



FUSE – Jordan Activities Update

August, 2021

The FUSE project is addressing food-water-energy challenges, opportunities, and solutions, with a major focus on Amman and the greater Amman region. The project has recently published its main analyses of Jordan's urban food-water-energy nexus, which reveal a bleak outlook: Under a business-as-usual approach – more than half of all households in Jordan will have fewer than 40 liters per person per day by 2060. We find that this water crisis can be averted, however, but only if all nexus sectors, the water and energy sector, agriculture, and municipalities, collaborate in a transition to more sustainable management of food-water-energy nexus resources.

The overall project duration of FUSE is from mid-2018

to mid-2022. In March 2019, a series of Sustainability Living Lab workshops took place in Amman, where more than 80 stakeholders and policy experts shared visions, challenges, coping strategies, and potential policy solutions. Subsequently, the FUSE project team has created a systems model, integrating the information gathered during the workshops and exploring the efficacy and likely impacts of the proposed solutions. The model results have then been analyzed in exchange with experts from the Jordanian Ministry for Water and Irrigation (MWI), the Water Authority of Jordan (WAJ), and the Jordan Valley Authority (JVA). Here we present an overview of FUSE's progress in its third project year, preparing its final set of stakeholder workshops.

FUSE in a nutshell

FUSE (Food-water-energy for Urban Sustainable Environments) is a transdisciplinary research project involving the Food-Water-Energy nexus in Jordan, with a focus on the Amman region. The project will develop a long-term systems model that can be used to identify viable paths to sustainability. It brings together natural and social scientists from Stanford University in California, USA, IIASA (International Institute for Applied Systems Analysis) in Laxenburg, Austria, UFZ (Helmholtz Centre for Environmental Research) in Leipzig, Germany, and ÖFSE (Austrian Foundation for Development Research) in Vienna, Austria. The project is a not-for-profit research effort and is part of the Sustainable Urbanisation Global Initiative of JPI Urban Europe and the Belmont Forum. Each of the national teams is supported individually by its own national science funding agency.

More information: <https://fuse.stanford.edu/>

Contact: Prof. Steven Gorelick (Stanford University): gorelick@stanford.edu (Project Coordination)
Ines Omann / Karin Küblböck (ÖFSE): k.kueblboeck@oefse.at (Stakeholder Participation)

FUSE – the third year

FUSE has now reached the end of its third year and is entering the final project stage. The past year was a particularly challenging and stressful time for Jordan and the whole world due to the COVID-19 pandemic. We hope that you, your families, and the organizations you work for have found ways to cope with this terrible crisis. For FUSE, the situation has required adaptation to new circumstances and delays, but we are grateful also to report important progress and new additions to our team during the past year.

We have completed a rigorous analysis of the food, water, and energy sector challenges identified by stakeholders in the first series of Sustainability Living Labs. This analysis gave us new insights into how various challenges are linked in the food-water-energy nexus.

Published results from our core model show paths for navigating Jordan's dire water security outlook and that affect all three food-water-energy nexus dimensions. Moreover, five new members have joined the FUSE team during the past year to conduct additional nexus analyses addressing these challenges.

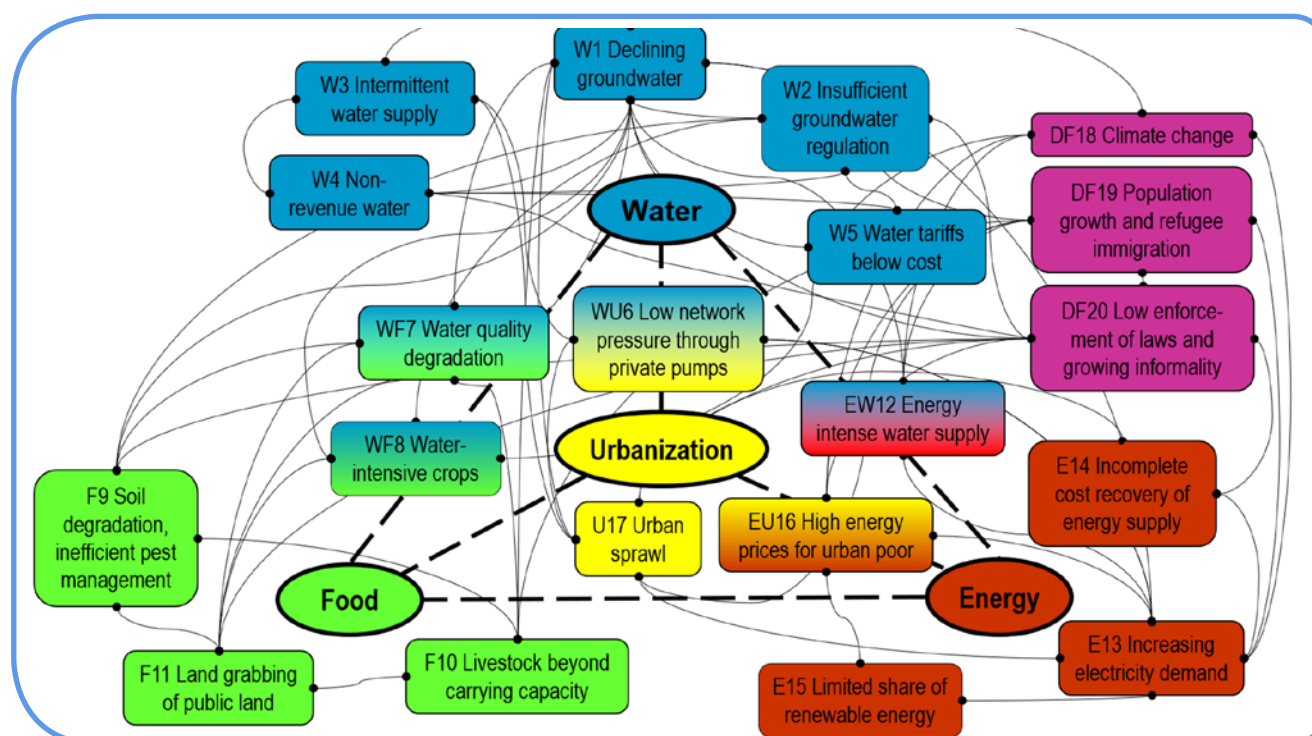
Integrated Model Development

From stakeholder input to model development: The FUSE team believes that the development of an integrated system simulation model that aims to effectively inform and support policy makers and practitioners in their decision-making is essential. We take the concrete problems and challenges faced by stakeholders as our starting point. This was the motivation for the participants of the 2019 workshops, who expressed their food-water-energy (FWE) challenges

and potential solutions. To integrate them into the model, a substantial reduction in complexity of the challenges and solutions was required. Based on input from stakeholders and experts, a comprehensive list of 20 FWE challenges for Greater Amman were distilled (see Figure 1). In the figure, challenges are arranged according to their proximity to one of the three FWE nexus dimensions plus urbanization as an additional dimension. Five challenges were assigned

to two dimensions. The magenta boxes indicate governance challenges. The closeness and intensity among food, water, energy, and urbanization only become apparent when the numerous connections between the challenges (uni-directional or mutually influential) described by participants are taken into consideration. These interdependencies and influences between the different challenges are shown as connecting lines.

Figure 1: FWE-Urban nexus challenges and interlinkages based on discussion with stakeholders in Amman



Source: Based on Klauer et al.'s presentation "Challenges of the food-water-energy nexus in Amman, Jordan", Sustainable & Resilient Urban-Rural Partnerships – URP2020 conference, 26.11.2020

These challenges and their connections to the FWE-Urban nexus informed our development of the integrated systems model. They were used to define model inputs, such as scenarios and policy interventions, but also our formulation of well-being metrics that reflect vulnerability, resilience, and equity. This novel process aimed at systematic complexity reduction and translation of stakeholder knowledge into components of the integrated model was presented at a conference.¹ A corresponding journal article is in preparation.

Publication of core model results: During the past year, we have completed the analysis of results from

our core integrated model, the Jordan Water Model, which have been published and is available here: <https://doi.org/10.1073/pnas.2020431118>

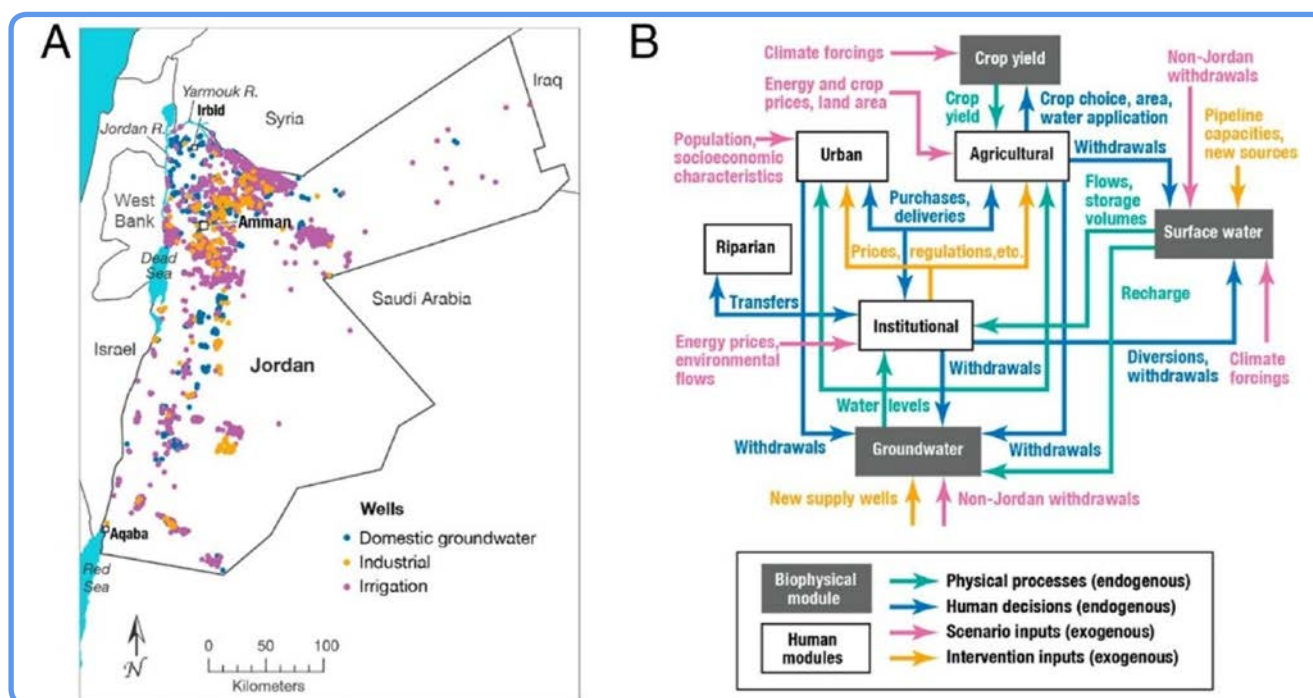
A coupled human–natural system analysis of fresh-water security under climate and population change, (2021), Jim Yoon, Christian Klassert, Philip Selby, Thibaut Lachaut, Stephen Knox, Nicolas Avisse, Julien Harou, Amaury Tilmant, Bernd Klauer, Daanish Mustafa, Katja Sigel, Samer Talozi, Erik Gawel, Josue Medellin-Azuara, Bushra Bataineh, Hua Zhang, and Steven M. Gorelick, Proceedings of the National Academy of Science of the United States (PNAS), 118 (14), e2020431118.

¹ Sustainable & Resilient Urban-Rural Partnerships – URP Conference, 26-27 November 2021

The published analyses address the water scarcity issue driving developments in Jordan's food-water-energy nexus, as well as linkages to agricultural production and increasing energy needed to pump groundwater. The challenge of freshwater sustainability in Jordan and its largest city and capital, Amman, are enormous. The Jordan Water Model enables water managers and policy makers

to evaluate a suite of policy interventions that have the potential to stem the water crisis. This crisis has already emerged and seems almost certain to worsen in the coming decades given the detrimental impacts of climate change and population growth. Figure 2b shows the modular structure of the Jordan Water Model, the key linkages, and inputs that include scenarios and interventions.

Figure 2: Map of Jordan and conceptual model



Note:

“(A) Jordan relies on surface-water sources (primarily the Yarmouk River) and groundwater wells for water supply.”

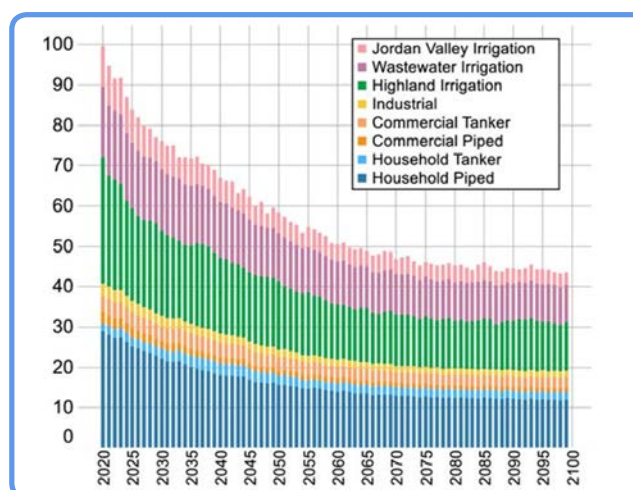
“(B) The JWM consists of two types of modules: human modules (white rectangles) and biophysical modules (gray rectangles) of natural and engineered physical phenomena, linked by human decisions (blue lines), endogenous physical flows and production (green lines), and exogenous scenarios (pink lines) and human interventions (yellow lines).”

Source: Yoon et al. (2021).

Our model analyses show that the freshwater situation is likely to deteriorate significantly under business as usual policies, even with moderate climate change and population growth. Even under these optimistic assumptions about future developments, annual per capita water use across all sectors decreases by half from nearly 100m³ per person in 2020 to 43m³ per person by the end of the century (see Figure 3).

Supply enhancement projects (e.g., desalination) and demand management interventions (e.g., higher tariffs on large water users) mitigate the future water vulnerability of households, relative to continuing with business as usual policies (see Figure 4).

Figure 3: Annual per capita water use by sector

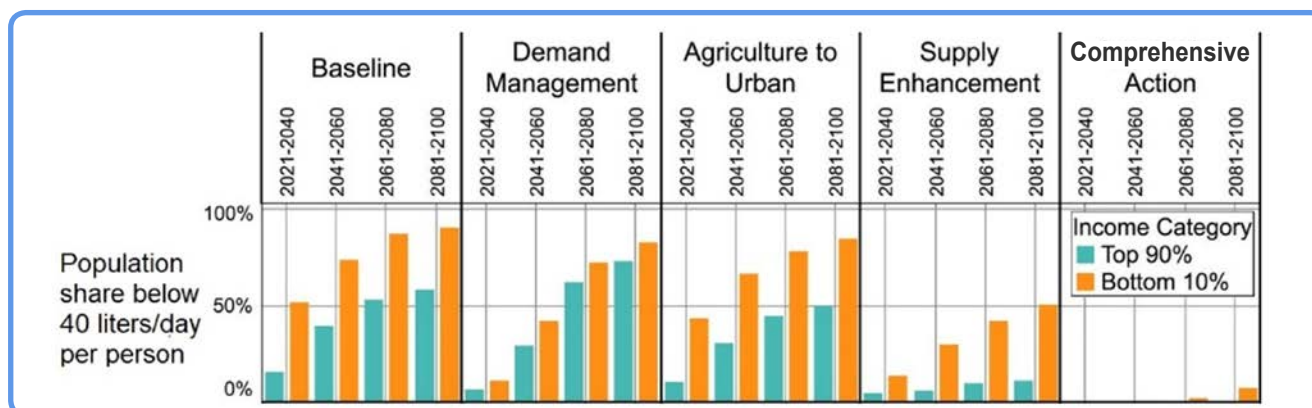


Source: Yoon et al. (2021)

Such interventions, however, are not enough to prevent major shortages, long-periods of diminished supplies, groundwater depletion, and negative economic

impacts. Without comprehensive action, involving multi-pronged interventions, the future problems of freshwater provision and equity will persist and worsen.

Figure 4: Projected future water vulnerability of households, measured as the percentage of households consuming less than 40 liters per person per day, across five interventions



Source: Yoon et al. (2021)

The comprehensive action intervention involves: the desalination of Dead Sea water and other projects to augment water supply to cities (particularly Amman), substantial decreases in non-revenue (lost or stolen) water, large freshwater transfers from agriculture to the municipalities, water tariff increases imposed on the largest consumers, and a more equitable distribution of water among users. These measures rely crucially on adjustments in all dimensions of the food-water-energy nexus, e.g., developing new energy sources to support large-scale desalination or adapting food

production to the use of less water-intensive, climate-adapted crops.

Additional nexus analyses: Building on the examination of nexus linkages in the core model, we are currently preparing analyses of additional interventions addressing the urban food-water-energy nexus. For these, we are also asking for your ideas in a survey sent with this newsletter to learn more about potential interventions you would like to see evaluated: [Go to survey](#).

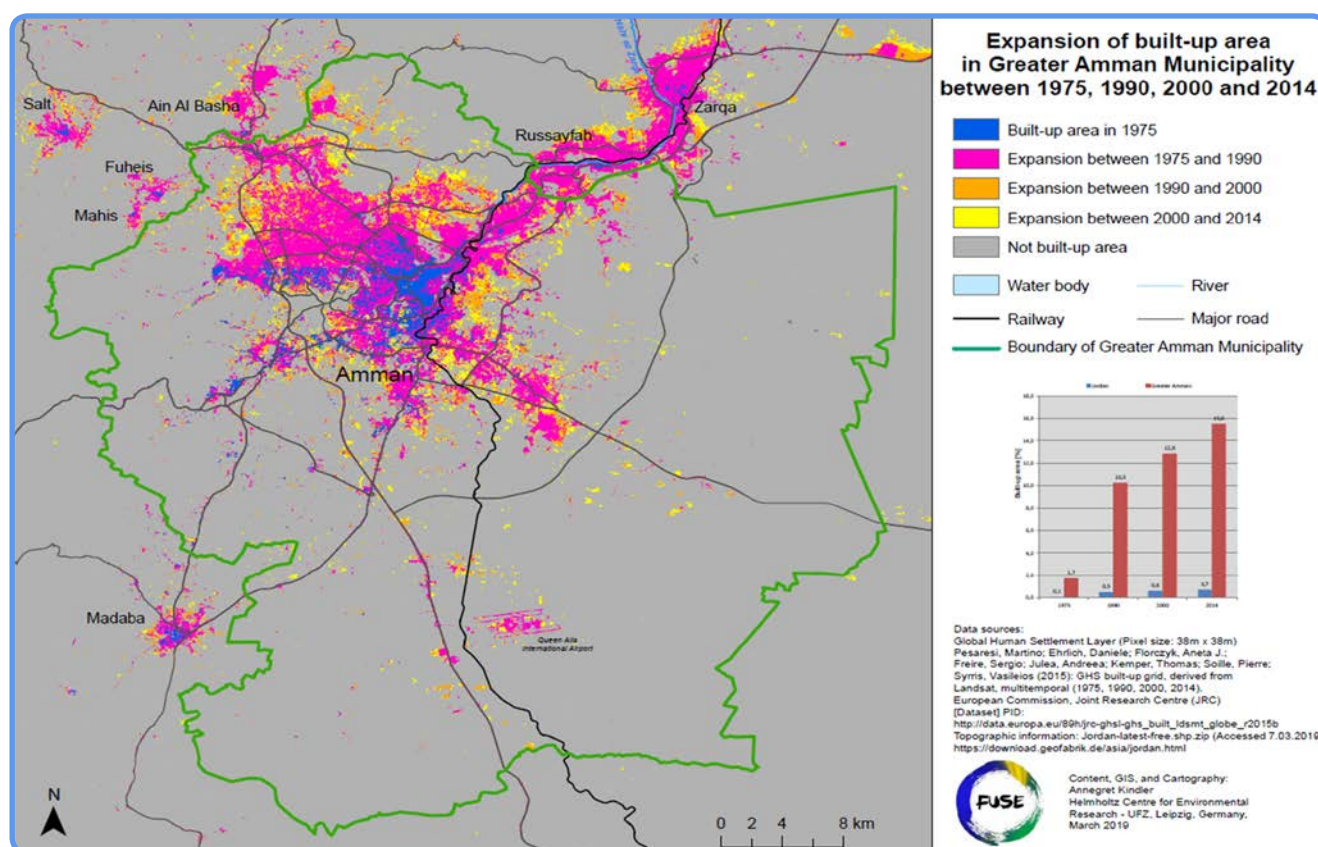
Table 1: Existing interventions tested in Yoon et al. (2021) and planned interventions.

Intervention	Description
Current interventions in the core model analyses	
Baseline	No additional interventions
Demand management	Doubling of piped water tariffs for higher tiers, equalization of piped supply for all household users on a per capita basis, administrative NRW reduction (50% of current losses)
Agriculture to Urban	25% transfer of groundwater production transfer capacity from agricultural
Supply Enhancement	Red Sea–Dead Sea desalinization phase 1 (80 MCM/year), Red Sea–Dead Sea desalinization phase 2 (150 MCM/year), all other planned water supply projects (132 MCM/year), physical NRW reduction (50% of current losses)
Comprehensive action	Supply enhancement plus demand management plus agricultural to urban water transfer
Additional interventions addressing the urban food-water-energy nexus	
Solar energy for water	Increased desalination (water-energy) powered by solar farming (food-energy)
Climate-adapted crops	Support for climate-adapted crops AND/OR full-cost pricing for irrigation water (water-food)
Decentralized urban growth	Redirecting urban growth from Amman to smaller cities (demand for all nexus resources)
Please suggest additional interventions in the survey	

Modeling future urban growth and population distribution: Jordan's population has significantly increased within the last century. While the country was comprised of less than a quarter of a million citizens in 1950, the current population in 2021 is estimated to be over 10 million. In modern Jordan, the vast majority of the country's population growth is centralized in urban areas, and urbanized areas have expanded to incorporate the growing population. This expansion of urbanized land has historically encompassed surrounding areas of previously rural land, and has created modern urban centers that are noticeably larger than they were historically (see Figure 5 for

spatial expansion of Amman). Urban growth is strongly linked to the country's food, water, and energy nexus, since it entails changes both on the resource supply side (e.g., conversion of agricultural land, change in rainwater infiltration due to sealed surfaces) and on the demand side (e.g., concentration of demands in urban areas, changes in lifestyles). Therefore, the FUSE project aims to effectively project urban growth for the city of Amman and the country of Jordan. To do so, we are developing a novel approach combining statistical methods and spatial evolution to successively project future urban growth and population distribution for different scenarios.

Figure 5: Urban Expansion of Amman between 1975 and 2014



What's new?

Plans for this year

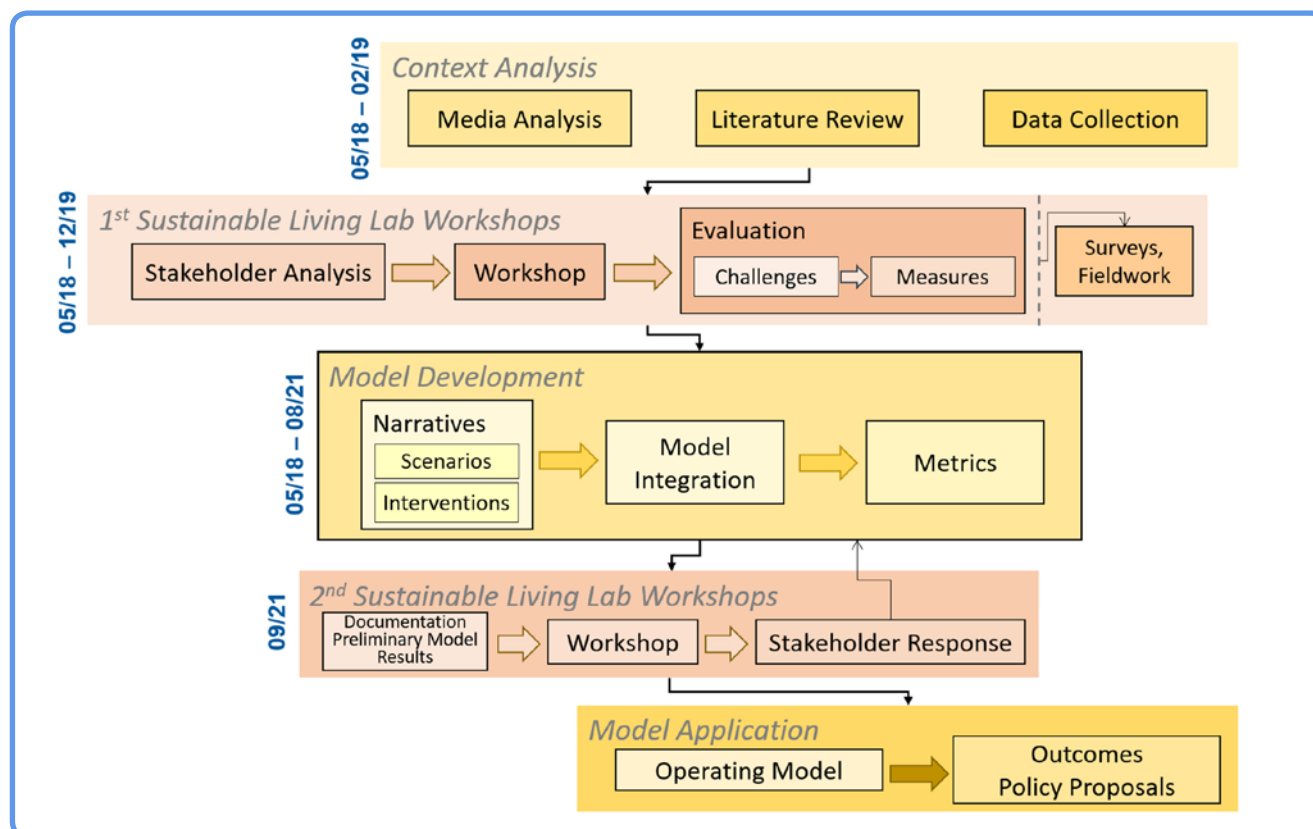
In the year ahead, the FUSE team is preparing the second series of Sustainability Living Lab workshops, building on the core model analysis results we have published this year. We will conduct detailed analyses of additional aspects of the urban food-water-energy

nexus. These analyses will incorporate the contributions of the new members that have joined the FUSE team, as well as additional analyses using the Jordan Water Model to simulate the effects of policy interventions aimed at improving the sustainability of further components of the urban food-water-energy nexus. Based on challenges and solutions identified in our first series of stakeholder workshops, our aim is to provide an initial analysis of key policy options

required by Jordan to navigate its future food-water-energy needs. The results of these analyses will be presented to our Jordanian stakeholders and policy experts in the form of narratives during a

second set of workshops in which reactions will be elicited and discussed. COVID-19 permitting, we hope to hold these workshops in September 2021 (see Figure 6).

Figure 6: FUSE Progress and Timeline



We take this opportunity to thank our valuable partner in Jordan, whose cooperation makes the implementation of the workshops possible:



MIRRA, Methods for Irrigation and Agriculture, has been the local coordinator for the FUSE project in Jordan. MIRRA contributed to the mapping and analysis of the stakeholders of the project, outreaching to and communicating with them, the integrated logistical organizing of the Jordanian FUSE's sets of workshops, and the continuous follow-up and feedback with the stakeholders.

MIRRA is a Jordanian, private, non-governmental research and development organization established

in 2007. MIRRA works locally in Jordan and regionally in the MENA region in the fields of research, development and innovation in order to contribute to the United Nations Sustainable Development Goals (SDGs), local and regional strategies and social and economic prosperity. MIRRA focuses mainly on the sectors of agriculture, irrigation, water including Water, Sanitation and Hygiene (WASH), the food-water-energy nexus, climate change and environment. In a parallel manner, within all of its projects, MIRRA includes components addressing capacity building, raising awareness, advocacy and mobilization for various stakeholders and beneficiaries. MIRRA supports research and development through cooperation with farmers, private sector entities, the government and public sectors, and international research institutions.

New Team Members



Ankun Wang, integrated Food-Water-Energy systems modeling: Ankun joined the FUSE team at Stanford University as a PhD student beginning in the Fall of 2020. She has extensive training in environmental engineering with a BS degree from Chinese and Australian universities, and an MS from Stanford University. Before embarking on her PhD, Ankun was a research assistant on a variety of projects involving waste-water treatment, spatiotemporal dynamics of concentration “hotspots”, analysis of morphological features of land cover, and design of experimental methods to quantify the water balance of greenwall plants. She has extensive knowledge of fluid mechanics, water quality, hydrogeology, remote sensing, statistics, computer programming and large dataset analysis. Ankun has stepped into the important role of systems model integration in our other project study region, Pune, India.

Ahmed Al-Kebsi, energy consumption: Ahmed is working with our project partner MIRRA in Jordan. He will be guest researcher at UFZ in summer 2021. Ahmed’s role is to calculate the energy consumption for the main water conveyance system in Jordan. A considerable part of his work is to develop a Water Evaluation and Planning (WEAP) model that focuses on the major water conveyances to obtain the transferred water quantities and pumping energy requirements. The model investigates different scenarios based on externally driven factors such as population growth, living standards, and project development planned as part of the Jordan Water Policy (2016-2025).

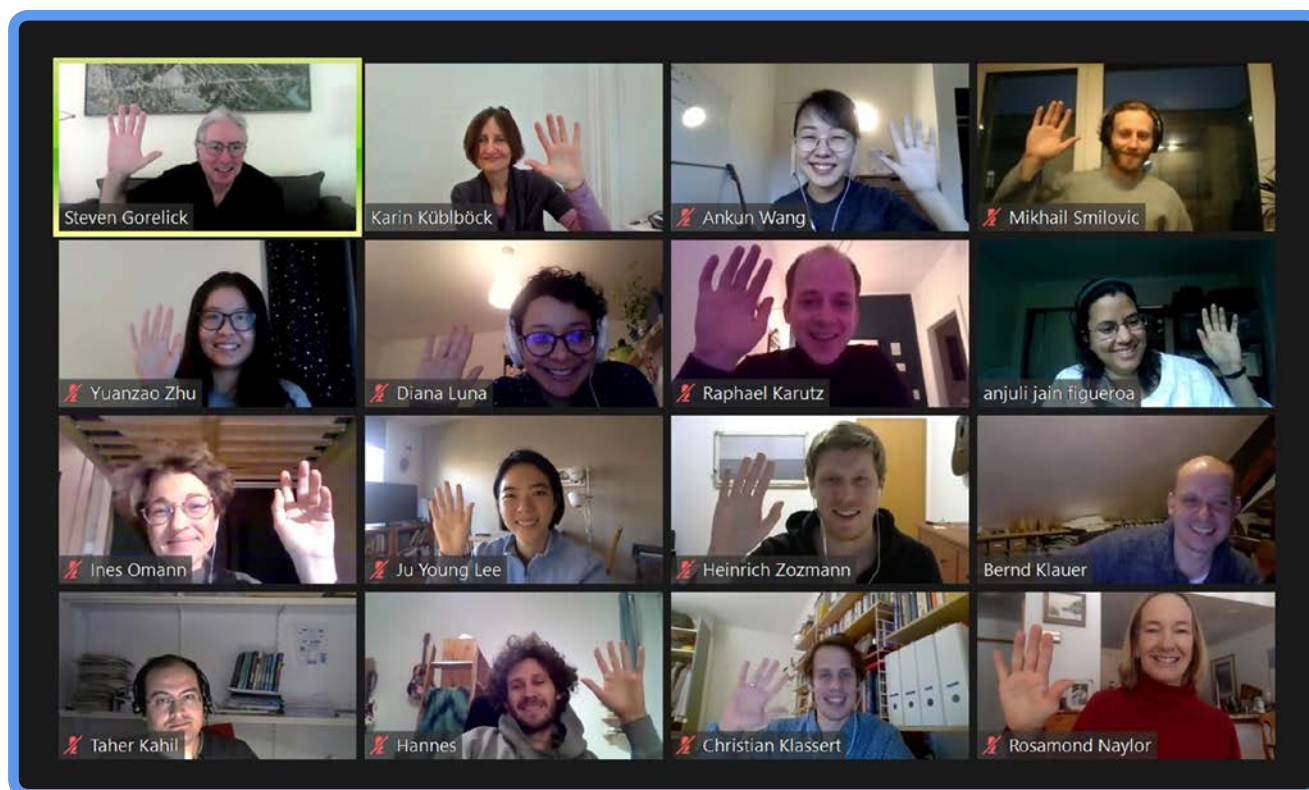


Helen Mayer, water network: Helen joined the FUSE team at UFZ in December 2020 for her bachelor’s thesis. Helen’s task is to conduct a spatial analysis of socio-economic, geographic and hydraulic factors influencing access to piped water in Amman. She is also supporting the UFZ team with smaller tasks involving geographic information systems.

Forrest Kluson, urban growth: Forrest joined the FUSE team at UFZ in the Winter of 2021. As a FUSE team member, Forrest is responsible for developing detailed spatial projections of urbanization in Jordan. Specifically, his contributions involve the creation and calibration of a spatial evolution (cellular-automata) model for determining built-up growth and population distribution under different scenarios. Forrest is completing this model for his master’s thesis at the University of Leipzig, and the completed model will be incorporated into the FUSE multi-agent model for Jordan.



Linda Maiwald, nexus footprint: Linda joined the FUSE team at UFZ in November 2020 where she is completing her thesis in the master program Sustainable Development Science in Utrecht (NL). She is working on an interdisciplinary perspective of the nexus. Based on a profound examination of water and carbon footprints, she demonstrates in her thesis how urban footprints can be set in context to each other for matters involving the energy-water nexus dimension.



Imprint: ÖFSE, Sensengasse 3, 1090 Vienna, Austria. Authors: Hannes Grohs, Ines Omann, Karin Küblböck, (ÖFSE); Raphael Karutz, Ahmed Al-Kebsi, Christian Klassert, Bernd Klauer, Forrest Kluson, Linda Maiwald, Helen Mayer (UFZ); Ankun Wang, Steven Gorelick (Stanford University), Samer Taloz, Elham Walid (MIRRA).

Design: Alexandra Erös (ÖFSE)

The FUSE team would like to thank all partners in Jordan for their valuable contributions. 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). Any opinions, findings, and conclusions or recommendations expressed in this material do not necessarily reflect the views of the funding organizations.