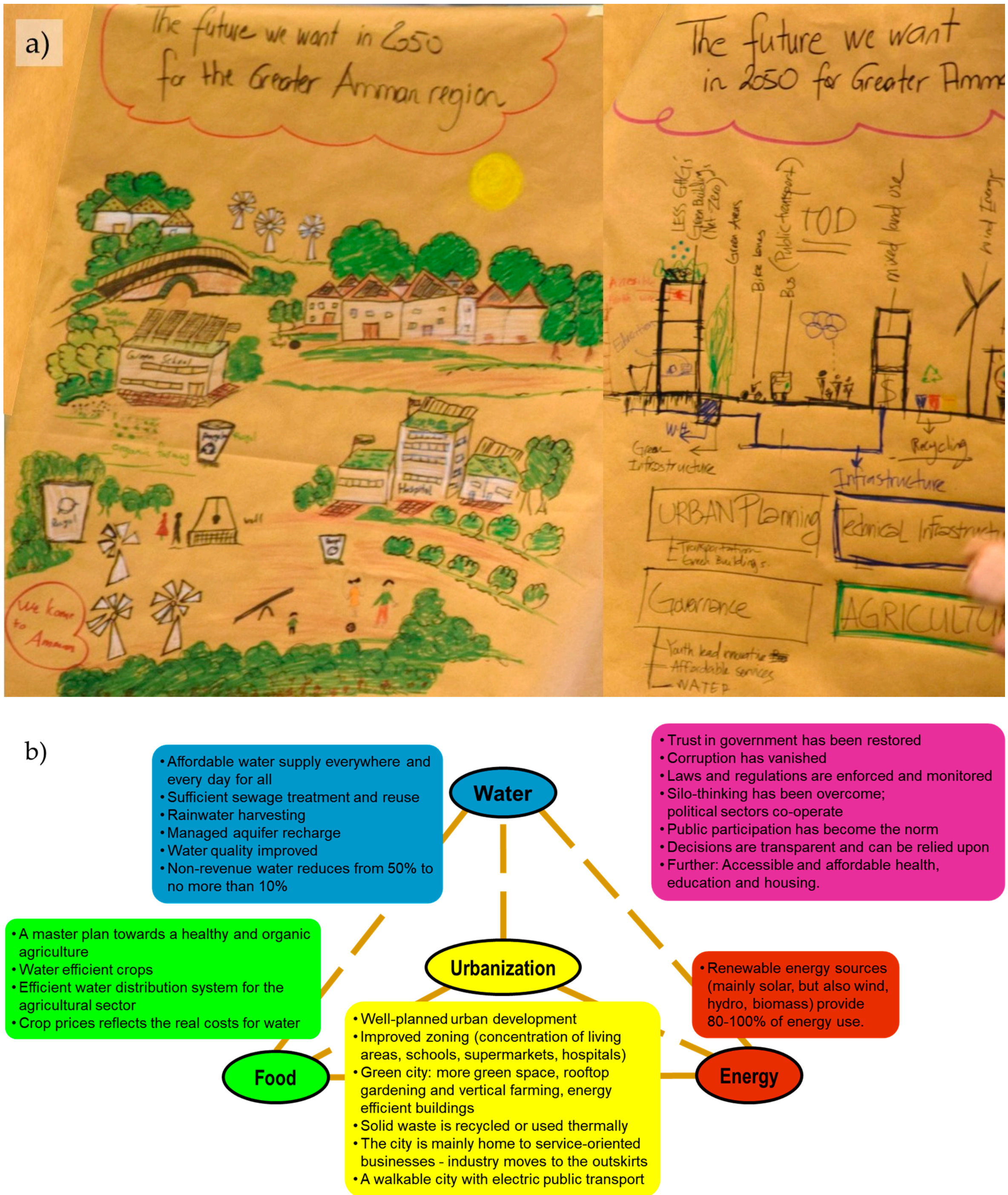

Figure 4. Vision for a sustainable Amman: (**a**) Two examples of flipcharts designed by the groups illustrating their versions, (**b**) Summary of visions.

3.3. Policy Solutions Proposed by Experts

As a second step, the experts elaborated on how their vision can be reached. Table 2 summarizes the proposals of policy solutions that expert participants came up with. As expected, most of the proposed solutions and measures would have to be implemented by government institutions. However, some could also be initiated and implemented by individuals, private initiatives or companies.

Table 2. Policy solutions proposed by participants to meet their vision of a sustainable Amman (selection) ordered by the four perspectives on future developments under SSP2 (see Table 1).

Perspective	*Short Description of Discussion*
• **Specific policy solutions to meet vision (list)**	
PI: Climate Change and Water Security	*Participants agreed that water scarcity is Jordan's overriding resource problem, which will be significantly exacerbated by climate change. Suggestions for management measures to increase water security include those in the areas of technology and infrastructure as well as governance and reflect the state of discussion in the literature.*
Infrastructure/Technology • Implementation of large infrastructure projects, such as the Red Sea–Dead Sea conveyance project and other desalination projects powered by solar farming • Realization of small-scale projects, such as reducing non-revenue water losses • Rainwater harvesting: capture and store the rare-event urban flood waters • Fostering water saving technologies and practices in all sectors: agriculture, household, commercial, and industry • Further expanding wastewater treatment and reuse to support agriculture that does not divert water resources from other sectors Governance • Better agreements for transboundary water use • Regulated management of wells with enhanced enforcement • Full-cost pricing for irrigation water • Reducing virtual water exports leading to reduced water demand by agriculture • In addition to public investment, private sector involvement and investment are needed	
PII: Amman: Growing Metropolis	*A key concern of the group was that Greater Amman Municipality meets the challenges of a fast-growing city with broad-based strategic planning. A master plan of urban development is needed. The plan contains guidelines for land development including the development of settlements, resource supply, waste management, transport infrastructure, and the acquisition of private land by the Greater Amman Municipality at strategically important locations.*
• Overcoming the critical budget constraints of the Greater Amman Municipality and developing innovative financing instruments (Private Public Partnerships, etc.) • Densification and intensification of urban areas to limit urban sprawl to the west • Redirecting urban growth from Amman to smaller cities • Raising awareness among citizens about the importance of green development in Amman • Implement planning principles for transit-oriented development, including an affordable bus rapid transit system • Better maintenance of the existing drainage system to prevent flooding after rain events • Additional flood protection through green infrastructure in valleys where open and vegetated land can improve storm-water retention • Development of green and resource-efficient building guidelines	
PIII: Agriculture—Highlands under pressure	*The water for irrigating the agricultural land in the Jordanian highlands has to be pumped from deep wells which, due to their overuse, increasingly carry salty water from deeper, fossil groundwater layers. The future of agriculture in the highlands has been therefore the subject of controversial debate.*
• To shift away from traditional water-intensive crops to a more sustainable high-tech agriculture and climate-adapted crops • Market access for producers from the highlands • Potential reallocation or sale of water from agriculture to urban uses • "Solar farming" as an alternative source of income for farmers • Agro-tourism projects for foreigners and locals	

Table 2. *Cont.*

Perspective	*Short Description of Discussion*
PIV: Increased energy independence	*The energy group discussed whether a scenario of unsatisfied power demand is realistic in Jordan and concluded that the opposite is true, since the country is currently producing more electricity than it consumes using imported fossil fuels. This trend is likely to continue because long-term natural gas delivery contracts have been signed recently. To move towards a more sustainable energy system based on a mix of different renewable energy sources (including photo voltaic) the group proposed an integrated strategy taking into account supply and demand side measures as well as the legal situation and the current dependencies from other countries.*
• Support (decentralize) renewable energy production and eventually export it to neighboring countries • Improve and expand the electricity grid and perform load management so that renewable energy can be used more extensively • Install energy storage systems (primarily decentralized systems) • Develop Jordan's fossil fuel resources • Use excess electricity for pumping water or for seawater desalination; requires intensified cooperation between the Ministry of Water and Irrigation and the Ministry of Energy and Mineral Resources	

3.4. FUSE Team's Summary: List of Interventions and Intervention Portfolios

The results of the workshops, particularly the lists of challenges and potential solutions, form a rich reservoir for the identification of interventions and intervention portfolios. The FUSE team will analyze and assess them in detail by their integrated FWE model in Phase 3. However, not all challenges and solutions mentioned in the workshops can be examined in more detail. On the one hand, a limitation of the number of policy interventions is necessary for capacity reasons, and on the other hand, the integrated model cannot map all technical and political measures equally well and analyze them for their various effects.

Using the principles mentioned in Section 2.7, the FUSE team came up with a list of interventions (see Table 3). These singular interventions were then grouped to form intervention portfolios characterizing a range of strategies for each of the nexus fields. Most of the interventions are complementary, but for one exceptional case in the field of agriculture where interventions point in opposing directions: there were many voices in favor of greater autonomy for Jordan in enhancing food supply, which would inevitably mean an increase in irrigated farmland and others in favor of reducing agriculture to counteract water shortages.

Table 3. Policy interventions to be analyzed by the integrated FWE model.

FWE Dimension	Policy Interventions
Water	• *Supply Management:* Increased efficiency through physical non-revenue water reduction/Additional local water supply projects • *Demand Management:* Raising piped water tariffs for high-volume users/Equalization of piped supply availability for all household users on a per capita basis/Administrative non-revenue water reduction
Water-Energy	• *Solar Energy for Water Supply:* Large-scale Red Sea desalinization project (e.g.: *Red Sea–Dead Sea* Conveyance project, *Aqaba Amman Water Desalination and Conveyance* project), powered by solar photovoltaics
Energy	• *Supply Management:* Expansion of capacities for electricity production (on the basis of renewable energies) • *Demand Management:* Raising electricity prices for high-volume users
Food-Energy	• *Solar Farming:* Promoting solar farming to increase the share of renewable energy in electricity production (to 100% in the long run)

Table 3. *Cont.*

FWE Dimension	Policy Interventions
Food	• *Strengthen Jordan's Food Autonomy:* Supporting staple food crops to reduce reliance on food imports
Food-Water	• *Climate-Adapted Crops:* Subsidizing climate-adapted agriculture and water-efficient plants • *Reallocating Irrigation Water to Urban Uses:* Regulating groundwater abstractions by agriculture/Reassigning agricultural wells to provide municipal water supply
Food-Water-Energy	• *Regulating Irrigation* via *Electricity Price:* Increase in electricity prices for groundwater pumping in agriculture
Urbanization	• *Decentralized Urban Growth:* Redirecting urban growth from Amman to smaller cities • *Urban Densification:* Equal population growth rate with slower growth of land to protect rainfed ecosystems

4. Discussion

4.1. Nexus Challenges in Amman and Silo Thinking

The 1st Stage Sustainability Nexus Workshops in Phase 2 and particularly the affected-stakeholder workshop produced a clear picture of the challenges of the current water, energy, and food supply situation in Greater Amman Municipality, expectations about future developments, and ideas on how to tackle them. Unsurprisingly, it became clear that in Amman and Jordan as a whole, water scarcity presents the overriding resource problem and a limiting factor for prosperity, which climate change will make even worse in the future. But, at the same time, a close nexus between water, energy, food, and urbanization is evident. The stakeholders are well aware of the fact that different challenges are connected—often across the nexus dimensions. In most cases, combinations of technical solutions, policy measures, and individual behavioral changes are needed as remedies for existing and worsening FWE problems. The prerequisite, however, is that the widespread silo thinking is overcome.

Al-Zu'bi [217, particularly pp. 170–171] sees the centralized and hierarchical structure of the Jordanian state, which can be found in a similar way in other Arab states, as a major reason for silo thinking. The nexus between food, water, and energy is indeed perceived at the local level, because local politicians are directly confronted with their negative consequences. However, the central government keeps ignoring local governments' problems and concerns. The central government, in turn, is organized sectorally. The combination of strongly hierarchical structure and sectoral organization has been argued to be particularly prone to promoting silo thinking. Different ministries are responsible for the nexus dimensions of agriculture, water, energy, urban development, and environment. In addition, frequent changes of ministers and the use of personal connections to gain preferential treatment (Arabic: "wasta") hinder good governance [31].

Mohtar and Lawford [32] argue that a dialogue on the FWE nexus must transcend horizontal hurdles in governance as well as vertical hierarchies and must engage a wide range of stakeholders. This requires policy and institutional reforms that take time to succeed and require political will for change. Indeed, participants in the SNW demonstrated a keen awareness of challenges spanning several FWE nexus dimensions and repeatedly confirmed that the workshop format has enabled and stimulated exchange across sectoral and administrative boundaries. A first step has, thus, been taken towards overcoming silos.

4.2. The Key Role of Informal Institutions

Informal institutions have an ambiguous role in the allocation of WEF resources: they can impede or circumvent public resource management policies, but they also extend resource availability to those with insufficient access to formal supply systems [33,34]. In Jordan, water supplied by tanker trucks is crucial in alleviating the intermittency of the public water network, though it also undermines the water ministries' efforts to reduce groundwater abstractions [29,35–37] and is highly energy- and emissions-intensive [29,38]. Besides these markets, informal political institutions have been found to strongly influence the policy-making process in Jordan, often preventing progress towards resource sustainability, particularly with regards to the agricultural and water sectors [39–44].

In the SNW, we learned there is an unexpected degree of congruence between this literature evaluation of informal institutions and stakeholders' bottom-up perspective on the phenomenon. Stakeholders expressed that they perceive informal markets as well as systematic violations of rules and their toleration as both necessary strategies for coping with nexus challenges and causes of these problems. More importantly, however, participants in the 1st Stage SNW clearly identified "low law enforcement and growing informality", along with "climate change" and "population growth," as critical factors exacerbating nexus challenges and as key to understanding and addressing them. It became clear that informal structures and illegal activity are widespread in all dimensions of the nexus, and their motives and mechanisms must be considered when seeking solutions and choosing policies. Informal institutions provide a poignant example of types of phenomena, for which stakeholder knowledge is particularly well-suited to enhance system understanding.

4.3. Possible Courses of Action—Contradicting Proposals

The suggestions of the workshop participants on how to remedy the FWE challenges were very diverse—which can probably be explained by the diversity of the invited stakeholders and the open format of the workshops—and go beyond what, for example, Talozi [25] and Al-Zu'bi [21] discuss. It is not surprising that some of the proposals contradict each other. For example, should agriculture in the highlands of Jordan rather be cut back to save water, or remain at existing levels, or even be expanded to improve food security (see Table 2 under PI and PIII, also compare [45])? Talozi [25] argues for incentives to shift agriculture from desert locations to the Jordan Valley because of the excellent growing conditions there and the greater use of surface water for irrigation instead of non-renewable groundwater resources. It is debatable whether this would be politicly feasible. Another example of opposing proposals is "affordability" and "cost-recovery water pricing." Cost recovery leads to more economical water use and higher efficiency. However, cost recovery is associated with higher costs for consumers, who are financially more burdened and may no longer be able to afford their water services. A third example of opposing proposals is the question whether Jordan's energy industry should fully exploit the potential of solar energy in the future or rather intensify the search for its own fossil energy sources such as shale gas (Table 2, PIV). While the construction of a nuclear power plant is also being discussed intensively in the public debate (e.g., Jordan Times, 2020-09-21 [46]), it was not mentioned during the workshops.

Though many important policy measures and solutions for addressing the FWE nexus challenges Jordan will face over the coming decades were mentioned, it was striking that no vision was developed that seemed sufficiently comprehensive for overcoming at least the key challenges. As outlined in Yoon et al. [28], addressing issues related water scarcity alone requires an ambitious portfolio of actions. Workshop participants when confronted with the central findings of Yoon et al. proposed individual interventions but struggled with the prognosis that all those measures and more would be needed to avoid a resource security crisis.

4.4. Reflecting on the Two-Stage Sustainability Nexus Workshops Approach

The FWE nexus calls for a broad involvement of stakeholders to work collaboratively to address the challenges [47]. Often, stakeholders are consulted only at the beginning of a project to use their knowledge for the research process. Ideally, stakeholders would be involved instead on an ongoing basis and evenly over the entire project duration, and project progress would be communicated promptly and linked back to them to get their feedback. Mainly for logistical reasons, we were unable to realize this ideal in the FUSE project. However, in order to come as close as possible to this ideal, we have divided the research process into five phases in our SNW approach, in which phases of intensive stakeholder interaction alternate with phases of scientific analysis, resulting in an overall co-creative process.

The SNW can be compared to a long-term experiment: the solutions proposed by the stakeholders and selected by the FUSE team in the early stages of SNW can be seen as hypotheses for how to solve the nexus challenges. The workshop design heuristically supports and guides the process of collecting and processing the personal knowledge, assessments, and opinions of stakeholders into a list of proposed solutions in Phase 2. These "hypotheses" are explored and tested in Phase 3 using integrated systems models. In Phase 4, the stakeholder involvement subjects the results of the modeling process to a critical review by those who are most confronted with the problems in practice, namely, the affected persons, affected social groups, and local decision makers.

One could even argue that the entire process across the five phases could be considered a Sustainability Living Lab. Originally developed for the collaborative design (co-design, co-creation) of technical products by developers and end users [48], Living Labs are increasingly also being used to engage stakeholders through the co-development of technical, institutional, and behavioral approaches to solving sustainability problems (so-called Sustainability Living Labs; [49,50]). However, while Sustainability Living Labs typically extend only over a short period of time of days or weeks, in the FUSE project, the span between the 1st and 2nd stakeholder workshop was approx. 3.5 years.

It should be noted that the FUSE SNW process is a co-creative process involving stakeholders, policy makers, and scientists hearing and understanding each other's concerns. Policy proposals are an important outcome of the SNW. The scientists take on the role of an "honest broker" [51], i.e., their proposals are not value-free and completely objective, but they are nonpartisan and not interest-driven. Overall, the involvement of stakeholders in the analysis process sharpens the analysts' judgment. The design of the SNW seeks to push back subjective influences in judgments and strengthen the role of objective influences (see Appendix B).

5. Conclusions and Outlook on Fusing System Modeling and Stakeholder Involvement

We presented here a concept for "sustainability nexus workshops" to gain relevant practical knowledge for nexus modeling. Applying the concept to the nexus problem of the Amman metropolitan region in Jordan showed how stakeholder workshops can provide important insights into the challenges and problems of providing the food, water, and energy, as well as approaches for policy interventions. In principle, the concept of two-stage sustainability nexus workshops is reproducible and transferable to other urban regions with FWE nexus problems [19], but it is also very time-consuming and labor-intensive. The transferability is limited to the rough concept described in Section 2. For the concrete detailed workshop organization and planning of the stakeholder involvement, many peculiarities have to be taken into account and adaptations to local conditions have to be made.

In recent years, modeling of coupled human–natural systems has made great strides so that it can now be used to study complex, real-world problems and inform stakeholders and decision makers. Although the empirical basis of the models is usually a variety of statistics and monitoring data on the state of the environment and society, the key is that the model takes a holistic approach that considers FWE nexus interactions and feedback. It makes sense and is desirable to systematically include the specific practical and action knowledge of affected persons, stakeholders, experts, and decision makers in the process of model development and the evaluation of results. This is essential to increase the accuracy of the problem representation as well as the virtue of the predictions, and above all to improve the usability of the analyses for policy guidance. The 1st Stage SWE, which we have described and discussed here, was able to provide concrete inputs for model development and application. When the 2nd Stage is completed, we will also be able to see how the results of the model analyses are assessed by the stakeholders and to what extent they are considered useful by them.

Author Contributions: The article is the result of close cooperation within the FUSE project. However, the following contributions can be assigned: conceptualization and methodology: B.K., K.K., I.O., R.K., S.G., C.K., Y.Z., H.Z., M.S., and A.J.F.; empirical analysis: K.K., I.O., B.K., R.K., C.K., S.G., Y.Z., H.Z., H.G., M.S. and S.T.; writing—original draft preparation: B.K.; writing—review and editing, B.K., I.O., K.K., R.K., C.K., S.G. and J.H.; visualization, B.K. and J.H.; main responsibility for project administration and funding acquisition, S.G. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Science Foundation (NSF) under Grants GEO/OAD-1342869 and ICER/EAR-1829999 as part of the Belmont Forum—Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus theme). Funding to the Helmholtz Centre for Environmental Research (UFZ) was provided by the Deutsche Forschungsgemeinschaft (DFG) (KL 2764/1-1) and the German Federal Ministry of Education and Research (BMBF) (033WU002) as part of the Belmont Forum. The Austrian partners ÖFSE and IIASA are funded by the Austrian Research Promotion Agency (FFG) (Project Number 868550). The University of Manchester's Computational Shared Facility is acknowledged. Any opinions, findings, and conclusions or recommendations expressed in this material are solely those of the authors and do not necessarily reflect the views of the NSF or other agencies that provided funding or data.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank all participants in the stakeholder and expert workshops in Amman on 24 and 26 March 2019 for their valuable contributions. We are grateful to the support of the FUSE project provided by the Jordanian Ministry of Water and Irrigation (MWI) and particularly by Hazim El-Naser and Eng. Ali Subah.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Guiding Model Design and Specification of Parameters

The primary aim of the 1st Stage SNW is to guide the design of the integrated FWE nexus model and to identify necessary model features so that FWE challenges along with suggested solutions and policy interventions raised by stakeholders can be accurately represented (see Table A1 for terminology).

Table A1. Terminology for describing the process of framing the urban FWE-nexus model.

Term	Definition
Challenge	A "challenge" is what has been perceived by stakeholders as a problem that needs to be overcome in order to reach a sustainable use of and fair access to the resources land, water, and energy.
Solution	A "solution" is an action or measure of a state authority, a water or energy provider, a farmer, a household, or any other agent that—in the view of the participants in the stakeholder workshop—has the potential to resolve one or more of the FWE challenges and to foster a development towards a more sustainable use of the resources land, water, and energy.
Driving force	A "driving force" is a process in the coupled human–environment system that exerts pressure on the supply of a city with the resources land, water, and energy and may cause problems.
Policy intervention	A "policy intervention" is the formalization of a solution in the context of the model development. It is an input parameter to the model that can be determined by the decision maker. For the analysis, several policy interventions might be grouped to "intervention portfolios" [28].

Table A1. *Cont.*

Term	Definition
Scenario	In general, a scenario is a consistent and coherent description of a possible future development. In the context of policy analyses, it is useful to distinguish whether the future development can be influenced or not by decision makers. Therefore, we define a "scenario parameter"—as opposed to a policy intervention—as an input parameter to the model that cannot be controlled by the decision maker, such as weather and climate [28]. For practical purposes we differentiate on the one hand between "global scenario parameters" that influence the system under consideration on a large scale such as climate, population development, and economic growth on the one hand, and on the other hand "regional/nexus specific scenario parameters" that are specific to the region and its nexus challenges. For the analysis, several scenario parameters may be grouped to a "scenario".
Narratives	A "narrative" is a combination of one scenario and one intervention portfolio [28].
Evaluation metrics	An "evaluation metric" is a normative output variable of the model that can be used to evaluate the impact of policy interventions, scenarios, and narratives on the system.

The model represents a complex coupled human–natural system and contains modules representing endogenous and exogenous processes. On one hand, endogenous processes are ones simulated by the model, such as hydrologic behavior, crop yields, urban water use for various economic sectors, and farmer decision making. Data to develop models of endogenous processes come from government and industry statistics, existing literature, as well as surveys and measurement campaigns. When endogenous processes cannot be adequately specified due to lack of data or because foundational information is highly uncertain, these processes are treated parametrically to cover a range of possible behavioral outcomes. On the other hand, exogenous processes are specified by those who use the model, such as policymakers. Such processes are driving forces and include future climate, population, future commodity prices, and the trajectory of socio-economic development. Because exogenous processes are highly uncertain, particularly over time, they are necessarily treated as scenarios, such as moderate or extreme climate change, rapid or slow population development, and expansive or modest economic growth.

The simulated processes are coupled to create the agent-based systems model. It accounts for interactions and feedback between the process modules and the human and institutional decision-making agents that they contain. Agent behavior is based on empirically grounded decision rules (water administration), estimated demand functions (households, commercial, industrial users), or profit maximization (farmers, resellers) [28,36,37,52]. The end result of the model is a set of metric values reflecting various aspects of well-being and FWE security. These evaluation metrics can be compared to assess the effectiveness of policy interventions on changes in the future state of well-being. These include evaluation of the state and reliability of meeting agents' FWE future needs, reduction in FWE vulnerability, and improvements in FWE allocation equity. The model is also used to explore the sensitivity of the simulated FWE predictions due to uncertainty in both the endogenous and exogenous process models.

Appendix B. The Role of Judgment and Heuristics in Model Development

To better understand why the stakeholder involvement via Sustainability Nexus Workshops can guide the model design, we use the philosophical concept of judgment, which is explained in this short appendix. In general, the process of decision-making is not a straightforward derivation of decisions from facts using an intelligent algorithm but a delicate process of balancing that needs judgment. This holds particularly for political decisions that should be based on data, facts, and scientific methods but require judgment that balances various interests and deals with uncertainty due to our lack of knowledge. However, judgment is also needed for the creative act of developing and applying scientific methods such as models to real-world problems and for providing sound advice.

A comprehensive analysis of the concept of judgment is provided by Immanuel Kant in one of his main works, the "Critique of the Power of Judgement" [53]. He understands judgment as the faculty of a person to apply general insights to specific, contingent situations. For example, one uses judgment already, when one recognizes an object with a trunk, branches, and leaves as a "tree". Judgment is also needed when abstract scientific findings are to be applied for making a concrete practical or political decision. Judgment comprises two complementary elements, namely, "heuristics" and "intuition" [18]:

Heuristics: Judgment proceeds heuristically, i.e., it uses general rules of procedure. Heuristics (from ancient Greek: heuriskein = to find) are mentally rules of thumb that helps in the search for solutions. Such guidelines can be very fruitful, but they do not have to be applied compulsorily; they also allow deviations and exceptions. And they can be modified, developed further, or repealed over time. The guidelines establish a relationship between a specific situation and general conditions [18].

Intuition: To make heuristics fruitful, they must be handled playfully and creatively. Karl Popper [54] says that to formulate a scientific hypothesis, you have to make a presumption, and in order to make a good presumption, you need "feeling" for the subject. So, judgment is based on a feeling or—more precisely—on "intuition". Intuition is the ability to acquire knowledge without deductive, discursive thinking. It is partly a gift, but it can also be acquired through experience. Because judgment is based on intuition, a decision made with its help can never be completely free of ambiguity. Arguments for the decision may be put forward, but dissenting opinions are always possible [18].

With respect to the development and application of models, it can be summarized that both are needed—intuition as well as heuristics. While intuition is a personal and subjective skill of a scientist, heuristics are an important means of strengthening the objective side of the power of judgment. They can be debated and communicated.

We consider the entire five-phase Two-Stage-Sustainable-Living-Lab approach as a heuristic for the development of advice on how to tackle nexus challenges. The 1st Stage—on which this paper focuses—can be seen as a heuristic to support the entire model development process. It guides the process of how insights from stakeholder involvement about the specific problem, the political economy, the history, the interests, and viewpoints of the involved parties are taken up. Within this structured process, stakeholders help to determine important input features of the model, particularly the identification of viable policy interventions to be analyzed in the later phases of the SSL approach. It is in the nature of a heuristic that its success cannot be proven unequivocally, but its usefulness can be made plausible by applying it empirically to case studies.

Appendix C. Logistics and Participants of the Workshops

The first series of workshops in Amman took place from 24–27 March 2019. They were organized in cooperation with our local partner organization, MIRRA (Methods for Irrigation and Agriculture). To give a balanced voice to the different social positions and opinions, we organized separate workshops for affected stakeholders and for experts. Both the affected-stakeholder workshop and the expert workshop lasted one full day, while the third workshop with the modeling experts took half a day.

To identify relevant participants, we drew on knowledge and contacts from previous research of team members in the region and on consultations with MIRRA. In addition, we conducted a context analysis to identify further stakeholders, based on scientific and grey literature as well as media. These activities resulted in a first list of potential stakeholders. To select stakeholders, we divided them into the following categories: public institutions, non-governmental organizations, research institutions, commercial and industrial organizations, and independent actors. As a next step, all stakeholders were assigned an area of their main activity (food, water, energy, urban, environmental). This list was then jointly validated and complemented with MIRRA. Lastly, we applied an iterative "snowballing" technique, through which key actors could suggest further stakeholders from their field. Subsequently, we mapped the stakeholders according to their estimated level of interest/affectedness and influence (scores from 0–2) in the nexus system. This approach supported for the selection of two types of stakeholders for the workshops: the ones who represent groups with high interest/affectedness ("affected stakeholders") and those who represent groups with high influence ("experts and policy makers"). Other criteria (gender, professional experience, and proximity to an economic sector) were also used to select participants to obtain a diverse and balanced group of participants.

Some facts about the participants:

- *Affected-stakeholders workshop, 24 March 2019*

Purpose: participants shared and discussed the FWE challenges they face, coping strategies, ideas, and solutions to overcome the challenges in the future.

There was a total of 35 participants from diverse Non-Governmental Organizations (NGOs) and civil society associations representing affected stakeholders (17), public institutions (11), academia (2), youth group representatives (2), and private businesses (3). They covered the areas of water (12), food (7), energy (3), urban matters (4), environmental protection (6), and social issues (3).

- *Expert workshop, 26 March 2019*

Purpose: participants created a common vision of the Greater Amman Region in 2050 and developed ideas and proposals for measures and policies aimed at developing a sustainable FWE system.

There was a total of 42 participants. Persons from public institutions were present (29) but also from research-oriented NGOs (8) and academia (5). Their areas of expertise comprised water (11), food (10), energy (5), urban matters (7), and environmental protection (4) and crosscutting issues (5).

- *Modeling expert workshop, 27 March 2019*

Purpose: feedback to the FUSE modeling concept.

There was a total of 12 modeling experts from universities, public entities, and research institutions.

The workshop documentation [17] was sent to all participants after its completion. The documentation contains a list of participating institutions. From time to time, they have been informed about the project process and important results.

Appendix D. Description of Nexus Challenges from the Stakeholders' Perspective

Table A2. Overview of food–water–energy nexus challenges and driving forces from the point of view of the stakeholders. The statements by the workshop participants have been carefully condensed and clustered. The challenges have been color-coded and letter-coded according to their belonging to one or more nexus dimensions: water: W—blue, food: F—green, energy: E—red, urbanization: U—yellow; striped, and coded with two letters if belonging to two nexus dimensions; driving forces: DF—magenta; uni-directional or mutual influences, effects or relationships between the challenges are indicated by reference arrows followed by the respective challenge ID.

ID	Challenge	Description of Challenge from Stakeholders' Point of View
W1	**Declining ground-water**	The groundwater level in Jordan has been falling for years because of excessive groundwater pumping (→**W2**, **WF8**, **EW12**). Increasingly wells fall dry and saline groundwater from deeper aquifers is pumped (→**WF7**, **F9**).
W2	**Insufficient groundwater regulation**	The over-pumping of groundwater for agriculture and industry as well as for the tanker water market is a common practice which contributes to declining groundwater tables (→**W1**). Furthermore, water theft (→**W4**) and illegal pumping of groundwater in the surrounding of Amman, but also in the highlands, is a growing problem (→**DF20**).

Table A2. *Cont.*

ID	Challenge	Description of Challenge from Stakeholders' Point of View
W3	**Intermittent water supply**	Water resources are extremely scarce (→**W1**). Piped water supply in Amman is already limited to one or two days a week with limited hours during the day. Connection to the water supply networks is also better in areas of higher socio-economic status, which increases inequality in the city (→**WU6**).
W4	**Non-revenue water**	Unmetered water connections (in rural areas), water theft and incorrect billing (administrative non-revenue water) as well as pipe losses (physical non-revenue water) are considerate which leads to overuse of water resources (→**W1, W2, DF20**) as well as unmet demand (→**W3**).
W5	**Incomplete cost recovery of water supply**	Water tariffs in Jordan usually range below the operating cost stimulating waste of scarce resources (→**W1**). In general, the water sector is insufficiently funded (→**W2**). The high level of non-revenue water contributes to incomplete recovery of water supply costs and low economic returns for utilities (→**W4**).
WU6	**Low network pressure through private pumps**	According to the geographic location, some areas of Amman experience low water network pressure. Households try to get more water by actively pulling it out of the pipes with suction pumps (→**W3, E13**).
WF7	**Water quality degradation**	Agriculture in Jordan has low crop diversity and excessively uses fertilizers and pesticides resulting in water quality degradation as well as soil degradation (→**F9**). Sewage water in rural areas is not always treated properly as well.
WF8	**Water-intensive crops**	Water intensive "cash crops" mainly produced for export require intensive irrigation all year round and use a lot of water. When planning their crops, farmers, especially in the highlands, do not adequately account for climate change and growing water scarcity (→**W1, W2, DF18**).
F9	**Soil degradation and inefficient pest management**	Soil viruses and other pathogens as well as irrigation with saline groundwater (→**W1**) reduce the overall quality of the soil and water (→**WF7**). Rare crop rotation also leads to a reduced availability of nutrients and a decreased soil quality. Too many pesticides are used due to the farmers' lack of knowledge and insufficient regulation and law enforcement (→**W2, DF20**). This hinders the export of agricultural products to other countries with higher food quality standards and particularly stricter limits for pesticide residues.
F10	**Livestock beyond carrying capacity**	Overgrazing leads to soil degradation (→**F9**) and damages to vegetation. Growing population (→**DF19**) and changing lifestyles increases demand for meat. Additionally, livestock consume (directly and indirectly) large amounts of water if fattened with fodder cultivated on Jordan's arable land (→**W1, WF7**).
F11	**Land grabbing of public land**	It is observed that farmers plough fields that belong to the public and then claim the land for themselves (→**DF20**). Because these fields are then intensively cultivated, the consumption of irrigation water, fertilizer, and pesticides increases (→**W1, WF7, WF8, F9, F10**).
EW12	**Energy intense water supply**	A considerable part of the electricity in Jordan is already consumed for pumping and treating water (→**W1, E13, DF18, DF19**). Water is pumped from great depths and over long distances, and, in some cases, it also must be desalinated.
E13	**Increasing electricity demand**	The growing population (→**DF19**), lifestyle changes, and climate change (→**DF18**) lead to increasing electricity demand by private households and commercials. Pumping water from deeper wells and over longer distances, as well as desalination, also require more energy (→**W1, WU6**) and stimulate fears about the security of supply (→**E15**).
E14	**Incomplete cost recovery of energy supply**	Manipulated electricity meters, incorrect billing, and illegal connections to the power grid (→**DF20**) are the main reasons why the production costs for electricity are often not fully covered pushing electricity demand (→**E13**).
E15	**Limited share of renewable energy**	Long-term supply contracts for oil and gas with other countries (esp. Saudi Arabia and Israel) are important reasons for the currently, and probably also in the near future, very low share of renewable energies. The potential for the use of solar energy, but also for wind energy, nevertheless is extraordinarily high in Jordan, but it is not taken advantage of. In addition to the contractual ties, it seems that there is still a lack of political will in Jordan to significantly strengthen renewable energies and to meet the increasing electricity demand (→**E13, EU16**).
EU16	**High electricity prices for urban poor**	The rising electricity prices are not affordable for the poor population of Amman (→**DF18**). Therefore, often illegal connections are installed which are tolerated by authorities (→**E13, DF20**).
U17	**Urban sprawl**	Population pressure (→**DF19**) is leading to urban sprawl, especially to the west of Amman, where fertile farmland lies. Lack of spatial planning (→**DF20**) leads to a lack of infrastructure, supply problems, and inefficient resource use (→**W1, W3, WU6, E13, E14**). Land sealing leads to loss of habitat.
DF18	**Climate change**	The effects of climate change in Jordan intensify the previous water scarcity (→**W1**) and energy demand (→**E13**). Crop yields are decreasing and conflicts over water use become more frequent and severe.
DF19	**Population growth and refugee immigration**	The population in Amman is growing significantly, which is mainly due to the influx of refugees from Syria. The refugee camps have a poor infrastructure and living conditions of refugees inside and outside of the camps are low (→**DF20**). Wealthier refugees tend to settle in cities (→**U17**), causing tension in the housing market and in terms of water and energy supply (→**W1, E13, EU16**).

Table A2. *Cont.*

ID	Challenge	Description of Challenge from Stakeholders' Point of View
DF20	**Low enforcement of laws and growing informality**	The general lack of enforcement of laws is hindering an efficient regulation of the water and electricity sector and leads to excessive water and energy consumption (→**W1**, **E13**). Especially among the refugee communities, most labor is informal (→**DF19**). Land grabbing (→**F11**) and urban sprawl (→**U17**) are additional effects. Less than half of the refugees are registered. Many water and electricity connections in refugee camps are unmetered (→**W2**, **E14**, **DF19**). Large parts of the market for tanker water are informal, fostering illegal groundwater abstraction (→**W2**).

References

1. Hubacek, K.; Guan, D.; Barrett, J.; Wiedmann, T. Environmental implications of urbanization and lifestyle change in China: Ecological and Water Footprints. *J. Clean. Prod.* **2009**, *17*, 1241–1248. [CrossRef]
2. Khan, S.; Hanjra, M.A. Footprints of water and energy inputs in food production—Global perspectives. *Food Policy* **2009**, *34*, 130–140. [CrossRef]
3. Vörösmarty, C.J.; Green, P.; Salisbury, J.; Lammers, R.B. Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science* **2000**, *289*, 284–288. [CrossRef] [PubMed]
4. Hellegers, P.; Zilberman, D.; Steduto, P.; McCornick, P. Interactions between water, energy, food and environment: Evolving perspectives and policy issues. *Water Policy* **2008**, *10*, 1–10. [CrossRef]
5. Siegfried, T.U.; Fishman, R.; Modi, V.; Lall, U. An Entitlement Approach to Address the Water-Energy-Food Nexus in Rural India. *AGU Fall Meet. Abstr.* **2008**, *11*, H11G-0846.
6. Rasul, G. Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environ. Sci. Policy* **2014**, *39*, 35–48. [CrossRef]
7. Romero-Lankao, P.; McPhearson, T.; Davidson, D.J. The food-energy-water nexus and urban complexity. *Nat. Clim. Change* **2017**, *7*, 233–235. [CrossRef]
8. Scott, C.A.; Kurian, M.; Wescoat, J.L. The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges. In *Governing the Nexus: Water, Soil and Waste Resources Considering Global Change*; Kurian, M., Ardakanian, R., Eds.; Springer International Publishing: Cham, Switzerland, 2015; pp. 15–38. [CrossRef]
9. Wahl, D.; Ness, B.; Wamsler, C. Implementing the urban food–water–energy nexus through urban laboratories: A systematic literature review. *Sustain. Sci.* **2021**, *16*, 663–676. [CrossRef]
10. Albrecht, T.R.; Crootof, A.; Scott, C.A. The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. *Environ. Res. Lett.* **2018**, *13*, 043002. [CrossRef]
11. Heinz, I.; Pulido-Velazquez, M.; Lund, J.R.; Andreu, J. Hydro-economic Modeling in River Basin Management: Implications and Applications for the European Water Framework Directive. *Water Resour Manag.* **2007**, *21*, 1103–1125. [CrossRef]
12. Kallis, G.; Videira, N.; Antunes, P.; Pereira, Â.G.; Spash, C.L.; Coccossis, H.; Corral Quintana, S.; del Moral, L.; Hatzilacou, D.; Lobo, G.; et al. Participatory Methods for Water Resources Planning. *Environ. Plan. C Gov. Policy* **2006**, *24*, 215–234. [CrossRef]
13. Treemore-Spears, L.J.; Grove, J.M.; Harris, C.K.; Lemke, L.D.; Miller, C.J.; Pothukuchi, K.; Zhang, Y.; Zhang, Y.L. A workshop on transitioning cities at the food–energy–water nexus. *J. Environ. Stud. Sci.* **2016**, *6*, 90–103. [CrossRef]
14. Culwick, C.; Washbourne, C.-L.; Anderson, P.M.L.; Cartwright, A.; Patel, Z.; Smit, W. CityLab reflections and evolutions: Nurturing knowledge and earning for urban sustainability through co-production experimentation. *Curr. Opin. Environ. Sustain.* **2019**, *39*, 9–16. [CrossRef]
15. Lehmann, S. Implementing the Urban Nexus approach for improved resource-efficiency of developing cities in Southeast-Asia. *City Cult. Soc.* **2018**, *13*, 46–56. [CrossRef]
16. Yan, W.; Roggema, R. Developing a in design-led approach for the food–energy–water nexus cities. *Urban Plan* **2019**, *4*, 123. [CrossRef]
17. Omann, I.; Küblböck, K.; Gorelick, S.; Figueroa, A.J.; Karutz, R.; Klassert, C.; Zozmann, H.; Smilovic, M. Sustainability Living Lab for Food—Water—Energy in Urban Environments: Documentation of Stakeholder and Expert Workshops in Amman, Jordan [WWW Document]. FUSE. 2019. Available online: https://fuse.stanford.edu/sites/g/files/sbiybj13226/f/amman_dokumentation_final.pdf (accessed on 21 June 2021).
18. Klauer, B.; Manstetten, R.; Petersen, T.; Schiller, J. *Sustainability and the Art of Long-Term Thinking*; Routledge: London, UK, 2016; 230p. [CrossRef]
19. Karutz, R.; Omann, I.; Gorelick, S.M.; Klassert, C.J.A.; Zozmann, H.; Zhu, Y.; Kabisch, S.; Kindler, A.; Figueroa, A.J.; Wang, A.; et al. Capturing Stakeholders' Challenges of the Food-Water-Energy Nexus. A Participatory Approach for Pune and the Bhima Basin, India. *Sustainability* **2022**, *14*, 5323. [CrossRef]
20. DOS (Department of Statistics). Estimated Population of the Kingdom by Governorate, Locality, Sex and Households, 2020. 2021. Available online: http://dosweb.dos.gov.jo/DataBank/Population_Estimares/PopulationEstimatesbyLocality.pdf (accessed on 1 March 2022).
21. Al-Zu'bi, M. *Water–Energy–Food–Climate Change Nexus in The Arab Cities: The Case of Amman City, Jordan*; PRISM: Calgary, AB, Canada, 2017. [CrossRef]

22. Whitman, E. A land without water: The scramble to stop Jordan from running dry. *Nature* **2019**, *573*, 20–23. [CrossRef]
23. Ministry of Water and Irrigation. *Water Sector—Facts and Figures 2015*; MWI: Amman, Jordan, 2015. Available online: http://www.mwi.gov.jo/ebv4.0/root_storage/ar/eb_list_page/%D9%82%D8%B7%D8%A7%D8%B9_%D8%A7%D9%84%D9%85%D9%8A%D8%A7%D9%87_%D8%AD%D9%82%D8%A7%D8%A6%D9%82_%D9%88%D8%A7%D8%B1%D9%82%D8%A7%D9%85_-2015.pdf (accessed on 21 June 2022).
24. World Bank. World Development Indicators: Agriculture, Forestry, and Fishing, Value Added (% of GDP). The World Bank, 2021. Available online: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=JO (accessed on 30 June 2022).
25. Talozi, S.; Al Sakaji, Y.; Altz-Stamm, A. Towards a water–energy–food nexus policy: Realizing the blue and green virtual water of agriculture in Jordan. *International J. Water Resour. Dev.* **2015**, *31*, 461–482. [CrossRef]
26. Katz, D.; Shafran, A. Energizing Mid–East water diplomacy: The potential for regional water–energy exchanges. *Water Int.* **2020**, *45*, 292–310. [CrossRef]
27. Lahn, G.; Grafham, O.; Sparr, A.E. Refugees and Energy Resilience in Jordan. Research Paper. 2016. Available online: https://www.chathamhouse.org/sites/default/files/publications/research/2016-08-03-refugees-energy-jordan-lahn-grafham-sparr.pdf (accessed on 21 June 2022).
28. Yoon, J.; Klassert, C.; Selby, P.D.; Lachaut, T.; Knox, S.; Avisse, N.; Harou, J.; Tilmant, A.; Klauer, B.; Mustafa, D.; et al. Integrated modelling of Jordan's freshwater security. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2020431118. [CrossRef]
29. Klassert, C.; Yoon, J.; Sigel, K.; Klauer, B.; Talozi, S.; Lachaut, T.; Selby, P.; Knox, S.; Avisse, N.; Tilmant, A.; et al. Unexpected growth of an illegal water market. *Nat. Sustain.* 2022; under review.
30. Riahi, K.; Van Vuuren, D.P.; Kriegler, E.; Edmonds, J.; O'neill, B.C.; Fujimori, S.; Bauer, N.; Calvin, K.; Dellink, R.; Fricko, O. The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Glob. Environ. Change* **2017**, *42*, 153–168. [CrossRef]
31. Dombrowsky, I.; Hägele, R.; Behrenbeck, L.; Bollwein, T.; Köder, M.; Oberhauser, D.; Schamberger, R.; Al-Naber, M.; Al-Raggad, M.; Salameh, E. *Natural Resource Governance in Light of the 2030 Agenda: The Case of Competition for Groundwater in Azraq, Jordan*; Studies 106; German Institute of Development and Sustainability (IDOS): Bonn, German, 2022.
32. Mohtar, R.H.; Lawford, R. Present and future of the water-energy-food nexus and the role of the community of practice. *J. Environ. Stud. Sci.* **2016**, *6*, 192–199. [CrossRef]
33. Pappas, K.; Hamie, C.S.; Daher, B. Water, Energy, Food Resource Challenges in Migration: Role of Informal Institutions. In *Peace, Justice and Strong Institutions*; Leal Filho, W., Azul, A.M., Brandli, L., Lange Salvia, A., Özuyar, P.G., Wall, T., Eds.; Encyclopedia of the UN Sustainable Development Goals; Springer: Cham, Switzerland, 2021. [CrossRef]
34. Garrick, D.; O'Donnell, E.; Moore, M.S.; Brozovic, N.; Iseman, T. *Informal Water Markets in an Urbanising World: Some Unanswered Questions*; World Bank Report No. AUS0000606; World Bank Group: Washington, DC, USA, 2019; Available online: https://cid.coherentdigital.net/20.500.12592/4z0bz8/card (accessed on 31 August 2022).
35. Mustafa, D.; Talozi, S. Tankers, wells, pipes and pumps: Agents and mediators of water geographies in Amman, Jordan. *Water Altern.* **2018**, *11*, 916–932.
36. Klassert, C.; Sigel, K.; Gawel, E.; Klauer, B. Modeling residential water consumption in Amman: The role of intermittency, storage, and pricing for piped and tanker water. *Water* **2015**, *7*, 3643–3670. [CrossRef]
37. Zozmann, H.; Klassert, C.; Klauer, B.; Gawel, E. Commercial Tanker Water Demand in Amman, Jordan—A Spatial Simulation Model of Water Consumption Decisions under Intermittent Network Supply. *Water* **2019**, *11*, 254. [CrossRef]
38. Choueiri, Y.; Lund, J.; London, J.; Spang, E.S. Energy-water nexus of formal and informal water systems in Beirut, Lebanon. *Environ. Res. Infrastruct. Sustain.* **2022**, *2*, 035002. [CrossRef]
39. Oberhauser, D.; Hägele, R.; Dombrowsky, I. Unravelling hidden factors explaining competition for and overuse of groundwater in Azraq, Jordan: Digging deeper into a network of action situations. *Sustain. Sci.* **2022**, *2022*, 1–15. [CrossRef]
40. Hussein, H. Tomatoes, tribes, bananas, and businessmen: An analysis of the shadow state and of the politics of water in Jordan. *Environ. Sci. Policy* **2018**, *84*, 170–176. [CrossRef]
41. Al Naber, M.; Molle, F. The politics of accessing desert land in Jordan. *Land Use Policy* **2016**, *59*, 492–503. [CrossRef]
42. Al Naber, M.; Molle, F. Controlling groundwater over abstraction: State policies vs. local practices in the Jordan highlands. *Water Policy* **2017**, *19*, 692–708. [CrossRef]
43. Yorke, V. Jordan's shadow state and water management: Prospects for water security will depend on politics and regional cooperation. In *Society–Water–Technology. A Critical Appraisal of Major Water Engineering Projects*; Hüttl, R.F., Bismuth, O.B.C., Hoechstetter, S., Eds.; Springer: Cham, Switzerland, 2016; pp. 227–251.
44. Bonn, T. On the political sideline? The institutional isolation of donor organizations in Jordanian hydropolitics. *Water Policy* **2013**, *15*, 728–737. [CrossRef]
45. Barham, N. *Is Good Water Governance Possible in a Rentier State? The Case of Jordan (Analysis)*; Center for Mellemøststudier, University of Southern Denmark: Odense, Denmark, 2012.
46. Jordan Times: Prince Hassan Calls for Establishing Water-Energy-Food Nexus in Arab Region [WWW Document]. Jordan Times. 2020. Available online: http://www.jordantimes.com/news/local/prince-hassan-calls-establishing-water-energy-food-nexus-arab-region (accessed on 1 June 2022).
47. Bhaduri, A.; Ringler, C.; Dombrowski, I.; Mohtar, R.; Scheumann, W. Sustainability in the water–energy–food nexus. *Water Int.* **2015**, *40*, 723–732. [CrossRef]

48. Schäpke, N.; Stelzer, F.; Caniglia, G.; Bergmann, M.; Wanner, M.; Singer-Brodowski, M.; Loorbach, D.; Olsson, P.; Baedeker, C.; Lang, D.J. Jointly Experimenting for Transformation? Shaping Real-World Laboratories by Comparing Them. *GAIA-Ecol. Perspect. Sci. Soc.* **2018**, *27*, 85–96. [CrossRef]
49. Liedtke, C.; Baedeker, C.; Hasselkuß, M.; Rohn, H.; Grinewitschus, V. User-integrated innovation in Sustainable LivingLabs: An experimental infrastructure for researching and developing sustainable product service systems. Special Volume: Why have 'Sustainable Product-Service Systems' not been widely implemented? *J. Clean. Prod.* **2015**, *97*, 106–116. [CrossRef]
50. Baran, G.; Berkowicz, A. Sustainability Living Labs as a Methodological Approach to Research on the Cultural Drivers of Sustainable Development. *Sustainability* **2020**, *12*, 4835. [CrossRef]
51. Pielke, R.S. *The Honest Broker: Making Sense of Science in Policy and Politics*; Cambridge University Press: Cambridge, UK, 2007.
52. Klassert, C.; Sigel, K.; Klauer, B.; Gawel, E. Increasing Block Tariffs in an Arid Developing Country: A Discrete/Continuous Choice Model of Residential Water Demand in Jordan. *Water* **2018**, *10*, 248. [CrossRef]
53. Kant, I. *Critique of the Power of Judgement*, *The Cambridge Edition of the Works of Immanuel Kant*; Guyer, P., Ed.; Cambridge University Press: Cambridge, UK, 1790.
54. Popper, K.R. *Logic of Scientific Discovery*; Routledge: New York, NY, USA, 1959.