

Article

Capturing Stakeholders' Challenges of the Food–Water–Energy Nexus—A Participatory Approach for Pune and the Bhima Basin, India

Raphael Karutz ^{1,*} , Ines Omann ² , Steven M. Gorelick ³, Christian J. A. Klassert ⁴ , Heinrich Zozmann ⁴ , Yuanzao Zhu ⁴ , Sigrun Kabisch ¹, Annegret Kindler ¹, Anjuli Jain Figueroa ³, Ankun Wang ³, Karin Küblböck ², Hannes Grohs ², Peter Burek ⁵, Mikhail Smilovic ⁵ and Bernd Klauer ⁴ 

¹ Department of Urban and Environmental Sociology, Helmholtz-Centre for Environmental Research—UFZ, Permoserstr. 15, DE 04318 Leipzig, Germany; sigrun.kabisch@ufz.de (S.K.); annegret.kindler@ufz.de (A.K.)

² Austrian Foundation for Development Research, Sensengasse 3, AT 1090 Wien, Austria; i.ommann@oefse.at (I.O.); k.kueblboeck@oefse.at (K.K.); h.grohs@oefse.at (H.G.)

³ Department of Earth System Science—ESS, Stanford University, 473 Via Ortega, Stanford, CA 94305-4215, USA; gorelick@stanford.edu (S.M.G.); ajainf@mit.edu (A.J.F.); ankunwang@stanford.edu (A.W.)

⁴ Department of Economics, Helmholtz-Centre for Environmental Research—UFZ, Permoserstr. 15, DE 04318 Leipzig, Germany; christian.klassert@ufz.de (C.J.A.K.); heinrich.zozmann@ufz.de (H.Z.); yuanzao.zhu@ufz.de (Y.Z.); bernd.klauer@ufz.de (B.K.)

⁵ International Institute for Applied Systems Analysis—IIASA, Schlossplatz 1, AT 2361 Laxenburg, Austria; burek@iiasa.ac.at (P.B.); smilovic@iiasa.ac.at (M.S.)

* Correspondence: raphael.karutz@ufz.de



Citation: 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. <https://doi.org/10.3390/su14095323>

Academic Editor: Lirong Liu

Received: 23 March 2022

Accepted: 25 April 2022

Published: 28 April 2022

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



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: Systems models of the Food–Water–Energy (FWE) nexus face a conceptual difficulty: the systematic integration of local stakeholder perspectives into a coherent framework for analysis. We present a novel procedure to co-produce and systematize the real-life complexity of stakeholder knowledge and forge it into a clear-cut set of challenges. These are clustered into the Pressure–State–Response (PSIR) framework, which ultimately guides the development of a conceptual systems model closely attuned to the needs of local stakeholders. We apply this approach to the case of the emerging megacity Pune and the Bhima basin in India. Through stakeholder workshops, involving 75 resource users and experts, we identified 22 individual challenges. They include exogenous pressures, such as climate change and urbanization, and endogenous pressures, such as agricultural groundwater over-abstraction and land use change. These pressures alter the Bhima basin's system state, characterized by inefficient water and energy supply systems and regional scarcity. The consequent impacts on society encompass the inadequate provision with food, water, and energy and livelihood challenges for farmers in the basin. An evaluation of policy responses within the conceptual systems model shows the complex cause–effect interactions between nexus subsystems. One single response action, such as the promotion of solar farming, can affect multiple challenges. The resulting concise picture of the regional FWE system serves resource users, policymakers, and researchers to evaluate long-term policies within the context of the urban FWE system. While the presented results are specific to the case study, the approach can be transferred to any other FWE nexus system.

Keywords: FWE nexus; stakeholder workshops; conceptual model; influence diagram; Pune; Bhima basin; India

1. Introduction

1.1. Background

Nearly one decade after the Food–Water–Energy (FWE) nexus discourse entered the center stage of political and research agendas [1–3], an integrated perspective on these critical resources seems more important than ever. Rapidly changing environmental and

societal conditions, characterized by complex interconnectedness and nonlinear feedbacks, cause uncertainty in the broad range of current societal challenges [4]. Today, we are already using more than half of the available renewable freshwater on the planet and half of the total arable land for agriculture [5]. By the year 2030, the global demands for food, water, and energy are likely to increase by 35%, 50%, and 40%, respectively, compared to 2012 [6]. Uncertainties regarding water availability, energy security, and food price volatility impact political and economic stability, which in turn is required for safeguarding the functioning of infrastructure and resource distribution systems. Traditional policymaking approaches that handle sectoral challenges independently (“siloes”), appear poorly suited to manage nexus challenges due to their insufficient accounting of potential detrimental effects, but also synergies on other sectors [7]. Nexus approaches have set out to investigate the most critical linkages among food, water, and energy systems and their implications for society in a multi-dimensional manner [8–10].

Arguably, cities, in which resource demand, as well as capital and political power, are concentrated, act as magnifying lenses of FWE issues [11]. Today, ~56% of the world’s population lives in urban areas, and by 2050 the share is expected to have reached ~68%—with 90% of the increase taking place in Asia and Africa [12]. Cities only cover about 3% of the world’s land surface, yet they account for ~75% of global electricity consumption and ~70% of anthropogenic greenhouse gas emissions [13,14]. Furthermore, rapid urbanization is exerting pressure on freshwater supplies, sewage treatment, and land use [14,15]. Besides this notion of urbanization as a *driver* of FWE challenges, Artioli et al. [16] present a second narrative, which sees cities as *points of high vulnerability* due primarily to their high population density and critical infrastructure. Cities’ central position in FWE resource networks can lead to cascading security risks transmitted into the hinterland [17]. Additionally, cities are often seen as innovation hubs that can spearhead transformation towards sustainability, and typical urban features, such as high densities, can foster greater resource-use efficiency [18]. To date, FWE nexus research that specifically addresses the urban context is surprisingly scarce and largely limited to the last decade [19,20]. Wahl et al. [21] diagnose, in their recent review, that existing urban FWE nexus research (1) does not adequately capture urban complexity, (2) is dominated by technical solutions, is lacking efforts to integrate societal factors, and (3) only rarely includes stakeholder participation. With this work, we aim to strengthen the system’s understanding of the FWE nexus in a rapidly urbanizing region: the Bhima basin in Maharashtra, India with its largest agglomeration, Pune. We collect and systematize stakeholder knowledge within the PSIR framework and translate it into a conceptual FWE nexus systems model to elicit interlinkages and evaluate implementable response options.

1.2. A Transdisciplinary Perspective on the FWE Nexus

From a transdisciplinary perspective, credible, salient, and legitimate sustainability research requires both high levels of integration across disciplines and genuine stakeholder involvement [22–24]. Lang et al. [22] (pp. 26–27) define transdisciplinarity as “a reflexive, integrative, method driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge.” Two archetypical research practices represent these qualities in FWE nexus research: (1) integrated systems modeling and (2) knowledge co-production, respectively.

1. The integrated modeling of natural and human systems for the simulation of long-term trajectories has received great interest in recent years, yielding a multitude of models of various degrees of complexity and scale. Ranging from simpler footprinting and material flow models [25,26] to system dynamics [27] and large integrated assessment models (IAM) [28]. Several reviews on FWE modeling show the full scope of approaches [19,29–31]. They have noted that urban FWE models are largely positioned in the realm of industrial ecology, typically applying material flow analyses and similar concepts within urban metabolism frameworks. In recent years, many

have argued that deeper integration is needed between modeling and social science perspectives, such as actors' behavior, dynamics of transformation, contextual embeddedness, and institutional setup [19,32,33]. Trutnevyte et al. [34] discuss collaboration strategies between modeling and social science with “merging” the co-development of models such as agent-based-IAM combinations promising the highest degree of integration. Besides various IAMs, coupled human-natural systems (CHANS) models are centered around complex interactions between human and ecological systems, acknowledging that none of the two spheres can be projected in isolation [35,36]. What all computational systems models have in common is their high degree of abstraction and formalization, requiring a radical reduction of real-world complexity to be implemented [34,37].

2. For transdisciplinary research, the reductionist modeling approach needs to be combined with reflections of the societal context and with the inclusion of non-academic perspectives. Stakeholders can broadly be defined as actors who influence—or are influenced by—the investigated system [38]. Stakeholder engagement throughout the research process is thus an integral part of transdisciplinary research [21]. As Moallemi et al. [39] (p. 310) stress, the combination of stakeholder engagement and modeling techniques offers “transdisciplinary innovation [and] will foster co-learning and collaboration between scientists and stakeholders for generating socially robust pathways.” A number of knowledge co-production concepts (here synonymously used with co-creation) have emerged in the past decade and, due to its popularity and wide use, definitions of the concepts vary greatly. In the context of sustainability research, Norström et al. [40] (p. 183) define co-production as “iterative and collaborative processes involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge and pathways towards a sustainable future.”

Several FWE nexus studies have developed participation formats that include local knowledge and foster ownership by policymakers. These knowledge elicitation methods feature workshops [4], interviews [41], and the Delphi technique [10]. Often, experts, rather than affected stakeholders, are consulted. While concepts such as participatory or companion modeling are established in neighboring research areas, such as environmental and resource management [42,43] or scenario development [44,45], only first steps towards the co-development of integrated FWE systems models with local stakeholders and experts have been taken [46]. Genuine stakeholder engagement and co-production approaches are challenging in the multi-faceted analysis of FWE nexus systems. However, including those stakeholders that are likely to be impacted by future FWE developments is required to gear research questions and study designs towards addressing actual needs, and fostering the adoption of results [8,21,31,47–49].

1.3. PSIR Framework and Conceptual Modeling

Developed and mainstreamed in the 1990s and early 2000s by OECD [50], EEA [51], and others, the DPSIR (Driver–Pressure–State–Impact–Response) was designed as a holistic problem-structuring framework for complex environmental management issues. It has since been used widely, e.g., in the urban domain [52,53] and stakeholder participation processes [54]. Many adaptations have been made to the DPSIR following critique regarding unclear terminology of the various elements, an under-representation of equity issues and structural factors, such as its implicit hierarchy, as well as a frequent lack of contextualization and a simplistic notion of cause–effect relationships [55–60]. In a few cases, the DPSIR has already been used in the context of participatory water systems modeling [61–63]. Recently, it was adapted by Hoekstra et al. [64] to PSIR, which the authors used to structure urban water security problems from a systems perspective. We build on this work, expand it to the entire (urban) FWE nexus system, and furnish it with empirical findings from the co-production process.

No matter what the ultimate form of a systems model is, the critical importance of conceptual modeling has been shown by many scholars: As Grimm and Railsback [65]

stress, no modeling process can start without a “purposeful representation” of the real system, i.e., a simplified, clearly defined representation of those components needed to answer the initial problem or question [49]. The key step here is the selection and abstraction from the complex real system, to not have overly complex models by trying to model everything known about the system under investigation [66]. This abstraction is achieved through the conceptual model’s more formalized representation of the system’s structural components (i.e., subsystems, variables), and dynamics (processes that cause a change of the structural components [65]). Conceptual models in literature vary greatly and no universal definition is available [67,68]. We use the well-established influence diagrams to conceptualize the FWE system of Pune and the Bhima basin.

1.4. Aim

This work aims to contribute to the combination of the two previously mentioned FWE nexus approaches—integrated systems modeling and the co-production of FWE nexus knowledge. While other disciplines have found ways to systematically integrate these two approaches, we find that in-depth stakeholder participation in FWE nexus modeling is scarce. Affected resource users and local decision-makers have the most accurate knowledge of FWE nexus issues and come up with the most suitable policy responses. Thus, what we aim to contribute here is the discovery of complex systems’ interactions within the nexus, and an enhanced ability to realistically evaluate proposed responses. In order to do so, we propose a novel translation and abstraction procedure to co-produce and systematize FWE knowledge. We first elicit and structure stakeholder knowledge with the help of the Pressure–State–Impact–Response (PSIR) framework, and subsequently translate this into a conceptual systems model. Two research questions guided the work: (1) what challenges characterize the FWE system of Pune and the Bhima basin?; and (2) how can the challenges help to formalize the FWE system in a conceptual model? The remainder of this article is structured as follows: first, we introduce the case study region and describe the process of identifying and structuring stakeholders’ FWE challenges within the PSIR framework. Second, we present the resulting 22 challenges. Third, this procedure results in the development of a conceptual systems model, which we use to evaluate exemplary response options.

2. Materials and Methods

2.1. The Study Site: Pune and the Bhima Basin

The Bhima basin is located in Maharashtra and Karnataka and extends from the Western Ghats in the northwest, where the Bhima River originates, to the downstream Krishna basin in the southeast. It supports a population of approx. 18.4 million (2015, [69]), distributed over 45,800 km² of largely agricultural land. Water in the Bhima basin is distributed through a network of reservoirs and canals, supplemented by groundwater abstraction. It supports the basin’s growing population and a legacy of agriculture throughout the year. Most of the rain falls only over five months of the year (June–October) and is concentrated in the Western Ghats. Therefore, in the Bhima basin freshwater is redistributed spatially and temporally, altering the natural flows.

The emerging megacity Pune is located upstream in the Bhima basin (Figure 1). Its metropolitan region (PMR) consists of the municipal corporations Pune and its twin city Pimpri Chinchwad, as well as adjacent villages. Hosting ~8.36 million residents, PMR is the basin’s largest agglomeration, followed by Solapur with ~1.2 million residents [69]. Pune is one of India’s most rapidly growing cities. It features high density and rapid demographic and spatial expansion with associated land use change at the fringe, and it has high socio-economic and cultural diversity [70]. Typical for emerging megacities, the city faces infrastructural deficits (insufficient water, energy, and transport systems), as well as regulatory and governance problems due to institutions being incapable of keeping up with the city’s rapid expansion. Kantakumar et al. [71] show that urban growth has been largely unregulated in the past, despite development plans.

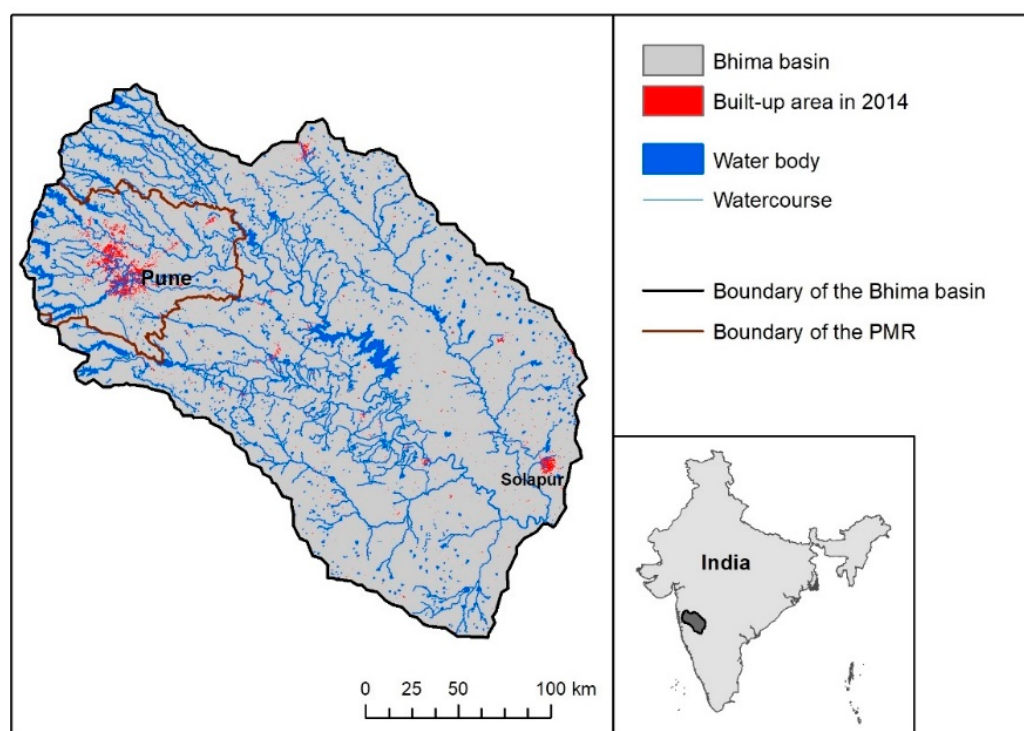


Figure 1. The Bhima basin on the western peninsular of India with its main water bodies and built-up area. Date Source built-up area: [72].

2.2. Co-Production Workshops

The co-production of stakeholder challenges consisted of a series of physical workshops, and periods of desk research as well as online communication in between (cf. [73]). Four workshops formed the core part of the co-production process. These are described below. Supporting information on stakeholder mapping, workshop documentation, and participants' lists can be found in the Supplementary Information (SI).

Stakeholder analysis: After an in-depth context analysis of scientific, grey, and news media, we conducted a three-step mapping of key actors relating to the FWE nexus and urban institutions. First, we compiled an initial list of potentially relevant public institutions, non-governmental organizations, research institutions, commercial and industrial, as well as independent actors. All stakeholders were assigned an area of main activity (food, water, energy, urban, environmental). During a two-month research stay in Pune, this list was then jointly validated and complemented with our local research partner and workshop host, the Gokhale Institute of Politics and Economics, Pune. Lastly, an iterative “snowballing” technique was used, through which key actors suggested further stakeholders from their field. All remaining stakeholders were then mapped based on their estimated level of interest/affectedness and influence (scores from 0–2) regarding the nexus system (cf. [74]). This provided the basis for the selection of two types of stakeholders for the workshops: The ones with high interest/affectedness (“resource users”) and those with high influence (“policymaker and expert”). To reduce power imbalances and allow for every voice to be heard, these two groups were invited to separate workshops at this stage. Further selection criteria, such as gender, sectoral representation, and professional experience, were applied to allow for diverse and balanced groups.

Affected resource user workshop: In the first workshop (Figure 2), a total of 30 stakeholders from farmers' /citizens' associations (10), urban and environmental NGOs (11), research (5), and small companies (4) discussed current and potential future challenges, their coping strategies, and ideas for policy responses. The moderation team employed a specific appreciative approach (“Art of Hosting” [75]) and made it clear from the outset that their task was to learn and to listen. Different methods, e.g., visioning or storytelling were

applied to motivate participants to share their challenges and coping strategies. The stakeholders were presented with different future perspectives related to business as usual trajectories of climate change and urbanization, and they discussed how these might influence their daily lives. This was done in four small groups of five to ten participants of similar backgrounds (e.g., groups of farmers, urban residents/activists, environmentalists), each with one facilitator and one note-taker. The setup resembled, in format and intention, a set of parallel focus group discussions [76]. The results were harvested on flipcharts, filled-in templates, notes, and audio recordings (see Supplementary Materials).



Figure 2. Impressions from Pune stakeholder workshops. Photos: H. Zozmann.

In a preliminary analysis after the workshop, the findings of the resource user group discussions were collected, discussed, and clustered by the research team. A diverse collection of 57 individual and collective FWE nexus challenges, as well as coping strategies and responses, were identified and clustered along the three FWE nexus dimensions (see Supplementary Materials).

Policy maker and expert workshop: In the second workshop, a total of 35 experts from public institutions (20), research institutions and NGOs (11), and the private sector (4) were presented with these initial resource user challenges to review and complement them and to derive potential policy responses. Again, plenary sessions were followed by more targeted focus-group discussions, and documentation was achieved analogously to the first workshop.

Modeling workshop for systems understanding: In this smaller third workshop, 15 local experts from government (4), NGOs (6), and academia (5) were invited to discuss initial ideas for a conceptual systems model and its components. In particular, they provided feedback on first drafts of system components and their interlinkages. As the key guardrails for model development, the co-produced FWE challenges were not distilled at this point; concept designs remained generic at this stage.

2.3. Distillation of Stakeholder Challenges and Solutions

After completion of the first set of workshops, notes and recordings were analyzed systematically for a first coherent set of stakeholder challenges. Core passages of the workshops were transcribed verbatim and coded in MAXQDA using an inductive approach, iteratively distilling the challenges. The resulting intermediate set of challenges was then amended and validated in several steps to reduce the biases inherent in the information

from the focus groups [77]. Controversial perspectives, constraints, and emerging tradeoffs were marked for further fact-checking via the literature and expert consultations, as well as site visits, targeted in-depth analyses, and the subsequent validation workshop.

Validation workshop: After these processing steps, a consolidated set of challenges was presented for validation and prioritization to 36 key stakeholders; most of whom were selected from the participants of the previous workshops (see Supplementary Materials). Different to the previous workshops, the validation workshops brought together resource users and policymakers, allowing for a joint reflection of the different perspectives and the development of a common understanding. This workshop and subsequent adjustments yielded the final set of 22 FWE nexus challenges (Figure 3, Tables 1–4).

2.4. PSIR Framework and Conceptual Model Development

Due to the very different nature of the co-produced challenges, we chose the approach of Hoekstra et al. [64] to differentiate four types of challenges based on their position within the PSIR framework. Following their modification from the original DPSIR, we subsume drivers (typically socio-economic) and pressures (typically natural) into a joint category that we call *pressure challenges*. We modify their framework, however, by distinguishing between endogenous and exogenous pressures (cf. [56,78]), as this was found critical for the subsequent formalization of the conceptual systems model. According to Elliott et al. [56], exogenous pressures emanate outside the system's boundaries and can only be addressed by managing their consequences (e.g., climate change). Endogenous pressures, on the other hand, are pressures within the system, and thus under the influence of the decision-makers, who can respond by addressing both cause and consequence of the pressure (e.g., land use change). In some cases, the distinction is not entirely clear-cut as pressure challenges, such as urbanization, have both exogenous and endogenous components. In the case of urbanization, this was dealt with by splitting the pressure into an exogenous (urbanization with a demographic focus) and an endogenous (land cover/use change) challenge, each representing one key aspect of the overall phenomenon.

Analogous to the approach of Hoekstra et al. [64], *state challenges* are defined as describing the characteristics of subsystems in the form of indicators (e.g., cropped area, cost recovery in electricity supply, flood occurrence), and *impact challenges* as those that directly represent the system's functions and services for the users (e.g., intermittency of water supply, economic pressure on farmers). At this point, all stakeholder challenges are clustered along the P–S–I dimensions of the framework. Tests for interlinkages between the individual challenges yield a tight weave of interrelated issues across all nexus dimensions (exemplified for one challenge in Figure 3).

The P–S–I challenges are subsequently translated into components of the conceptual systems model. As mentioned in the introduction, various approaches to conceptual modeling exist. We apply influence diagrams consisting of structural and dynamic elements [67]. After the delineation of systems boundaries based on geographical boundaries and sectoral scope [31], the structural components of the model are designed in the form of *subsystems*, i.e., clusters of contiguous elements that are defined by several state variables. These relate to the *state challenges*, e.g., the level of pollution (cf. [79]). The subsystems are linked through *processes of influence*, corresponding to effects that one subsystem has on the other, and feedback loops (one-to-one, one-to-many, many-to-many). These dynamic levers are associated with *endogenous pressures challenges*, such as water abstraction (cf. [63]). Any systems model needs to account for *external effects*, posing constraints and pressure [49]. These external effects, typically considered as scenarios in simulation models, are informed by the *exogenous pressure challenges* and correspond to factors not under the direct control of the region, e.g., climate change, population growth, economic growth, etc. Lastly, a central motivation for the modeling process is the assessment of impacts on society. These are captured by suitable *output metrics* produced by the model. This becomes especially important when quantifying the systems model at later stages. Output metrics operationalize PSIR's *impact challenges* and may relate, for example, to access to FWE resources or flood damage.

2.5. Response Development

The formulation and evaluation of responses to the identified challenges are a main objective of this study. Their initial formulation consequently stands at the beginning of the modeling process [37]. Effective responses can address all three P–S–I domains: reduce endogenous pressures, improve the system’s state, or counter the impacts. Exogenous pressure challenges are not within the actors’ influence and are thus not addressed by the responses (cf. [79]). During the workshops, affected resource users and policymakers co-produced collections of potential coping strategies and policy responses, respectively (see Supplementary Materials). These form the basis for the response options evaluated in this work. Section 3.6 provides an illustrative example along three prominently discussed responses of how the model helps to assess points of leverage and potential downstream effects of responses to the entire FWE system.

3. Results and Discussion

3.1. 22 P–S–I Challenges

As described in Section 2, a set of 22 FWE challenges for Pune and the Bhima basin is derived based on resource users’ and experts’ input during the stakeholder workshops. Figure 3 provides an overview of all of the challenges and an illustrative flow of interlinkages, in which selected cause–effect links are drawn that influence the impact challenge W6—*Constrained & unequal access to water*. Similar flows could be drawn for other challenges.

More details on the individual challenges are presented in Table 1 (exogenous pressures), Table 2 (endogenous pressures), Table 3 (system state), and Table 4 (impacts). In the following sections, key issues and interlinkages of the Bhima basin’s stakeholder challenges are discussed in more detail, explaining the co-produced results from the table and linking them to the literature and data. We point to interlinkages between challenges by referring to their IDs specified in the first column of the tables and a short title (e.g., X1—*climate change*).

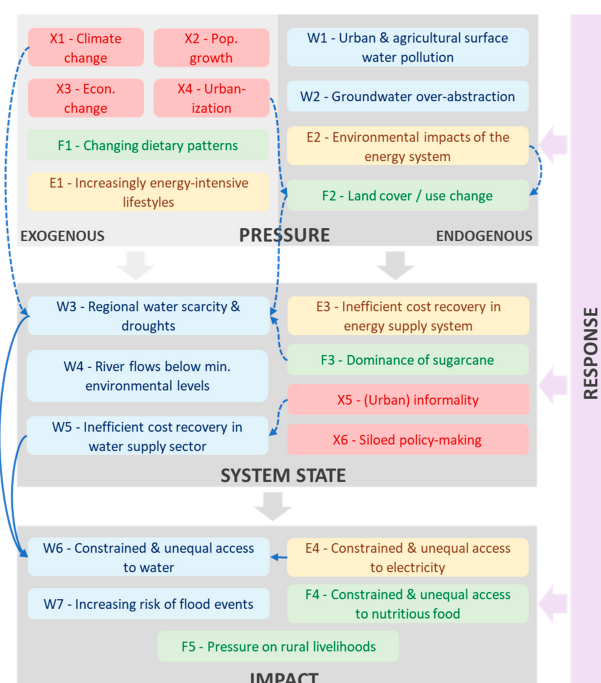


Figure 3. Overview of 22 stakeholder challenges positioned within the PSIR framework. Colors correspond to the primary nexus domain: blue = water, yellow = energy, green = food and agriculture, and red = overarching challenges. There are multiple interlinkages between all challenges. The blue arrows illustrate a causal flow centered around the impact challenge W6, which is directly influenced by the challenges W3, W5, and E4 (solid arrows), and indirectly influenced by X1, F3, and others (dotted arrows).

3.2. Exogenous Pressure Challenges

The FWE nexus of regional systems is influenced by intersecting meta-factors on higher scales, posing pressure on the system [9,45,47]. In the workshops, six of such *exogenous pressure challenges* were discussed, encompassing general trends such as climate change, population growth, and macro-economic developments, but also more context- and nexus-specific challenges related to urbanization, changing lifestyles, and consumption behaviors (see Figure 3, Table 1). The literature and existing data support these co-produced exogenous pressure challenges: Maharashtra has been among India's states most severely affected by climate change. According to Vörösmarty et al. [80], large parts of the Bhima basin are among the world regions where threats to human water security and biodiversity coincide with increasingly frequent and severe droughts and floods (W3—*water scarcity*, W7—*flood risk*). Heat stress impacts the local FWE nexus through higher water and electricity consumption (W—*groundwater over-abstraction*, E1—*energy-intensive lifestyles*), lower cooling capacity of thermal power plants, and losses in agricultural yield (F4—*access to food*, F5—*pressure on rural livelihoods*) [81]. The basin's population grew from 7.9 million in 1975 to 18.7 in 2015, primarily in urban areas [69], which have become popular migration destinations [70,82]. The per capita GDP (PPP) of Maharashtra has increased more than six-fold since 1980 [83]. At the same time, the overall economic inequality has increased over the last decades with the GINI coefficient rising from ca. 0.32 in 1994 to 0.35 in 2012 [84]. FWE resource consumption is directly linked to economic development: between 1970/71 and 2018/19, Maharashtra's electricity consumption increased by a factor of 17 (from 7,65 GWh to 131,87 GWh, [85]) and urban diets are relying less on local agricultural production.

Table 1. Stakeholders' **exogenous pressure challenges**. With links to other nexus dimensions (column 3) and quotes from the stakeholder workshops. Colors correspond to the primary nexus domain: blue = water, yellow = energy, green = food and agriculture, and red = overarching challenges.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
X1	Climate change	All	Temperature in the basin has been increasing over the last decades and precipitation patterns, e.g., the onset of the monsoon, have begun to change. Though the total precipitation is not declining in the Bhima basin, reliability for farmers is decreasing, extremes are more frequent, and high temperatures pose pressure on the urban population.	<i>"There will be a lot of worsening trends due to increasing water scarcity and increased temperature."</i> <i>"There have been heat island effects in all pockets, the temperature in Pune City is rising—which never used to go beyond 30 °C or 35 °C even in summer."</i>
X2	Population growth	All	The basin's population has more than doubled in the last forty years and the growth is expected to continue. The population increase entails pressures on the nexus resources, especially in combination with the economic (X3) and lifestyle (E1) changes.	<i>"Now things are going from bad to worse. The reason is too much population growth—and the governance is bad."</i>
X3	Economic and technological change	All	The basin's economy, especially in the PMR, where the industrial city Pimpri Chinchwad is located, has been growing rapidly. Quantitative and qualitative changes in the consumption of FWE nexus resources are driven by industrial development as well as changing lifestyles and production processes. However, prosperity remains unequally distributed, especially between urban and rural areas.	<i>"Change in industry: there are more IT startups which use more energy. Lots of industries shifted to Pune [. . .]."</i>

Table 1. Cont.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
X4	Urbanization	All	Urban areas, in particular Pune and, to a lesser extent, Solapur, have grown rapidly in the last decades both in terms of population and spatial extent. A major growth factor is that the city is increasingly receiving migrants, both from other cities and rural areas. Nexus conditions act as push (e.g., droughts) and pull (better supply) factors for migration.	<i>“The one challenge is too much [. . .] population concentration.”</i> <i>“There is no water. So, no farming, no jobs, nothing to earn. So, this is why migration is happening from the rural areas to the urban area because jobs and water is available.”</i>
E1	Increasingly energy-intensive lifestyles	Water (Food)	Maharashtra’s energy demand has increased strongly over the last decades and is projected to further grow. In urban areas, new household appliances and industrial developments fuel the growth. Decarbonization efforts such as transport electrification additionally drive electricity demands.	<i>“We had big changes in the energy system, big increase in demand [. . .] due to lifestyle changes and population [growth]. Now we have ceiling fans, fridges, and washing machines.”</i>
F1	Changing dietary patterns	Water	Stakeholders have reported changing dietary patterns associated with increasingly urban lifestyles. This can lead to a more balanced and diverse diet, but also manifest in increasing consumption of fast/convenience food and decreasing traditional local food cooking/consumption.	<i>“20 years ago, 100% of the food was local. There was no salad, no broccoli. If you wanted to eat a particular thing you had to travel to Mumbai. Now global markets are opening up here.”</i> <i>“The habit of having seasonal food and vegetable has changed. [. . .] This all has to do with the stress over food and lifestyle changes.”</i>

Table 2. Stakeholders’ endogenous pressure challenges. With links to other nexus dimensions (column 3) and quotes from the stakeholder workshops. Colors correspond to the primary nexus domain: blue = water, yellow = energy, green = food and agriculture, and red = overarching challenges.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
W1	Urban and agricultural surface water pollution	(Food)	Insufficient sewage and solid waste management of urban areas, as well as excessive use of fertilizers and pesticides in agriculture, lead to deterioration of downstream water quality, affecting agriculture (livestock diseases) as well as urban areas (Solapur).	<i>“The rivers are dealing with heavy pollution. Downstream it is even worse.”</i> <i>“Subsurface and surface water management was done very poorly.”</i>
W2	Groundwater over-abstraction	Energy (Food)	Groundwater abstraction is largely unregulated in urban and agricultural areas, creating over-abstraction pressure. Among the reasons is the unmetered electricity supply for agricultural water pumping and lacking water infrastructure in the urban fringe that requires (illegal) wells and tanker water.	<i>“Groundwater is one of the key challenges. It’s the ungoverned and unregulated extraction.”</i> <i>“[Farmers] keep their pumps switched on [. . . to] start pumping as soon as there is electricity.”</i>

Table 2. Cont.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
E2	Environmental impacts of the energy supply system	Water (Food)	Despite an increase in renewable capacities, Maharashtra's electricity generation is still largely based on coal power, emitting large quantities of CO ₂ every year. Besides its high carbon intensity, ecosystems are degraded due to mining, hydropower, and other energy infrastructure. Back-up generators used to compensate for blackouts drive urban air pollution.	<i>"The use of diesel engines went up to circumvent power outages, this led to more CO₂ emissions."</i> <i>"[E]nergy sources will have to adapt. We expect that there is less water available for hydropower because the water needs would be greater and the water availability from other sources is smaller."</i>
F2	Land cover/use change	Water Energy	Urbanization and industrialization lead to a loss of fertile and natural land, potentially entailing reduced local food provision, an altering of the regional hydrological system, etc. The built-up land in the Bhima basin has increased between 1975 and 2014 by the factor 8. If solar farming should be adopted more widely, competition for land might increase.	<i>"The more competition there is for land: more land for the city, more land for sugarcane, maybe for solar farming. Less land will be there for farming."</i> <i>"Land surrounding Pune city used to be fertile agricultural land and now it is converted due to civil construction and industries [. . .]. The farmers are then selling their land [. . .]."</i>

3.3. Endogenous Pressure Challenges

The *endogenous pressure challenges* found in the workshops all relate to one or more particular FWE dimensions within the Bhima basin: both agriculture and urban/industrial consumers rely on groundwater as well as surface water sources. Although the region is generally not water-scarce, the cumulative demands can temporally exceed the available freshwater supply. The basin's water quality is partly insufficient. Pune is relatively upstream in the Bhima basin, warranting good water quality. However, downstream of the city, it deteriorates strongly, impacting people's health and livelihoods (W6—*access to water*, F5—*pressure on rural livelihoods*). Despite ambitious decarbonization plans by national and state government and the high potential of competitive renewable energy generation [86,87], coal power plants still account for 59% of Maharashtra's installed capacity, compared to 30% of renewables [88]. The latter includes large-scale hydropower with its own environmental impacts (E1—*energy-intensive lifestyles*, W3—*water scarcity*, cf. [15]).

A local effect of the strong reliance on fossil energy sources are Pune's high pollution levels, especially particulate matter (PM_{2.5}): the city is among India's six most polluted cities [89]. Land cover and land use change affect the basin's availability of farmland: 80% of Pune's built-up growth between 1985 and 2005 took place on former agricultural land; in sum, 192 km² of agricultural land in the PMR and 323 km² in the entire basin were lost to built-up areas [90]. This loss was partly compensated for by the conversion of natural shrubland in the periphery. New land-intensive developments in the energy sector—large-scale photovoltaics (solar farms) and sugarcane for energetic use—potentially aggravate the pressure on agriculture in the future. To date, over three gigawatts (GW) of grid-connected solar capacity have been commissioned in Maharashtra, of which 1.34 GW is located in the Bhima basin [91]. Assuming land requirements of 1.4 ha/MW installed capacity [92], this corresponds to an area of 18.76 km² in the basin.

3.4. System State Challenges

Many challenges relate to changes in nexus subsystems. These are often consequences of exogenous or endogenous pressure challenges, as presented above.

Water: In the case of temporal and regional deficit irrigation due to water scarcity, agricultural yields decrease (F4—*access to food*, F5—*pressure on rural livelihoods*). This has

been reported especially from the southern parts of the basin, where droughts have in the past lead to villages abandoning their farms to move to the city (X4—urbanization). The water revenues of municipalities such as the PMC are insufficient to cover the operation and maintenance costs of services. The metered system has been completely abandoned in the residential sector and was replaced with a water tax based on property tax. Today, only non-residential establishments, which account for less than 40% of the total water revenue, are metered [93]. This reduced the incentive to use freshwater efficiently (W2—groundwater over-abstraction, W3—water scarcity, W4—low river flow levels).

Table 3. Stakeholders’ state challenges. With links to other nexus dimensions (column 3) and quotes from the stakeholder workshops. Colors correspond to the primary nexus domain: blue = water, yellow = energy, green = food and agriculture, and red = overarching challenges.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
W3	Regional water scarcity & droughts	Energy (Food)	Climate-change-induced precipitation and temperature changes, as well as agricultural and urban water abstraction, have altered surface water flows and groundwater levels in the basin. While the Western Ghats are likely to receive more water in the future, regions to the east and south may face increasing temporal scarcity. This negatively affects crop yields, increases prices, and threatens livelihoods.	<i>“Increased temperature and therefore increasing water scarcity because of the polarization of rainfall increases. There is more rainfall in total but also more dry days and the rainfall might not always be in the place needed.”</i>
W4	River flows below min. env. levels	Energy (Food)	In times and regions of water scarcity, the river flows are diminished. With continuous agricultural, hydroelectric, and urban extraction, the sustaining of ecosystem functioning may be jeopardized.	<i>[no direct quote from workshops]</i>
W5	Inefficient cost recovery in water supply sector	Energy	Largely absent metering, high non-revenue water, and partly dysfunctional water institutions have detrimental effects on the supply system. Infrastructure development is lagging behind and costly tanker water has to compensate for missing pipe networks.	<i>“It’s the mismanagement and inequitable water supply [that] is a problem.” “The private tanker lobbies steal water and make money out of it. This needs to be stopped or better controlled.”</i>
E3	Inefficient cost recovery in the energy supply system	Water Food	A non-transparent governance structure and partial privatization have led to an inefficiently regulated energy supply system. The agricultural sector consumes almost a third of Maharashtra’s electricity at very low rates, cross-subsidized by urban and commercial users.	<i>“The quality of the energy production is going down.” “Businesses using household connection [. . .] so that they do not have to pay the high commercial tariff. They have to cross-subsidize [. . .] it’s a burden on them.”</i>
F3	Dominance of sugarcane	Water Energy	Sugarcane provides higher and more reliable income to farmers due to subsidies and guaranteed prices compared to other, more nutritious crops, and thus reduces their cropping volumes. Its high water demand and its low nutritional value impact the local food supply.	<i>“The floodplain where the produce used to come from has been turned into sugarcane.” “There is less diversity in the crops: Before, they used to have more crops, and now there is more monoculture.”</i>
X5	Urban and economic informality	Water (Energy)	Over 20% of Pune’s population live informally, ranging from improvised roadside tents to consolidated, declared slums. Pune’s slums often have deprived/unequal access to water, electricity, and to some extent, food and are highly vulnerable in the face of environmental hazards. Informality extends beyond living conditions: informal labor, water vending by unregistered tanker trucks, or the illegal sharing of electricity meters.	<i>“Already, poor people have to wait for water 2–3 hours, especially in the slums. This will increase” “[. . .] in some cases, people have to rely on unofficial or even illegal ways of getting water and energy. This is where illegal connections come into place”</i>
X6	Silo-thinking in FWE nexus governance	All	The workshops yielded that in Pune’s FWE nexus, silo thinking prevails not only across sectors but also across spatial and institutional levels, i.e., local bodies and state administration, as well as metropolis and periphery.	<i>“Governance is based on good knowledge and information and it is working together, not in silos. So that there is an integrated response towards sustainability”. (future vision of SH).</i>

Energy: After periods of power shortages, Maharashtra reached a surplus of electricity in recent years. Therefore, scheduled blackouts (load shedding) in Pune have become limited to weekly maintenance works. Unscheduled supply interruptions for shorter durations, however, are still common. Consequently, many urban residential and commercial users have costly and polluting backup generators (*E2—env. impacts of energy system, E3—costly energy system*). In rural areas, supply interruptions are more frequent, particularly in the agricultural feeders that power groundwater irrigation pumps. Farmers report that due to the unreliability and low price of the power supply, they leave on the pump throughout the nights, leading to frequent excess pumping and groundwater depletion (*W2—groundwater over-abstraction*).

Food and agriculture: Fixed prices and the comparatively low labor demand have made sugarcane a preferred crop even in regions with low precipitation, entailing surface and groundwater (over-)abstraction (*W2—groundwater over-abstraction, W4—low river flow levels*). Today, around 4800 km² (~20% of the total cultivated area) are used for sugarcane cultivation in the Bhima basin, accounting for approximately 80% of the total irrigation water use [94]. Increasingly, molasses, a by-product of sugar processing, is used for bioethanol production to be blended with gasoline. If the ambitious blending target of the government leads to increased cropping of sugarcane in future, competition for land (and water) with food crops can arise. As Lee et al. [94] show, the land and water demand to reach the national blending target of 20% would increase by approx. 385% if solely met by molasses-based ethanol. There is, however, an overproduction of sugar in India. If bioethanol production would move towards direct use of sugarcane juice instead of molasses, no additional land would be required.

Urban and institutional: Urban informality was a prominent, cross-cutting topic during all workshops, indicating how intricately it is linked with many other challenges—and in some cases opportunities—of the FWE nexus. FWE nexus informality in Pune can be found in many areas: living conditions (slums), informal labor (e.g., in agriculture; *F5—pressure on rural livelihoods*), water vending by unregistered tanker trucks (*W5—costly water system*), or the illegal sharing of electricity meters (*E3—costly energy system*) were raised by stakeholders. The FWE nexus in Pune and the Bhima basin is still largely governed in silos. For the case of Delhi, Malik [95] illustrates how electricity and water utilities fail to coordinate for better water supply by constantly blaming each other publicly for the intermittencies. Similar reflexes have been discussed during our workshops in Pune.

3.5. Impact Challenges

FWE impact challenges relate to the effects of nexus issues on society, e.g., welfare. In the case of the Bhima basin, they largely refer to access barriers of households for water and electricity, and to some extent for food.

Water: Access to freshwater involves four dimensions of hurdles, temporal, spatial, qualitative, and pecuniary, which consumers need to overcome to secure water [96]. As described by users and experts in the workshops, in Pune, the piped water distribution is highly intermittent and spatially unequal. Contamination and water pressure problems arise from intermittent supply and aging water infrastructure. Many newly developed areas in the city fringe are out of reach of the current piped water supply network. The insufficient piped water supply forces people to adopt coping strategies, such as using water storage or choosing alternative sources [93,97], which require additional actions from consumers. They usually also require additional energy inputs, e.g., delivery by tanker trucks (*E1—energy-intensive lifestyles*) [95]. As Link et al. [82] show, Pune's recent floods hit slum dwellers and rural migrants especially hard (*X5—informality*), with many casualties and grave economic consequences. The stakeholders were convinced that these are consequences of both climate change and insufficient infrastructure (*X1—climate change, W5—costly water system*).

Energy: Notwithstanding the overall surplus of electricity, about 16% of Maharashtra's population still lacks access to power altogether, especially in rural areas (*E3—costly energy*

system) [98]. Energy prices have risen considerably in the past 10 years, particularly for commercial and industrial consumers, which cross-subsidize the almost free electricity for the agricultural sector [99]. Urban consumers have started to turn towards the use of captive power generation, i.e., self-generated electricity. This puts the overall financing of the public electricity system, which is already dependent on subsidies, in further jeopardy.

Food and agriculture: Nutritious food is not affordable for everyone in Pune and the Bhima basin. Further FWE nexus tradeoffs can emerge due to the aforementioned competition for land with urban and energy use (X4—urbanization, F2—land use change, E2—env. impacts of energy system), and associated availability concerns and price increases in local produce. The transformations in the agricultural sector not only alter the regional food supply, but exert pressure on rural livelihoods (F5—pressure on rural livelihoods) through reduced labor demand and changing land ownership, often culminating in migration to the cities (X4—urbanization).

Table 4. Stakeholders' impact challenges. With links to other nexus dimensions (column 3) and quotes from the stakeholder workshops. Colors correspond to the primary nexus domain: blue = water, yellow = energy, green = food and agriculture, and red = overarching challenges.

ID	Challenge	FWE Links	Description	Stakeholder Perspective
W6	Constrained and unequal access to water	Energy (Food)	The piped water supply of households and commercial establishments is intermittent and does not cover the entire (urban) area. The service level of alternative water supplies, such as tanker trucks, is often lower than that of piped services or more expensive, adding qualitative and economic barriers to the constrained access.	<i>"For the municipal supply, the water is [only] coming in some period in the morning and some period in the afternoon."</i> <i>"Poor people will, first of all, pay more, because they cannot so easily select the water source they want to use, they will experience impact on their health [...]"</i>
W7	Increasing risk of flood events	(Food)	Pune experienced severe flood damage in the last three consecutive years. They were caused by heavy rains, insufficient infrastructure, and emergency dam discharge. Especially vulnerable urban groups located close to the rivers or on sloped terrain suffered severe damage.	<i>"Pune has a fast-changing climate. There can either happen many droughts or heavy rainfall events, so far there is no policy in place; leading to crises such as flooding."</i>
E4	Constrained and unequal access to electricity	Water	Around 16% of Maharashtra's population lack access to electricity. Weekly maintenance blackouts in Pune limit access temporarily. The price per kWh has increased over the last years, especially for commercial and industrial users as well as households.	<i>"There are still many areas which experience electricity interruptions, especially in the outskirts. On Thursday, most of the area does not have power. In slum areas, it is very interrupted on an irregular basis."</i> <i>"Some people do not have the money for electricity."</i>
F4	Constrained and unequal access to nutritious food	Water	Rural poor face (temporal) food shortage in years of low yields. This is one of the push factors of migration to the city. In urban slums, many people are dependent on low and stable food prices.	<i>"I think [...] there is more dependence on non-local food, coming with advantages and disadvantages."</i> <i>"The slums still depend on local food while everyone else is also buying imported food."</i>
F5	Impacts on rural livelihoods of transformations in the ag sector	Water Energy	Global food markets, the industrialization of agriculture, and changing consumption patterns pose pressure on smallholder farmers. Socio-cultural effects, such as a perceived superiority of urban lifestyles, make rural life less attractive, often triggering migration.	<i>"Previously, the farming was for the sustainability for the family and now it has become a business."</i> <i>"[W]omen in the city are not ready to marry men who are farming, they want men who are in service."</i>

3.6. Conceptual Model

As described in the methodology, the conceptual systems model—an influence diagram—consists of structural and dynamic elements that each reflect a dimension of the PSIR framework. Structural elements are represented by subsystems, while dynamic elements comprise processes of influence, external effects, and output metrics (see Figure 4). For illustration, we added the stakeholder challenges to the corresponding elements.

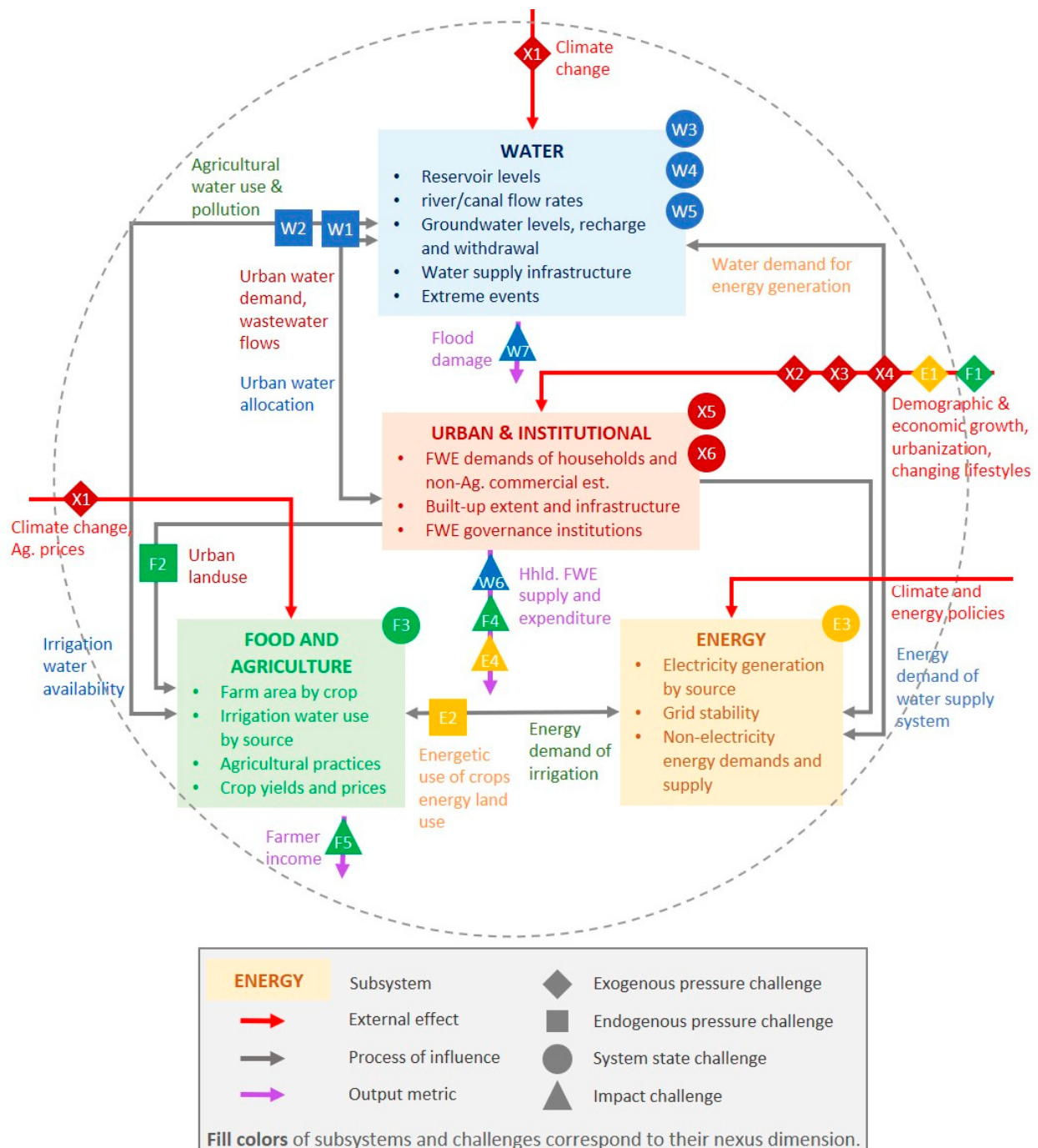


Figure 4. Conceptual model with subsystems (large boxes) linked by processes of influence (grey arrows). External effects (red arrows) pose pressure from outside the system boundaries (dashed line). Output metrics (purple arrows) determine impacts on society. P–S–I stakeholder challenges are placed at the corresponding model element.

The system boundaries (dashed line) are defined physically by the Bhima basin and sectorally by the urban FWE nexus. Within these boundaries, four subsystems have been selected for analysis: all FWE nexus dimensions, as well as an urban and institutional subsystem. Subsystems can be broken down into smaller components defined by variables and indicators, such as electricity generation by the various sources, piped water infrastructure extent, yields per crop and area, and industrial resource consumption. State challenges, constituting each subsystem in the form of round symbols, are found in the subsystems' upper right corner. Most subsystems are interlinked with bidirectional (fewer with unidirectional) *processes of influence* (grey arrows), such as the effect of urban land use change on agriculture or the agricultural energy demand for water pumping. Corresponding *endogenous pressure challenges* are symbolized in squares on the arrows. *External effects*, as defined by the *exogenous pressure challenges*, encompass biophysical changes related to climate change, as well as demographic and socioeconomic drivers. They are illustrated as red arrows from outside the system boundary with diamond-shaped challenges. Lastly, *output metrics*, e.g., the number of households with certain levels of FWE supply, are depicted as purple arrows and match the *impact challenges* (triangles).

3.7. Response Evaluation

The list of coping strategies and responses by resource users and decision-makers to address the identified challenges is long (see Supplementary Materials). We use the conceptual systems model to make the primary points of leverage explicit and show through which processes influence other subsystems may be affected downstream. We can thus detect synergies and tradeoffs early on in the design and evaluation of response options. Three illustrative suggestions from the stakeholder workshops show how systems thinking can improve the understanding of causal loops throughout the FWE nexus. All three responses relate to existing plans or strategies in different stages of implementation, warranting relevance.

1. **Pune 24/7:** Ensuring uninterrupted water supply to urban households
2. **Ag PV:** Solar farming for decentralized agricultural pumping
3. **Limit Sprawl:** Limitation of urban sprawl through city development plans

Challenges related to resource access constraints (*E4—access to energy*, *F4—access to food*, and in particular *W6—access to water*) featured prominently in the workshops. Consequently, responses to ensure adequate access to water, electricity, and nutritious food were discussed by the stakeholders. The city of Pune is currently implementing a major restructuring of its water supply system, aiming at “safe and equitable water supply to the entire population in Pune city [. . .] during the entire day, full water meter coverage, and the reduction of losses and non-revenue water” [93] (p. 41). This “Pune 24/7” strategy is flanked with major supply enhancement projects to increase the city’s total water availability through conveyance from surrounding reservoirs. As Figure 5 shows, Pune 24/7, if implemented successfully, directly and positively addresses the challenges *W5* and *W6*. If the improved availability of water in the city leads to an overall increase in water consumption, tradeoffs with water allocation for agriculture (*W3—water scarcity*) and lower natural river flows (*W4—low river flow levels*), as well as increased energy demand for water (*E1—energy-intensive lifestyles*) may arise.

Solar energy is considered a cornerstone element in Maharashtra’s renewable energy strategy [100]. The agricultural sector consumes approximately one-third of the state’s electricity, and is largely unregulated. With collection efficiencies of merely 13% and little prospects of change [101], it poses a financial burden on the entire electricity system [98]. Since 2017’s “*Mukhyamantri Saur Krishi Vahini Yojana*” (Chief Minister’s solar power plan for agricultural feeders), the government of Maharashtra aims to address both issues by supporting decentralized, grid-connected photovoltaic systems for agricultural feeders [102]. According to Gambhir et al. [103], this successfully improves farmer-centric and cost-effective rural electricity supply (*E2—env. impacts of energy system*, *E3—costly energy system*) and potentially benefits farmers’ livelihoods (*F5—pressure on rural livelihoods*). FWE

nexus tradeoffs may arise, however, where the improved access to solar power leads to further over-abstraction of groundwater (*W2—groundwater over-abstraction*), as well as the loss of arable land to solar farms (*F2—land use change*).

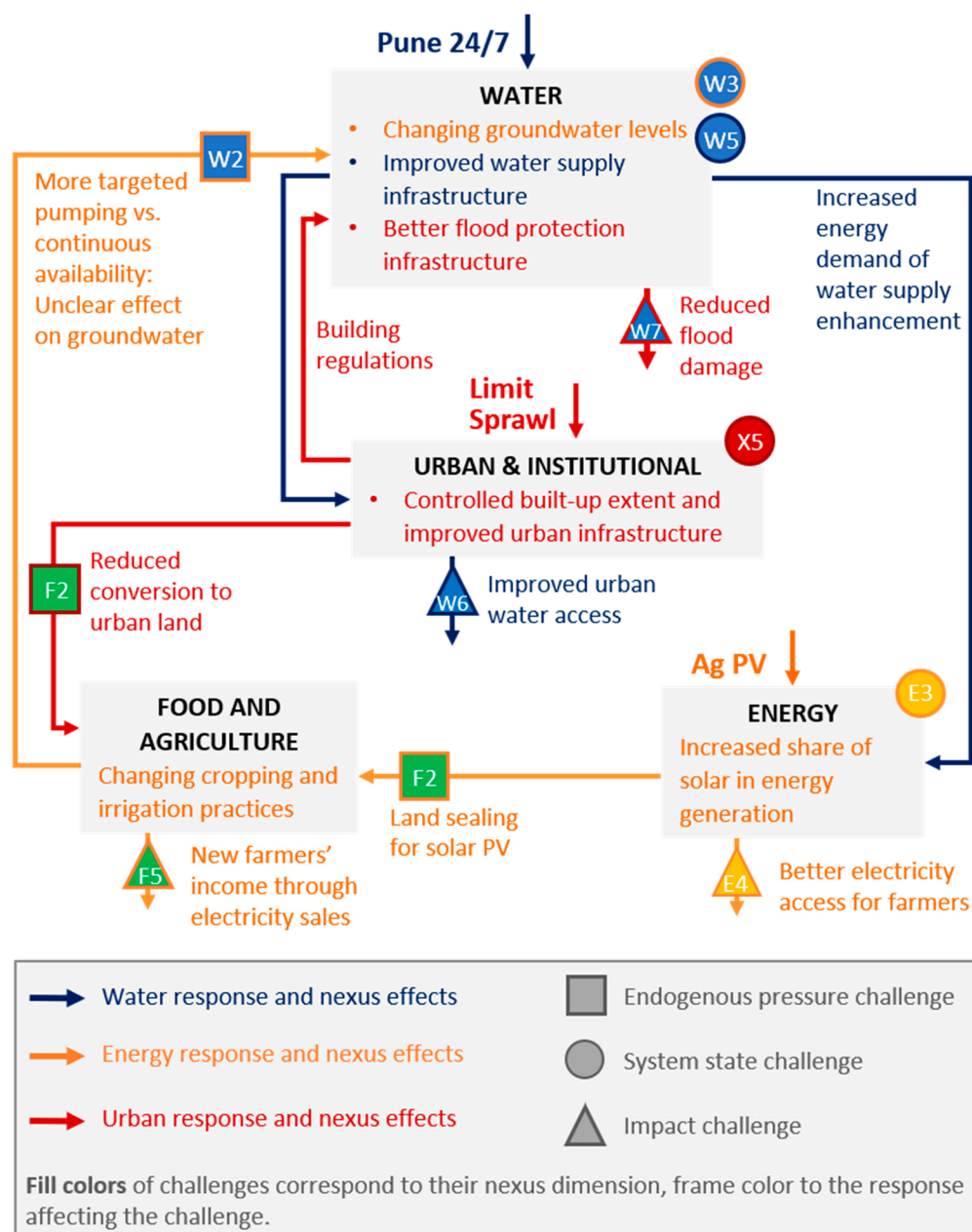


Figure 5. Illustration of three responses and their effects on the FWE nexus system: (1) Pune 24/7: continuous, efficient water supply in urban areas. (2) Ag PV: decentralized agricultural solar power for irrigation. (3) Limit Sprawl: regulation of urbanization to limit sprawl. All responses affect more than one subsystem and a number of challenges.

The basin's urbanization trend cannot be stopped by local responses alone. As workshop participants suggested, however, more attention could be placed on its adverse effects, namely the massive land sealing of urban sprawl. The municipal corporations of Pune and Pimpri Chinchwad, and recently the regional authority, have proposed development plans that guide the urban development through urban planning instruments [104–106]. All three authorities address urban sprawl and adopt various strategies to counter its adverse environmental effects. Effective implementation of the plans could lead to a reduced sealing of arable land (*F2—land use change*), lower risks of urban flooding (*W7—flood risk*), and possibly

benefit energy consumption (*E1—energy-intensive lifestyles*) due to reductions in commuting distance, and urban informality due to slum rehabilitation programs (*X5—informality*).

As Figure 5 shows, all three selected responses—though initially targeting individual challenges—affect further challenges (in the case of solar farming—Ag PV—as many as six challenges are affected, most of which positively).

4. Conclusions

This paper addresses three underrepresented aspects in current FWE nexus research: the integration of stakeholders that are directly affected by nexus developments, the explicit integration of urban facets to the FWE nexus, and the development of a conceptual FWE systems model based on the PSIR framework. We describe the process and result of the co-creative definition of 22 stakeholder challenges and the development of a conceptual systems model of the Bhima basin's FWE nexus. During a series of workshops, we encountered elaborate knowledge on Pune's and the basin's main issues regarding the FWE nexus and rapid urbanization that confirmed our hypotheses that affected resource users and local decision-makers know the systems components and related challenges best. The challenges range from changing precipitation patterns due to climate change and the associated temporal and regional water scarcity to increasing energy demands, inadequate access to water, energy, and in some cases food, by resource users. Major transformation dynamics are found in the agricultural sector, where small-scale farmers struggle with industrialization and cash crops, such as the water-intensive sugarcane. The explicit recognition of urban challenges in the FWE nexus yields insights into the rapid rural–urban migration, ubiquitous informality, and the competition for land. During the distillation of the challenges, it became apparent that they differ not only in terms of their corresponding sector (water, energy, food, urban), but also in their nature, or specifically, in their position within cause–effect systems. We thus set out to structure systems knowledge using a variation of the established DPSIR framework as an intuitive tool to categorize challenges and elicit cause–effect relationships [78]. We thereby show how Hoekstra et al.'s [64] PSIR can be applied to structure a real-world FWE nexus case. Building on this framework, we present an influence diagram consisting of subsystems connected through processes of influence, as well as external effects and output metrics.

Showcasing the effect flows of three selected responses proposed by the stakeholders, we illustrate the model's application potential. Based on our influence diagram, decision-makers can evaluate response options early on for synergies and tradeoffs throughout the nexus system. This allows for a design of long-term strategies geared towards an increasingly sustainable and resilient system, adapted to the exogenous pressures specified in this article. The visual character of the influence diagrams supports stakeholder interaction for further co-production steps. They will be used during another upcoming round of stakeholder workshops in Pune. While our results are specific to Pune and the Bhima basin, the developed methodology and the application of the conceptual systems model for the evaluation of response options are generalizable to any FWE nexus system. This is shown, for example, by [107], for the case of Amman, Jordan, where a similar approach was successfully tested in a very different context.

Our approach is rooted in a participation format. Norström et al. [40] developed four general principles of successful co-production along which we can assess our approach: (1) context-based (situated in specified context, place, or issue), (2) pluralistic (including multiple actors with diverse knowledge and skills), (3) goal-oriented (based on a shared understanding of challenges and goals), and (4) interactive (frequent interactions throughout all project phases). The first two principles can be confirmed through the nature of a clearly defined case study and the invitation of 75 highly diverse stakeholders. The research project was not co-designed, and thus did not include stakeholders in the early conceptualization stages. The workshop format may not be the most suitable environment for all stakeholders we want to reach (e.g., farmers, slum dwellers). Sharing their experiences may have been hindered by the academic language, unfamiliar setting, group dynamics, and other effects

inherent to focus group discussions. The substantial processing of initially collected stakeholder challenges may have altered the original perspective, and the described validation steps may have excluded extreme or unexpected views. The workshops, however, yielded a shared understanding of challenges and potential responses. Moreover, a meta-level objective of forming a community of practice to work on the realization of a sustainable vision for the Bhima basin and Pune were valued by the participants. The project aimed at high degrees of interaction throughout the entire time. This goal was reached to a moderate extent only, as the onset of the COVID-19 pandemic limited actions during a key phase to virtual communication, which do not provide the same experience. Therefore, validation steps beyond the discussed needed to be postponed. Nonetheless, very positive feedback by resource users and experts after the workshops, and continuous interaction with key stakeholders during the following steps, indicate that this has mainly been achieved. Or, as one stakeholder put it: “It is very right to plan for the year 2050 by including all people from all sectors together so that we can really plan very easily.”

Conceptually, the model development process presented in this article can be described as a series of three abstraction steps from the real world (or problem domain) to the conceptual model. According to Federici et al. [108], each step is critical to systematically reduce complexity without missing key components of the system: (1) the co-production of systems understanding in the form of stakeholder challenges can be viewed as a *selective description of the system*, focusing on the (subjective) main aspects relating to the FWE nexus system under investigation; (2) they are structured within the PSIR framework as a definition of the *target system*; (3) the definition of the abstract model, i.e., a non-quantified formalization, marks the transition from the problem domain (target system) to the model domain (cf. [66]). Although this work focuses on the qualitative understanding of the FWE system’s structural components and their interlinkages, the modeling process does not need to end at this point. Simulation efforts would proceed with the development of a computational model, which, after successful validation and verification, could aid further co-production of policy responses.

A descriptive collection of individual challenges related to the FWE nexus of an urbanizing region in itself is useful for a better qualitative understanding of both researchers and participating stakeholders. We argue, however, that the systematization of challenges within our FWE nexus PSIR framework adds value by making the different qualities of challenges visible. The often-claimed importance of nexus-thinking is proven in this work by investigating intricately linked real-world challenges. The translation into a conceptual systems model not only serves as the basis for any computational model, but already allows for a qualitative evaluation of how proposed responses may, directly and indirectly, affect the system.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su14095323/s1>, File S1: Documentation_StakeholderWorkshops_Pune, Table S1: First SH mapping, Table S2: Workshop Participants.

Author Contributions: Conceptualization, R.K., I.O., S.M.G., C.J.A.K., and B.K.; data curation, R.K. and H.G.; formal analysis, R.K.; funding acquisition, I.O., S.M.G., C.J.A.K., K.K., and B.K.; investigation, R.K., I.O., S.M.G., C.J.A.K., H.Z., Y.Z., A.J.F., A.W., K.K., H.G., P.B., M.S., and B.K.; methodology, R.K., I.O., S.M.G., C.J.A.K., H.Z., Y.Z., A.J.F., K.K., and B.K.; project administration, S.M.G.; supervision, S.K.; visualization, R.K. and A.K.; writing—original draft, R.K.; writing—review & editing, R.K., I.O., S.M.G., C.J.A.K., H.Z., Y.Z., S.K., A.K., A.W., K.K., M.S., and B.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was conducted as part of the Belmont Forum Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus theme for which coordination was supported by the US National Science Foundation under grant ICER/EAR-1829999 to Stanford University. The Austrian partners ÖFSE and IIASA are funded by the Austrian Research Promotion Agency (FFG). UFZ receives funding from the Federal Ministry of Education and Research (BMBF) under Grant number 033WU002. Any opinions, findings, and conclusions, or recommendations expressed in this material do not necessarily reflect the views of the funding organizations.

Institutional Review Board Statement: Ethical review and approval were waived for this study since no personal data was collected and analyzed. This study does not involve animals. The involvement of humans occurred during the stakeholder workshops, where no sensitive personal information was shared. Any notes and transcriptions of workshop discussions were anonymized before publication.

Informed Consent Statement: Informed consent was obtained from all participants of the stakeholder workshops.

Data Availability Statement: Supporting information can be found in the Supplementary Materials. This contains: (1) an explanatory note on the stakeholder analysis, (2) an initial stakeholder mapping overview, (3) a list of workshop participants for all stakeholder workshops, and (4) a detailed documentation of all stakeholder workshops.

Acknowledgments: We would like to thank our partner institution in Pune, the Gokhale Institute of Politics and Economics, for the fruitful cooperation, as well as Ann-Christine Link, Laura Warnecke, and Jasmin Heilemann for research assistance.

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

References

1. Bazilian, M.; Rogner, H.; Howells, M.; Hermann, S.; Arent, D.; Gielen, D.; Steduto, P.; Mueller, A.; Komor, P.; Tol, R.; et al. Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy* **2011**, *39*, 7896–7906. [CrossRef]
2. Hoff, H. Understanding the Nexus. In Proceedings of the Bonn 2011 Nexus Conference, Bonn, Germany, 16–18 November 2011; The Water, Energy and Food Security Nexus: Stockholm, Sweden, 2011.
3. Water Security: The Water-Food-Energy-Climate Nexus. In Proceedings of the World Economic Forum, Davos-Klosters, Switzerland, 26–30 January 2011.
4. Howarth, C.; Monasterolo, I. Understanding barriers to decision making in the UK energy-food-water nexus: The added value of interdisciplinary approaches. *Environ. Sci. Policy* **2016**, *61*, 53–60. [CrossRef]
5. Gunda, T.; Tidwell, V.C. A Uniform Practice for Conceptualizing and Communicating Food-Energy-Water Nexus Studies. *Earth's Future* **2019**, *7*, 504–515. [CrossRef]
6. NIC. Global Trends 2030: Alternative Worlds: A publication of the National Intelligence Council 978-1-929667-21-5. 2012. Available online: <http://www.dni.gov/nic/globaltrends> (accessed on 15 December 2021).
7. de Strasser, L.; Lipponen, A.; Howells, M.; Stec, S.; Bréthaut, C. A methodology to assess the water energy food ecosystems nexus in transboundary river basins. *Water* **2016**, *8*, 59. [CrossRef]
8. Liu, J.; Hull, V.; Godfray, H.C.J.; Tilman, D.; Gleick, P.; Hoff, H.; Pahl-Wostl, C.; Xu, Z.; Chung, M.G.; Sun, J.; et al. Nexus approaches to global sustainable development. *Nat. Sustain.* **2018**, *1*, 466–476. [CrossRef]
9. Scott, C.A.; Kurian, M.; Wescoat, J.L. The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges. In *Governing the Nexus*; Kurian, M., Ardakanian, R., Eds.; Springer International Publishing: Cham, Switzerland, 2015; pp. 15–38. ISBN 978-3-319-05746-0.
10. Smajgl, A.; Ward, J.; Pluschke, L. The water-food-energy Nexus—Realising a new paradigm. *J. Hydrol.* **2016**, *533*, 533–540. [CrossRef]
11. Schlör, H.; Venghaus, S.; Hake, J.-F. The FEW-Nexus city index—Measuring urban resilience. *Appl. Energy* **2018**, *210*, 382–392. [CrossRef]
12. UN DESA. World Urbanization Prospects: The 2018 Revision. Available online: <https://population.un.org/wup/> (accessed on 5 November 2020).
13. Kammen, D.M.; Sunter, D.A. City-integrated renewable energy for urban sustainability. *Science* **2016**, *352*, 922–928. [CrossRef]
14. UN. Sustainable Development Goals: Goal 11—Sustainable Cities and Communities. Available online: <https://www.un.org/sustainabledevelopment/cities/> (accessed on 5 November 2020).
15. Bogardi, J.J.; Dudgeon, D.; Lawford, R.; Flinderbusch, E.; Meyn, A.; Pahl-Wostl, C.; Vielhauer, K.; Vörösmarty, C. Water security for a planet under pressure: Interconnected challenges of a changing world call for sustainable solutions. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 35–43. [CrossRef]
16. Artioli, F.; Acuto, M.; McArthur, J. The water-energy-food nexus: An integration agenda and implications for urban governance. *Political Geogr.* **2017**, *61*, 215–223. [CrossRef]
17. Romero-Lankao, P.; Bruns, A.; Wiegand, V. From risk to WEF security in the city: The influence of interdependent infrastructural systems. *Environ. Sci. Policy* **2018**, *90*, 213–222. [CrossRef]
18. Seto, K.C.; Dhakal, A.S.; Bigio, H.; Blanco, G.C.; Delgado, D.; Dewar, L.; Huang, A.; Inaba, A.; Kansal, S.; Lwasa, J.E.; et al. Human Settlements, Infrastructure, and Spatial Planning. In *Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Minx, J.C., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eds.; Cambridge University Press: Cambridge, UK, 2014; ISBN 978-1-107-05821-7.
19. Newell, J.P.; Goldstein, B.; Foster, A. A 40-year review of food-energy-water nexus literature and its application to the urban scale. *Environ. Res. Lett.* **2019**, *14*, 073003. [CrossRef]

20. Zhang, P.; Zhang, L.; Chang, Y.; Xu, M.; Hao, Y.; Liang, S.; Liu, G.; Yang, Z.; Wang, C. Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review. *Resour. Conserv. Recycl.* **2019**, *142*, 215–224. [\[CrossRef\]](#)
21. 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. [\[CrossRef\]](#)
22. Lang, D.J.; Wiek, A.; Bergmann, M.; Stauffacher, M.; Martens, P.; Moll, P.; Swilling, M.; Thomas, C.J. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustain. Sci.* **2012**, *7*, 25–43. [\[CrossRef\]](#)
23. Mauser, W.; Klepper, G.; Rice, M.; Schmalzbauer, B.S.; Hackmann, H.; Leemans, R.; Moore, H. Transdisciplinary global change research: The co-creation of knowledge for sustainability. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 420–431. [\[CrossRef\]](#)
24. Tress, G.; Tress, B.; Fry, G. Clarifying Integrative Research Concepts in Landscape Ecology. *Landsc. Ecol.* **2005**, *20*, 479–493. [\[CrossRef\]](#)
25. Fan, J.-L.; Kong, L.-S.; Wang, H.; Zhang, X. A water-energy nexus review from the perspective of urban metabolism. *Ecol. Model.* **2019**, *392*, 128–136. [\[CrossRef\]](#)
26. Ramaswami, A.; Boyer, D.; Nagpure, A.S.; Fang, A.; Bogra, S.; Bakshi, B.; Cohen, E.; Rao-Ghorpade, A. An urban systems framework to assess the trans-boundary food-energy-water nexus: Implementation in Delhi, India. *Environ. Res. Lett.* **2017**, *12*, 25008. [\[CrossRef\]](#)
27. Hussien, W.A.; Memon, F.A.; Savic, D.A. An integrated model to evaluate water-energy-food nexus at a household scale. *Environ. Model. Softw.* **2017**, *93*, 366–380. [\[CrossRef\]](#)
28. van Vuuren, D.P.; Bijl, D.L.; Bogaart, P.; Stehfest, E.; Biemans, H.; Dekker, S.C.; Doelman, J.C.; Gernaat, D.E.H.J.; Harmsen, M. Integrated scenarios to support analysis of the food–energy–water nexus. *Nat. Sustain.* **2019**, *2*, 1132–1141. [\[CrossRef\]](#)
29. 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. [\[CrossRef\]](#)
30. Itayi, C.L.; Mohan, G.; Saito, O. Understanding the conceptual frameworks and methods of the food–energy–water nexus at the household level for development-oriented policy support: A systematic review. *Environ. Res. Lett.* **2021**, *16*, 33006. [\[CrossRef\]](#)
31. McCarl, B.A.; Yang, Y.; Schwabe, K.; Engel, B.A.; Mondal, A.H.; Ringler, C.; Pistikopoulos, E.N. Model Use in WEF Nexus Analysis: A Review of Issues. *Curr. Sustain. Renew. Energy Rep.* **2017**, *4*, 144–152. [\[CrossRef\]](#)
32. Allouche, J.; Middleton, C.; Gyawali, D. Technical veil, hidden politics: Interrogating the power linkages behind the nexus. *Water Altern.* **2015**, *8*, 610–626.
33. Foran, T. Node and regime: Interdisciplinary analysis of water-energy-food nexus in the Mekong region. *Water Altern.* **2015**, *8*, 655–674.
34. Trutnevyte, E.; Hirt, L.F.; Bauer, N.; Cherp, A.; Hawkes, A.; Edelenbosch, O.Y.; Pedde, S.; van Vuuren, D.P. Societal Transformations in Models for Energy and Climate Policy: The Ambitious Next Step. *One Earth* **2019**, *1*, 423–433. [\[CrossRef\]](#)
35. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J.; et al. Complexity of coupled human and natural systems. *Science* **2007**, *317*, 1513–1516. [\[CrossRef\]](#)
36. Yoon, J.; Klassert, C.; Selby, P.; Lachaut, T.; Knox, S.; Avisse, N.; Harou, J.; Tilmant, A.; Klauer, B.; Mustafa, D.; et al. A coupled human-natural system analysis of freshwater security under climate and population change. *Proc. Natl. Acad. Sci. USA* **2021**, *118*, e2020431118. [\[CrossRef\]](#)
37. Birta, L.G.; Arbez, G. *Modelling and Simulation: Exploring Dynamic System Behaviour*, 3rd ed.; Springer: Cham, Switzerland, 2019; ISBN 978-3-030-18868-9.
38. Freeman, R.E. *Strategic Management: A Stakeholder Approach*; Cambridge University Press: Cambridge, UK, 2010; ISBN 9781139192675.
39. Moallemi, E.A.; Malekpour, S.; Hadjidakou, M.; Raven, R.; Szetey, K.; Ningrum, D.; Dhiaulhaq, A.; Bryan, B.A. Achieving the Sustainable Development Goals Requires Transdisciplinary Innovation at the Local Scale. *One Earth* **2020**, *3*, 300–313. [\[CrossRef\]](#)
40. Norström, A.V.; Cvitanovic, C.; Löf, M.F.; West, S.; Wyborn, C.; Balvanera, P.; Bednarek, A.T.; Bennett, E.M.; Biggs, R.; de Bremond, A.; et al. Principles for knowledge co-production in sustainability research. *Nat. Sustain.* **2020**, *3*, 182–190. [\[CrossRef\]](#)
41. Halbe, J.; Pahl-Wostl, C.; A. Lange, M.; Velonis, C. Governance of transitions towards sustainable development—the water–energy–food nexus in Cyprus. *Water Int.* **2015**, *40*, 877–894. [\[CrossRef\]](#)
42. Jordan, R.; Gray, S.; Zellner, M.; Glynn, P.D.; Voinov, A.; Hedelin, B.; Sterling, E.J.; Leong, K.; Olabisi, L.S.; Hubacek, K.; et al. Twelve Questions for the Participatory Modeling Community. *Earth's Future* **2018**, *6*, 1046–1057. [\[CrossRef\]](#)
43. Manthirithilake, H.; Liyanagama, B.S. Simulation model for participatory decision making: Water allocation policy implementation in Sri Lanka. *Water Int.* **2012**, *37*, 478–491. [\[CrossRef\]](#)
44. Bryant, B.P.; Lempert, R.J. Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. *Technol. Forecast. Soc. Change* **2010**, *77*, 34–49. [\[CrossRef\]](#)
45. Wada, Y.; Vinca, A.; Parkinson, S.; Willaarts, B.A.; Magnuszewski, P.; Mochizuki, J.; Mayor, B.; Wang, Y.; Burek, P.; Byers, E.; et al. Co-designing Indus Water-Energy-Land Futures. *One Earth* **2019**, *1*, 185–194. [\[CrossRef\]](#)
46. Karlberg, L.; Hoff, H.; Amsalu, T.; Andersson, K.; Binnington, T.; Flores-López, F.; de Bruin, A.; Gebrehiwot, S.G.; Gedif, B.; Zur Heide, F.; et al. Tackling complexity: Understanding the food-energy-environment nexus in Ethiopia's lake TANA sub-basin. *Water Altern.* **2015**, *8*, 710–734.

47. Cremades, R.; Mitter, H.; Tudose, N.C.; Sanchez-Plaza, A.; Graves, A.; Broekman, A.; Bender, S.; Giupponi, C.; Koundouri, P.; Bahri, M.; et al. Ten principles to integrate the water-energy-land nexus with climate services for co-producing local and regional integrated assessments. *Sci. Total Environ.* **2019**, *693*, 133662. [\[CrossRef\]](#)
48. Endo, A.; Burnett, K.; Orencio, P.M.; Kumazawa, T.; Wada, C.A.; Ishii, A.; Tsurita, I.; Taniguchi, M. Methods of the water-energy-food nexus. *Water* **2015**, *7*, 5806–5830. [\[CrossRef\]](#)
49. Jakeman, A.J.; Letcher, R.A.; Norton, J.P. Ten iterative steps in development and evaluation of environmental models. *Environ. Model. Softw.* **2006**, *21*, 602–614. [\[CrossRef\]](#)
50. OECD. OECD Core Set of Indicators for Environmental Performance Reviews: A synthesis report by the Group on the State of the Environment; Environment Monographs No. 83, Paris. 1993. Available online: [https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD\(93\)179&docLanguage=En](https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(93)179&docLanguage=En) (accessed on 15 December 2021).
51. EEA. *Europe's environment: The Dobříš assessment GH-13-98-726-EN-Z*; European Environment Agency: Luxembourg, 1995.
52. Haase, D.; Nuissl, H. Does urban sprawl drive changes in the water balance and policy? *Landsc. Urban Plan.* **2007**, *80*, 1–13. [\[CrossRef\]](#)
53. Jago-on, K.A.B.; Kaneko, S.; Fujikura, R.; Fujiwara, A.; Imai, T.; Matsumoto, T.; Zhang, J.; Tanikawa, H.; Tanaka, K.; Lee, B.; et al. Urbanization and subsurface environmental issues: An attempt at DPSIR model application in Asian cities. *Sci. Total Environ.* **2009**, *407*, 3089–3104. [\[CrossRef\]](#)
54. Bell, S. DPSIR=A Problem Structuring Method? An exploration from the “Imagine” approach. *Eur. J. Oper. Res.* **2012**, *222*, 350–360. [\[CrossRef\]](#)
55. Atkins, J.P.; Burdon, D.; Elliott, M.; Gregory, A.J. Management of the marine environment: Integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Mar. Pollut. Bull.* **2011**, *62*, 215–226. [\[CrossRef\]](#)
56. Elliott, M.; Burdon, D.; Atkins, J.P.; Borja, A.; Cormier, R.; de Jonge, V.N.; Turner, R.K. “And DPSIR begat DAPSI(W)R(M)!”—A unifying framework for marine environmental management. *Mar. Pollut. Bull.* **2017**, *118*, 27–40. [\[CrossRef\]](#)
57. Gupta, J.; Scholtens, J.; Perch, L.; Dankelman, I.; Seager, J.; Sándor, F.; Stanley-Jones, M.; Kempf, I. Re-imagining the driver–pressure–state–impact–response framework from an equity and inclusive development perspective. *Sustain. Sci.* **2020**, *15*, 503–520. [\[CrossRef\]](#)
58. Carr, E.R.; Wingard, P.M.; Yorty, S.C.; Thompson, M.C.; Jensen, N.K.; Roberson, J. Applying DPSIR to sustainable development. *International. J. Sustain. Dev. World Ecol.* **2007**, *14*, 543–555. [\[CrossRef\]](#)
59. Svarstad, H.; Petersen, L.K.; Rothman, D.; Siepel, H.; Wätzold, F. Discursive biases of the environmental research framework DPSIR. *Land Use Policy* **2008**, *25*, 116–125. [\[CrossRef\]](#)
60. Tscherning, K.; Helming, K.; Krippner, B.; Sieber, S.; Paloma, S.G.Y. Does research applying the DPSIR framework support decision making? *Land Use Policy* **2012**, *29*, 102–110. [\[CrossRef\]](#)
61. Giupponi, C. Decision Support Systems for implementing the European Water Framework Directive: The MULINO approach. *Environ. Model. Softw.* **2007**, *22*, 248–258. [\[CrossRef\]](#)
62. Malmir, M.; Javadi, S.; Moridi, A.; Neshat, A.; Razdar, B. A new combined framework for sustainable development using the DPSIR approach and numerical modeling. *Geosci. Front.* **2021**, *12*, 101169. [\[CrossRef\]](#)
63. Zare, F.; Elsawah, S.; Bagheri, A.; Nabavi, E.; Jakeman, A.J. Improved integrated water resource modelling by combining DPSIR and system dynamics conceptual modelling techniques. *J. Environ. Manage.* **2019**, *246*, 27–41. [\[CrossRef\]](#)
64. Hoekstra, A.Y.; Buurman, J.; van Ginkel, K.C.H. Urban water security: A review. *Environ. Res. Lett.* **2018**, *13*, 53002. [\[CrossRef\]](#)
65. Grimm, V.; Railsback, S.F. *Individual-Based Modeling and Ecology*; Princeton University Press: Princeton, NJ, USA, 2005; ISBN 9780691096667.
66. Robinson, S.; Arbez, G.; Birta, L.G.; Tolk, A.; Wagner, G. Conceptual modeling: Definition, purpose and benefits. In Proceedings of the 2015 Winter Simulation Conference, Huntington Beach, CA, USA, 6–9 December 2015; Yilmaz, L., Ed.; IEEE: Atlanta, GA, USA; Omnipress, Piscataway: Madison, NJ, USA, 2015; pp. 2812–2826, ISBN 978-1-4673-9743-8.
67. Elsawah, S.; Pierce, S.A.; Hamilton, S.H.; van Delden, H.; Haase, D.; Elmahdi, A.; Jakeman, A.J. An overview of the system dynamics process for integrated modelling of socio-ecological systems: Lessons on good modelling practice from five case studies. *Environ. Model. Softw.* **2017**, *93*, 127–145. [\[CrossRef\]](#)
68. Robinson, S. Conceptual modelling for simulation: Progress and grand challenges. *J. Simul.* **2019**, *14*, 1–20. [\[CrossRef\]](#)
69. Schiavina, M.; Freire, S.; MacManus, K. Joint Research Centre. GHS-POP R2019A—Population Grid Multitemporal (1975–1990–2000–2015). 2019. Available online: <https://data.jrc.ec.europa.eu/dataset/0c6b9751-a71f-4062-830b-43c9f432370f> (accessed on 15 December 2021).
70. Butsch, C.; Kumar, S.; Wagner, P.; Kroll, M.; Kantakumar, L.; Bharucha, E.; Schneider, K.; Kraas, F. Growing ‘Smart’?: Urbanization Processes in the Pune Urban Agglomeration. *Sustainability* **2017**, *9*, 2335. [\[CrossRef\]](#)
71. Kantakumar, L.N.; Kumar, S.; Schneider, K. SUSM: A scenario-based urban growth simulation model using remote sensing data. *Eur. J. Remote Sens.* **2019**, *12*, 1–16. [\[CrossRef\]](#)
72. Corbane, C.; Florczyk, A.; Pesaresi, M.; Politis, P.; Syrris, V. R2018A. *GHS Built-Up Grid, Derived from Landsat, Multitemporal (1975–1990–2000–2014)*; European Commission: Brussels, Belgium, 2018.

73. Küblböck, K.; Omann, I.; Grohs, H.; Karutz, R.; Klassert, C.; Klauer, B.; Zhu, Y.; Zozmann, H.; Smilovic, M.; Gorelick, S.M. The Role of Sustainability Living Labs in Understanding Food-Water-Energy Nexus Challenges and Solutions in India and Jordan: ÖFSE Working Paper Nr. 63, Vienna. 2021. Available online: <https://www.oefse.at/fileadmin/content/Downloads/Publikationen/Workingpaper/WP63-FUSE-sustainability-living-labs.pdf> (accessed on 15 December 2021).
74. Reed, M.S.; Graves, A.; Dandy, N.; Posthumus, H.; Hubacek, K.; Morris, J.; Prell, C.; Quinn, C.H.; Stringer, L.C. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *J. Environ. Manage.* **2009**, *90*, 1933–1949. [\[CrossRef\]](#)
75. Handler, M.; Omann, I.; Hübner, R. Art of Hosting oder wie können Konferenzen durch ihre Gestaltung transformativ wirken? In *Das Transformative Potenzial von Konsum zwischen Nachhaltigkeit und Digitalisierung Chancen und Risiken*; Hübner, R., Schmon, B., Eds.; Springer: Heidelberg, Germany, 2019. (In German)
76. Krueger, R.A.; Casey, M.A. *Focus Groups: A Practical Guide for Applied Research*, 3rd ed.; Sage Publications: Thousand Oaks, CA, USA, 2000; ISBN 0-7619-2070-6.
77. Barbour, R.S. Analysing Focus Groups. In *The SAGE Handbook of Qualitative Data Analysis*; Flick, U., Ed.; SAGE: London, UK, 2014; pp. 313–326. ISBN 130685993X.
78. Giupponi, C.; Mysiak, J.; Sgobbi, A. Participatory Modelling and Decision Support for Natural Resources Management in Climate Change Research. FEEM Working Paper No. 13.2008. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1105109# (accessed on 15 December 2021). [\[CrossRef\]](#)
79. Giupponi, C. From the DPSIR reporting framework to a system for a dynamic and integrated decision making process. In *Beyond Developing a Decision Support Systems for Environmental Application, Proceedings of the MULINO Conference on European Policy and Tools for Sustainable Water Management, Venice, Italy, 21–23 November 2002*; Giupponi, C., Cogan, V., Mysiak, J., Fassio, A., Wood, M., Eds.; Helmholtz: Leipzig, Germany, 2002.
80. Vörösmarty, C.J.; McIntyre, P.B.; Gessner, M.O.; Dudgeon, D.; Prusevich, A.; Green, P.; Glidden, S.; Bunn, S.E.; Sullivan, C.A.; Liermann, C.R.; et al. Global threats to human water security and river biodiversity. *Nature* **2010**, *467*, 555–561. [\[CrossRef\]](#)
81. Olsson, G. Water, energy and food interactions—Challenges and opportunities. *Front. Environ. Sci. Eng.* **2013**, *7*, 787–793. [\[CrossRef\]](#)
82. Link, A.-C.; Zhu, Y.; Karutz, R. Quantification of Resilience Considering Different Migration Biographies: A Case Study of Pune, India. *Land* **2021**, *10*, 1134. [\[CrossRef\]](#)
83. DES. Economic Survey of Maharashtra: 2017–2018, Mumbai. 2018. Available online: https://mahades.maharashtra.gov.in/files/publication/ESM_17_18_eng.pdf (accessed on 16 July 2018).
84. World Bank. Maharashtra–Poverty, Growth & Inequality. 2017. Available online: <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjV2Oz265r0AhVx57sIHQtsCfoQFnoECAMQAQ&url=http%3A%2F%2Fdocuments1.worldbank.org%2Fcurated%2Fen%2F806671504171811149%2Fpdf%2F119254-BRI-P157572-Maharashtra-Poverty.pdf&usg=AOvVaw2IkIU-4fgUxnc6RJKKgWXM> (accessed on 15 November 2021).
85. DES. Economic Survey, Mumbai. 2019. Available online: <https://mahades.maharashtra.gov.in/publications.do?pubId=ESM> (accessed on 5 November 2020).
86. Creutzig, F.; Agoston, P.; Goldschmidt, J.C.; Luderer, G.; Nemet, G.; Pietzcker, R.C. The underestimated potential of solar energy to mitigate climate change. *Nat. Energy* **2017**, *2*, 17140. [\[CrossRef\]](#)
87. Rao, A.; Arora, A.; Kadav, K.; Nehete, G. RE-Energizing Maharashtra: An Assessment of Renewable Energy Policies, Challenges and Opportunities.: Report prepared by the Indian Institute of Technology Bombay, Mumbai. 2014. Available online: https://agora-parl.org/sites/default/files/67825b_7f36b4c5468841919549e5ea7e37341f.pdf (accessed on 24 April 2022).
88. CEA. Location Wise Western Region State-Wise Installed Capacity as on 31/10/2020. 2020. Available online: <https://npp.gov.in/publishedReports> (accessed on 8 December 2020).
89. IQAir. Air Quality in Pune: Air Quality Index (AQI) and PM2.5 Air Pollution in Pune. Available online: <https://www.iqair.com/us/india/maharashtra/pune> (accessed on 8 December 2020).
90. Roy, P.S.; Meiyappan, P.; Joshi, P.K.; Kale, M.P.; Srivastav, V.K.; Srivasatava, S.K.; Behera, M.D.; Roy, A.; Sharma, Y.; Ramachandran, R.M.; et al. *Decadal Land Use and Land Cover Classifications across India, 1985, 1995, 2005*; ORNL DAAC: Oak Ridge, TN, USA, 2016. [\[CrossRef\]](#)
91. MEDA. List of Grid Connected Solar Power Project Commissioned in Maharashtra State. 2020. Available online: https://www.mahaurja.com/meda/data/grid_solar_power/SPPCommissioned.pdf (accessed on 9 October 2020).
92. Fraunhofer ISE. Recent Facts about Photovoltaics in Germany: Version of June 10, Freiburg. 2020. Available online: <https://www.pv-fakten.de> (accessed on 24 April 2022).
93. PMC. *Water Supply System for Pune City: Detailed Project Report*; Studio Galli Ingegneria: Pune, India, 2014.
94. Lee, J.Y.; Naylor, R.L.; Figueroa, A.J.; Gorelick, S.M. Water-food-energy challenges in India: Political economy of the sugar industry. *Environ. Res. Lett.* **2020**, *15*, 84020. [\[CrossRef\]](#)
95. Malik, R.P.S. Water-Energy Nexus in Resource-poor Economies: The Indian Experience. *Int. J. Water Resour. Dev.* **2002**, *18*, 47–58. [\[CrossRef\]](#)
96. Gawel, E.; Bretschneider, W. Specification of a human right to water: A sustainability assessment of access hurdles. *Water Int.* **2017**, *42*, 505–526. [\[CrossRef\]](#)
97. Zozmann, H.; Klassert, C.; Klauer, B.; Gawel, E. Water Procurement Time and Its Implications for Household Water Demand—Insights from a Water Diary Study in Five Informal Settlements of Pune, India. *Water* **2022**, *14*, 1009. [\[CrossRef\]](#)

98. Chitnis, A.; Josey, A. Review of Maharashtra Power Sector Policy and Regulation: Lessons, Challenges and Opportunities, Pune. 2015. Available online: <http://www.prayaspune.org/peg/publications/item/301> (accessed on 15 December 2021).
99. Dixit, K. Political Economy of Electricity Distribution in Maharashtra. Working Paper, New Delhi. 2017. Available online: <http://www.raponline.org/wp-content/uploads/2017/07/rap-india-mappingpower-maharashtra-2017-july.pdf> (accessed on 15 December 2021).
100. GoM. *Comprehensive Policy for Grid-Connected Power Projects Based on New and Renewable (Nonconventional) Energy Sources–2015*; International Energy Agency: Paris, France, 2015.
101. MSEDCL. Annual Report 2016–17. 2018. Available online: https://www.mahadiscom.in/wp-content/uploads/2018/04/MSEDCL_ANNUAL_REPORT_ENGLISH_2016-17.pdf (accessed on 15 December 2021).
102. Mukhyamantri Solar Krishi Vahini Yojana: GoM. 2017. Available online: <https://www.maharashtra.gov.in/Site/Upload/Government%20Resolutions/English/201706141206080310.pdf> (accessed on 15 December 2021).
103. Gambhir, A.; Aggrawal, S.; Dixit, S.; Josey, A. Agriculture Solar Feeders in Maharashtra. Power Perspectives, Pune. 2021. Available online: <https://www.prayaspune.org/peg/resources/power-perspective-portal/267-agriculture-solar-feeders-in-maharashtra.html> (accessed on 15 December 2021).
104. PCMC. City Development Plan 2006–2012: Jawaharlal Nehru National Urban Renewal Mission. 2006. Available online: https://www.pcmcindia.gov.in/jnnurm_info/cdpvol1.pdf (accessed on 15 December 2021).
105. PMC. Revising/Updating the City Development Plan (CDP) for Pune City–2041: Under JNNURM, Pune. 2012. Available online: https://pmc.gov.in/sites/default/files/project-glimpses/Draft_City_Development_Plan_for_Pune_City_2041_Vol-1.pdf (accessed on 15 December 2021).
106. PMRDA. Draft Development Plan of Pune Metropolitan Region 2021–2041: Volume 1, Pune. 2021. Available online: <https://punezp.mkcl.org/user/pages/images/doc/DPReport2021vol1forUpload.pdf> (accessed on 24 November 2021).
107. 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. *Manuscr. Prep.* **2022**, *4*, 15.
108. Federici, M.L.; Redaelli, S.; Vizzari, G. Models, Abstractions and Phases in Multi-Agent Based Simulation. In Proceedings of the 7th WOA 2006 Workshop 204, Catania, Italy, 26–27 September 2006; pp. 144–150.