Stakeholder-supported Research on the Food-Water-Energy Nexus with three International Case Studies

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1 ABSTRACT

The projected increasing population in cities and metropolitan regions results in higher demands of resources, i.e., food, water, and energy (FAO 2018), that are essential for human well-being, poverty reduction, and sustainable development(Hülsmann and Ardakanian 2018).There are clear interactions between water, food, and energy that may result in synergies or trade-offs between different sectors or interest groups. To address the issue,the international project IN-SOURCE models and analyses the Food-Water-Energy Nexus (FWE Nexus) in three case study regions of Germany, Austria and the United States of America. Due to the complexity of the nexus issue, stakeholders have been involved actively in the research process, whose valuable output would strongly support the decision-making processes. This paper gives an overview of the methods, case studies, and stakeholder involvement of the whole project. With the novel methods, stakeholder-oriented process, and case studies' representativity, IN-SOURCE serves as a benchmark for future FWE researches.

Keywords: Urban Simulation Platform, CityGML, Stakeholder Engagement, Food Water Energy Nexus, Planning Tools

2 INTRODUCTION

Cities and metropolitan regions are deemed to face major urban management challenges in the future: 55 percent of the world's population already lives in urban areas, and according to a United Nations report(United Nations, Department of Economic and Social Affairs, Population Division 2019), it will be more than two-thirds by 2050. Such a high population density in a limited space requires even better planning of public infrastructure services, especially the secure and stable supply of food, water and energy. However, the growth of cities also opens up synergetic opportunities. With the expansion and reconstruction of sustainable infrastructures, cities can take comparatively large energy-efficient transformation steps to fulfil their climate protection goals.

In this context, the international project "INtegrated analysis and modelling for the management of Sustainable urban food, water, and energy resOURCEs" (IN-SOURCE) is aimed to model and analyse the Food-Water-Energy Nexus (FWE Nexus) in three case study regions of Germany, Austria and the United States of America. A common goal is to develop tools that support sustainable FWE strategies in collaboration with local stakeholders. The main focus is a shared open urban data and modelling framework, integrating 3D visualisation tools to assess FWE nexus impacts and support decision-making processes quantitatively.

The proposed modelling framework is based on the Open Geospatial Consortium (OGC) standardised open data model of CityGML and a newly proposed CityGML FWE Application Domain Extension (FWE ADE)[1] (Padsala et al., 2021). To date, this model, by finding its interfaces to urban simulation platforms such as UD_InfraSim[2] and SimStadt[3], can simulate energy, water and food potentials in decentralised supply infrastructures under boundary conditions such as climate change, population growth, and land use change in the timeframe to 2050 (Padsala et al., 2021). Nexus relations and further development of the FWE ADE to extend its support to the open source 3D City Database (3DCityDB) are currently being worked upon.

[1] https://transfer.hft-stuttgart.de/pages/in-source/in-source/FWEADE/
[2] https://www.ait.ac.at/en/research-topics/digital-resilient-cities/projects/ud-infrasim
[3] https://www.hft-stuttgart.de/forschung/projekte/aktuell/simstadt-20

Additionally, environmental footprint indicators are being analysed forfood supply and demand (Kaufmann et al., 2021) andwastewater treatment plant (WWTP) analyses, for which the FWE data model integration is currently being investigated.

To facilitate public authorities' engagement,co-creative stakeholder processes are aimed to configure alternative urban and regional scenarios for integrated carbon-neutral and sustainable infrastructure. The goal is to understand the interlinkages between food, water and energy demand and analyse the feasibility of a decentralised and increasingly autonomous FWE supply. This encompasses efficient wastewater treatment with sewage sludge to energy projects, treated effluent reuse for irrigation in agriculture or a high regional food production ratio including food, green and forest waste to energy concepts. Prototype solutions will be analysed for their scalability and transferability to other cities and regions.

This paper tries to 1) consolidate major outcomes and lessons learnt during the development of the FWE urban data and modelling framework and discuss 2) results derived from the past co-creative stakeholder processes in the three international case study regions of Germany, Austria and the United States of America for larger public awareness and scientific community reach.

The IN-SOURCE project (May/June 2018 – September 2021) is part of the Sustainable Urbanisation Global Initiative (SUGI), established by the Belmont Forum and the Joint Programming Initiative Urban Europe. The project is funded by the EU Horizon 2020 programme and national funders, the Federal Ministry of Education and Research in Germany, the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology in Austria and the National Science Foundation in the USA.

3 SHARED MODELING FRAMEWORK

3.1 Nexus relations

The workflows for food, water and energy productionpotentials and demand have now been elaborated. Recently, the team has been working on local food security and the sustainable food system, adding the food component to the existing energy-water simulation platform and thus finalising it. Food demand, productive potential and self-sufficiency can be analysed in the context of the food-water-energy nexus at community, sub-regional and regional levels. Currently, the nexus interrelations are being explored, which is intrinsically important for estimating future needs and potentials under changing boundary conditions. Lastly, visualisations of different FWE nexus related scenarios shall give decision support to stakeholders.

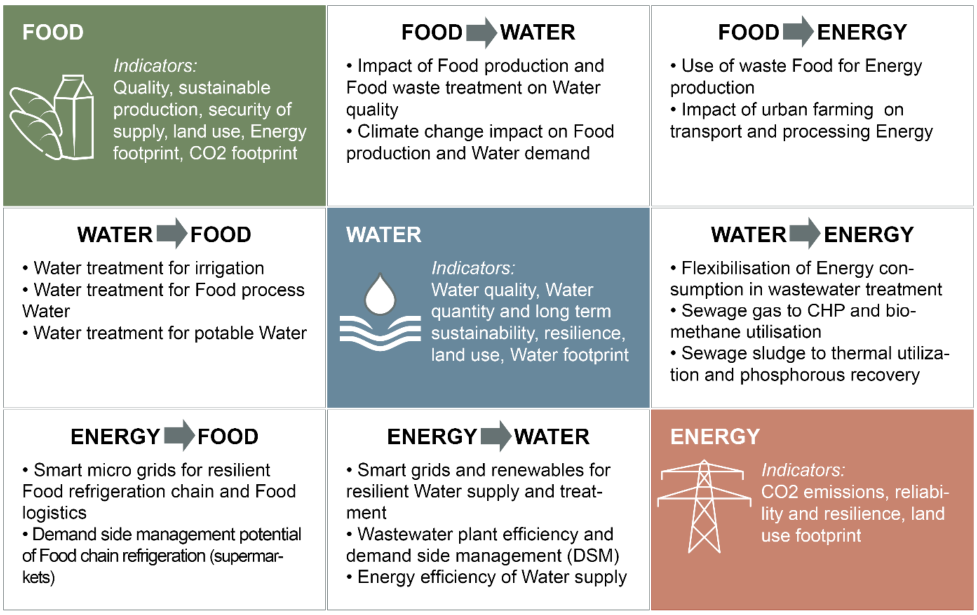

Fig. 1: The main indicators and FWE nexus questions addressed in IN-SOURCE (source: HFT Stuttgart)

3.2 Shared data model: developing a CityGML based Food-Water-Energy ADE

The development of the shared modelling framework is based on a 3D CityGML model depicting the county of Ludwigsburg in Germany, one of the three case study regions. The HFT research team set it up to model

FWE related scenarios, develop measures and work with the regional government to speed up implementing sustainable infrastructure for the whole region with 39 communities.

IN-SOURCE aims to model the impact of land use change and renewable energy transition on urban infrastructure using3D city models. The CityGML data model was extended for the food and water using CityGML's extension mechanism of the application domain extension (ADE). All national teams intensively worked on the definition of parameters according to their respective case study regions. The CityGML FWE ADE acted as a standard data exchange platformfor connecting domain specific tools to simulate FWE related scenarios. For example, to calculate biomass potential using SimStadt for a land use scenario simulated using UD_InfraSim based on Vienna's future population growth, climatic conditions and city development plan or simulating building stock energy demand using SimStadt for the neighbourhood development scenarios from the Gowanus case study of New York modelled initially using Rhinoceros3D (Padsala et al., 2020).

3.3 Simulation tools covering aspects of the FWE nexus

3.3.1 <u>SimStadt: A comprehensive bottom-up tool to simulate potentials and demands of FWE nexus</u>

Depending on the defined nexus relations, corresponding tools were applied and further developed to solve the nexus issue. To the author's knowledge, an assessment of biomass potentials along with other energetic potential and demand at the regional level based on a consistent set of geographical input has not been performed yet. The research question of this work will be: What are the local biomass resource potentials, their dependency on other resources, mainly water, their conflicts with other usages, i.e., food, competition with other energy technologies, i.e., wind and open land PV, and their contribution to renewable energy supply at the regional level?

To address this gap, work has been done to introduce a new workflow in SimStadt, the regional energy simulation platform developed at HFT Stuttgart (Nouvel et al., 2015). It evaluates the local biomass potential and irrigation demandon arable and forestry landsand its transformation to different forms of secondary energy, i.e., solid fuels, biogas, or bioethanol, based on geographical inputs. Based on the intermediate results of the above-mentioned biomass workflow, each land use field's vegetal and animal feed potentialsare simulated (Bao et al. 2020a).

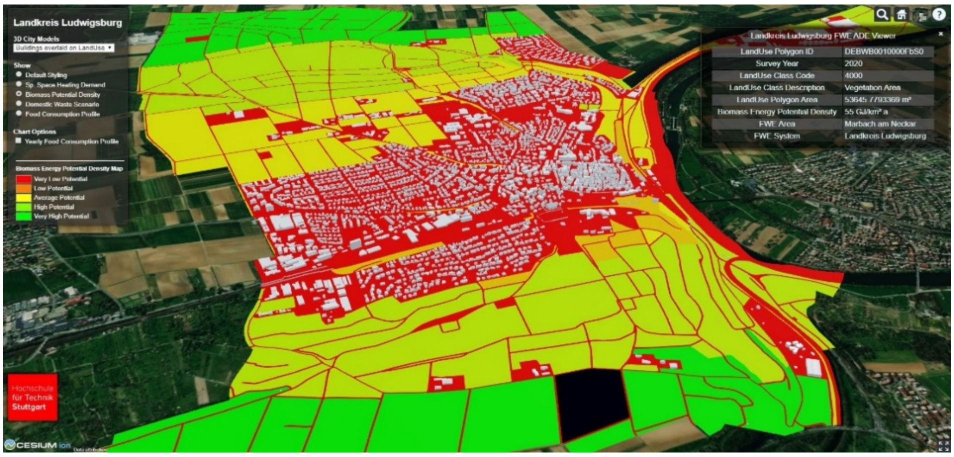

Fig.2: Biomass potential visualisation of Marbach,County of Ludwigsburg, Germany using CityGML 3D City Models (source: HFT Stuttgart, Bao/Padsala)

Since urban areas are the main consumers of resources, urban food[4] and water demand workflows (Bao et al. 2020b) were developed in SimStadt, including socio-economic factors, i.e., income, age, human development index, etc. While biomass in urban areas might not provide substantial amounts of bioenergy to local consumers, the example of green roof with PV modules is used to assess exemplarily the energetic impact and economic feasibility of urban biomass on the roof PV yield and heating demand (Weiler et al.

[4] Not published yet.

2019), which are simulated by existing and well-validated workflows in SimStadt, using the same geoinformatics input data.[5]

3.3.2 FWE Land Use Simulator: A tool to simulate urban growth induced land use change and impacts to Food, Water and Energy

The FWE Land Use Simulator was built usingUD_InfraSim. This simulation platform enables urban planners to estimate the impact of urban development, urban growth, infrastructure costs, for example, for road and water networks, in relation to changes in land use (growth patterns) in the urban region (Gebetsroither-Geringer et al., 2015). It is built upon earlier 'urban development simulation tools' (Gebetsroither-Geringer and Loibl, 2007; Gebetsroither, 2009; Gebetsroither and Loibl, 2014). Within the IN-SOURCE project, the simulation platform was used, adapted and extended to build the FWE Land Use Simulator. This FWE Land Use Simulator enables, e.g., to explore the impact of urban growth scenarios on arable land and biomass production, the water demand and roughly estimate the renewable energy production potential from rooftop PV production.

3.3.3 HANPP and eHANPP environmental footprint indicator: visualisation of urban food production and global impacts of food consumption

We quantify urban land use intensities using HANPP (Human Appropriation of Net Primary Production) as environmental footprint indicator. HANPP measures the depth of human interventions into the biological productivity of ecosystems. Human appropriation of NPP occurs through land cover/use change (e.g., from forest to cropland, HANPPluc) which alters ecological patterns and processes and through agricultural and forestry harvest, where biomass is removed from ecosystems (HANPPharv). In IN-SOURCE HANPP was calculated for the city of Vienna and its food demand. The interactive website called “HANPP Explorer”showsa visualization of the urban food production and the global impacts of food consumption as well as the simulated impacts of dietary changes (Kaufmann et al., 2021).

4 THE CASE STUDY REGIONS

4.1 Low-density metropolitan region: County of Ludwigsburg

The administrative district of Ludwigsburg – County of Ludwigsburg – is a Southern German region of 687 square kilometres with 39 small to medium-sized cities. 540.000 inhabitants (786 per square kilometre) live in that district. The county stands for a growing metropolitan region adjacent to the Baden-Württemberg state capital of Stuttgart, including agricultural land.

The county governance seeks to speed up implementation of sustainable infrastructure such as maximum renewable supply, efficient wastewater treatment with sewage sludge to energy projects, treated effluent reuse for irrigation in agriculture, or a high regional food production ratio including food, green and forest waste to energy concepts. IN-SOURCE took up the ambitious climate protection plan of the county to support its implementation and demonstrate synergies in the food-water-energy sector. For this purpose, the potential of sustainable energies that can be used locally was analysed, e.g. the county-wide biomass utilisation potential, taking into account a good energy-food balance. In the area of wastewater, waste2power plays a role. By switching to CHP, the self-supply of electricity in waste water treatment plants can be increased to over 90%.

Further potentials lie in co-digestion and the decoupling of upgraded biogas as biomethane. In Ludwigsburg County, agricultural food production (still) plays a role and can cover the local food demand to a certain extent. Increased direct marketing and water reuse for irrigation in agriculture are other relevant topics.

4.2 Medium-density urban area: Vienna

Vienna represents a rapidly growing European capital with currently just under 2 million inhabitants. The city is pursuing an urban development plan (STEP), a climate protection plan and a smart city initiative. Urban planning faces the challenge of creating infrastructure and housing in a sustainable manner while maintaining a high quality of life. Economic and population growth induce changes in land use as well as

[5] The workflows of roof PV potential and heating/electricity demand are developed in the project SimStadt 2.0 (03ET1459A) funded by BMWi.

energy, water and food consumption; in this context, the city government has a strong planning and regulatory role regarding water and energy supply and was therefore included in the stakeholder process. There are still a number of farms within the city limits, and initiatives to promote urban and vertical farming and food production are emerging and gaining public attention, therefore we invited stakeholders from NGOs as well.

The city of Vienna is a medium dense European city, where also a 3D CityGML model is available that was already in use for energy-related analyses (Skarbal et al., 2017). Within IN-SOURCE, the CityGML model,together with the CityGML FWE ADE and the FWE Land Use simulator,will analyse the consequences of land use change for biomass generation rooftop PV potential climate change adaptation and population growth (Padsala et al., 2021).Urban food production and biomass potentials (HANPP) and current food demand are analysed as well as global, international and national impacts of changes in dietary patterns (eHANPP) (Kaufmann et al.,2021).

4.3 High density urban area: New York City/Gowanus

The expanding and very dense city of New York faces challenges of a limited capacity urban infrastructure, particularly the electricity grid, and increasing needs to provide a resilient infrastructure for water and food supply. New York committed itself to reduce GHG emissions by 80% by 2050. This should be reached by transforming the energy system into a sustainable energy system with a reduced carbon footprint.

In New York, the district of Gowanus/Brooklyn was examined. The common data model based on the CityGML standard was used for modelling as in the European case studies.

Urban transformative change requires substantial changes in the supply system and affects the FWE system widely. Gowanus is to be restructured in a climate-neutral manner and is an example of a very densely populated urban district. The current industrial district will be rezoned to a combined residential and industrial area, increasing population. Due to the lack of arable land in the densely built area to grow food within the city, land cultivation will be limited, and the focus lies on the import of food and urban agriculture. In order to reduce the carbon footprint, NYC is investing in more efficient public transportation systems, other means of electric vehicles (scooters, bikes), ride sharing and vision zero NYC (safe streets for pedestrians). Efforts on improving the energy efficiency of large electricity consumers (subway systems, wastewater treatment plants, etc.) have been taken by the city.

5 STAKEHOLDER ENGAGEMENT

An important goal of the IN-SOURCE project was the involvement of stakeholders throughout the process. This meant first and foremost identifying the relevant stakeholders in each case study region, for example, administration/municipality representatives, urban planners, energy and water utilities, food producers and logistics companies, supermarket associations, food promoters, citizens and NGOs. A stakeholder mapping table was produced in order to get an overview. In addition, potential contact persons were evaluated in terms of their professional affiliation with the respective nexus elements and their possible influence on the project.

Fig.3: US and international experts at a cross-sectoral workshop held in December 2019 at the Center for Architecture in New York

A joint workshop design for all three case study regions, as initially foreseen, soon turned out to be not practicable. Each national team had to find asuitable form of co-operation. In the New York Gowanus district, a participation process was already initiated and mainly involved citizens, architects and urban planners (the Net Zero Neighborhoods project and Gowanus by Design, (http://gowanusbydesign.org/). Another stakeholder co-creation process running in parallel focused on optimising wastewater treatment plants throughout the city and involved, among others, NYC Agencies and the Mayor's Office.

In Vienna, a stakeholder process was started with identifying relevant stakeholders from the city administration and planning offices, civilly society organisations and NGOs. These were invited to a series of three half-day workshops (Smetschka 2020). The Vienna team developed a Causal Loop Diagram to discuss the FWE nexus and stimulatingco-operation. After elaborating a set of challenges and visions, keyfactors were identified, and available data analysed. Scenarios for sustainable urban development addressing food, water and energy production and demand were developed in the second workshop. In the final third workshop, results from modelling, visualisations of these results and the tools employed during the research will be presented, and their usability for city administration will be evaluated.

In the German case study, stakeholder engagement suffered from the Covid pandemic However, several consultation meetings were held to exchange mutual knowledge in wastewater treatment to enable the modelling of a wastewater treatment plant to identify flexibilities for the grid-serving operation of the power grid. In addition, virtual meetings are still planned to initiate stakeholder engagementin the County of Ludwigsburg, focusing on co-identifying and co-producing knowledge on varied elements of the urban FWE systems, which scenario simulations can now support.

Thus, in each local case study, stakeholders cooperate in developing a vision of how urban space and infrastructures should be designed, how FWE synergies can be optimised, renewables can best be integrated, and how population growth, land use changes and climate change challenges can be envisaged for future developments. Strategies and goals can be defined by converting these considerations into scenarios with key performance indicators (KPI), such as CO2emissions.

6 CONCLUSION

IN-SOURCE managed to develop a shared urban simulation toolbox and a single shared data framework for all three case study regions, which has a good replication potential for other cities and regions. Furthermore, the transferability of the shared urban modelling framework has been proved.

The stakeholder involvement helped to consider common urban and technological challenges in the three very different case studies. A joint workshop design was not feasible given the different stakeholder groups involved. However, a network of individuals with diverse professional backgrounds has been established, their visions and strategic planning skills pooled. With IN-SOURCE, an interesting learning process for stakeholders and researchers has begun.

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