Introduction of Key Nexus Indicators to Assess the Urban Food-Water-Energy Nexus within the SUNEX Project

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1 ABSTRACT

Within the SUGI initiative addressing the challenges of sustainable urban food, water and energy nexus (FWE-Nexus) the ongoing project SUNEX -funded by JPI Urban Europe in collaboration with the Belmont forum- is developing an integrated interdisciplinary approach to analyse the intersection between FWE-systems. It aims at supporting cities' decision-making process in formulating inclusive and sustainable urban FWE–strategies. The project has established an integrated modelling framework to model FWE demand and supply and assess their key intersections through a nexus approach that endorses sustainable and efficient solutions to cover cities FWE-demand. The modelling framework is being applied in 4 case studies for the cities Berlin, Bristol, Doha and Vienna. The applied Nexus-approach relies on profound urban FWE-data and consistent socio-economic and technological development scenarios constructed within a co-creation process supported by cities' stakeholder dialogue (Hainoun and Loibl, 2019). To address the complex interlinkages between the three systems and capture their key synergies, SUNEX has developed a novel concept called "Key Nexus Indicators (KINs)" that helps to quantify and monitor the key nexus-effects of urban FWE systems. The introduced KNIs are classified into two categories, addressing either dual effects (FW, FE, EW) or triple effects referring jointly to the 3 FWE systems. Altogether 6 triple KNIs and 22 dual KNIs of FWE-Nexus effects have been specified. The introduced KNIs are quantified based on the results of the developed future FWE demand-supply scenarios formulated using the established SUNEX-modelling framework. The scenario results are monitored and evaluated to specify the strength of coupling effects (nexus-grade) using the introduced KNIs.

Keywords: sustainable urban development, food-water-energy-nexus, Key nexus indicator, city decision making , SUNEX project

2 METHODOLOGY

The urban FWE-Nexus approach applied within SUNEX project focuses on analysing the intersection between the three systems along the supply chain of the considered urban area. For this purpose, an integrated demand-supply analysis of the FWE systems has been conducted using the newly established SUNEX-IMFA (Integrated Modelling Framework). In these Analyses sustainable FWE strategies for the considered demo cities has been formulated following expected future socio-economic and technological development aligned to the official cities' future visons (like SCWFS for Vienna) (Hainoun and Loibl, 2021). Due to the central role of the energy demand for the FWE-Nexus detailed modelling of the city's energy demand by sector and energy form (within SUNEX-IMFA) has been conducted using the end-use, bottom-up approach of the sub-module MAED-City. MAED-City concept disaggregates the urban energy demand by sector of consumption comprising building (household and service), agriculture, construction, manufacturing industry and transportation (passenger and freight). The future development by sector and fuel is projected following a sustainable, efficient and low-carbon transformation path. The employed drivers of the conceived transformation comprise energy efficiency improvement, switching to clean fuel, digitalisation and electrification. Considering the decarbonisation of electricity through increased renewable energy shares, the electrification accounts for increased penetration of electricity in the end-use of all consumption sectors like EV and H2 for passenger and freight transport, electrisation of building heat demand via heat pumps for space and water heating, etc. The energy supply accounts also for the increased need of flexibilization like P2H and P2G. However, the impact of sector coupling related to V2X is not considered within SUNEX-project. This is part of follow-up activities and other running projects. More detailed elaboration on the supply strategy for the case of Vienna city can be found by Horak and Hainoun (Horak et al., 2021).

Following an integrated demand-supply analysis an interdisciplinary approach is being applied aiming to quantify and optimise existing synergies between the three systems and thus supporting the desired sustainable urban transformation towards efficient, sustainable and low-carbon economy. Form the conceptual viewpoint the FWE-interlinkage is obvious, and the main related Nexus-Effects can be reasonably well defined. However, the quantitative analysis is challenging, in particularly for cities and urban areas with their strict geographic boundaries at which the considered FWE are balanced. Hence, many of the supply related effects lie fully or partially outside the boundaries of the cities on which the urban decision has no direct influence, e.g., the production and transport of food from long distances. However, cities -with their concentrated social and economic activities and intensive resources use- have their role to play in enabling the desired CC mitigation with focus on ensuring sustainable production and consumption pattern and working towards sustainable, resource-efficient and low-carbon economy where the expected growth is driven by the interaction between rapid technological innovation, sustainable infrastructure investment, and increased resource productivity (NCE, 2018). Moreover, the desired sustainable development needs to be balanced and inclusive resulting in efficient, liveable cities characterised by low-carbon, smart and resilient infrastructure. In this context the FWE-Nexus can provide a valuable contribution by harnessing existing synergies and making the intersection between the three systems impactful through innovative socio-economic and technological measures that focus on resource efficient practices like reducing food wastes and switching to renewable energy sources.

To quantify and monitor these interlinkages of FWE-systems, SUNEX has introduce the concept of "Key Nexus Indicators (KINs)". Two categories are identified addressing either dual effects among the three systems (FW, FE, EW) or triple effects where the three systems jointly interact with each other (Figure 1). Altogether 6 triple KNIs and 22 dual KNIs of FWE-Nexus effects have been specified.

As depicted in Figure 2 the multidisciplinary FWE systems are described following the associated demand and supply activities and then interrelated via the expected nexus-effects. The endorsed KNIs followed these effects and quantify the resulting impact associated with them. The total city energy demand is being specified by sector of consumptions with specific focus on energy needed for food and water provision, like energy for urban farming in agricultural sector, energy for food industry and energy for freight transport (including food and water), energy for cooking, etc (Hainoun and Loibl, 2021). The same applies for water being needed for irrigation, catering and beverage, household cooking, etc. The approach accounts only for the energy and water related to services and commodities provided within the city boundary. Energy and water embodied within the import food products are not considered. However, with focus on the different food supply routes (national, international) estimation are given for the transport distances to estimate the energy of food transport.

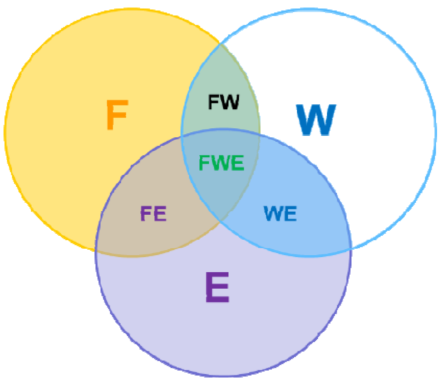

Figure 1: intersection of FWE systems and resulting KNIs

The established KNIs-concept is being integrated within the newly developed SUNEX-modelling framework focussing of formulating long-term future FWE-development scenarios (Hainoun and Loibl, 2021), (Doernberg et al, 2019). The scenario results are monitored and evaluated to specify the strength of coupling effects (nexus-grade) using the introduced KNIs.

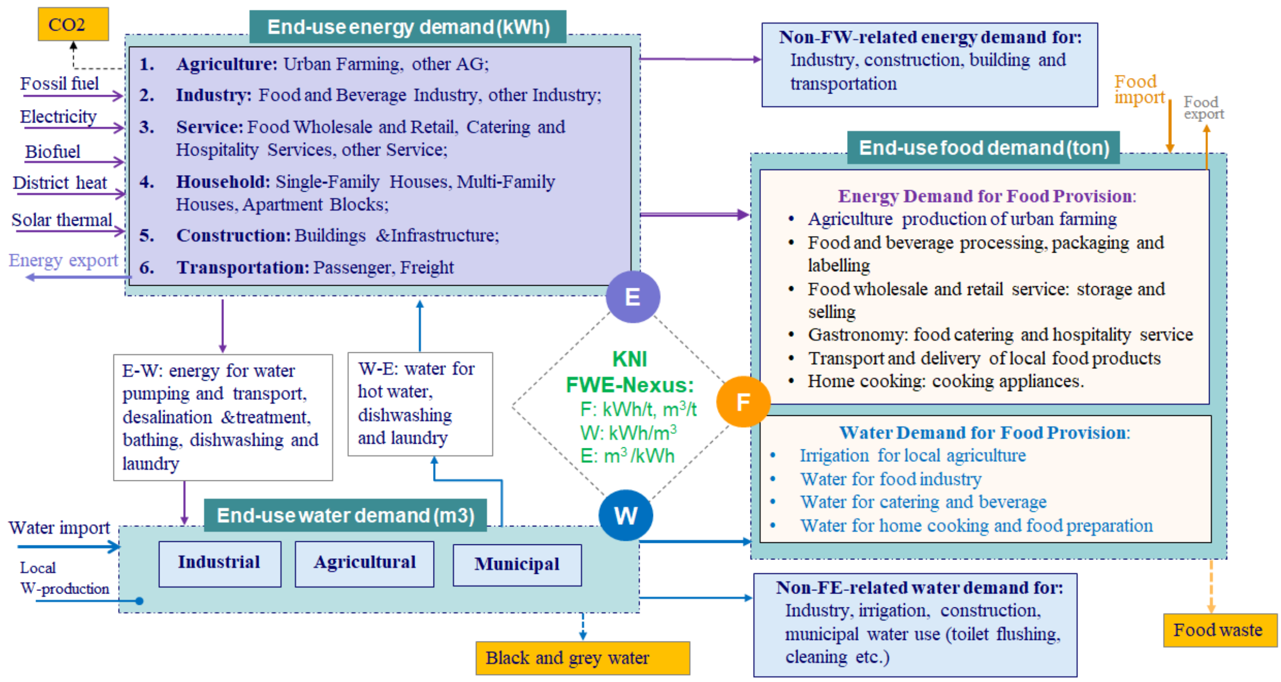

Figure 2: SUNEX-concept of the key nexus indicators (KNIs) to assess urban FEW-nexus.

3 APPLICATION

Tracing the main intersections along the FWE-supply chains 22 dual KNIs and 6 triple KNIs have been identified. Table 1 presents exemplary a selection among the identified KNIs. Permutation effects can play a roly if they are referring to different effects, like energy for water pumping and water for energy production (power plan cooling).

Considering the intersection of FWE-systems, the food perspectiveprovides the most interesting full FWE-Nexus-effects -along the food supply chains-, i.e. effects where the three systems are jointly interacting. These effects refer to the energy and water intensity in terms of energy and water amounts needed to generate one-unit of food. The resulting set of tripple KNIs are then associated to:

- Agricultural production of urban farming,
- Food and beverage processing,
- Packaging and labelling industry,
- Food wholesale and retail service (storage and selling)
- Household cooking and food provision in gastronomy (food catering and hospitality service within the service sector).

Besides, the mentioned steps along the food supply chain are associated with energy demand for food transportation (a dual KNI effect of energy for food).

With the set relation about the intensities -E(kWh)/F(ton), W(m3)/F(ton)- any future change in the amount or structure of food demand affects both energy and water demand via the specified KNIs that correlate with the existing nexus-effects. For example, the shift of demand per capita from meet to vegetable will reduce the energy and water demand due to the lower intensity of vegetable provision. From a holistic system perspective, this leads to reducing the CO_2 emission per unit of food. However, within the city boundary, any increase of local production would increase the local energy and water demand (and land-use) which might feature a new challenge for the city given its limited energy, water and resources. The answer for the city-decision making is to choose the optimal balance between food import and local production considering the prevailing limits and constraints of the considered city. With focus on future city vision this challenge is exaggerating in relation with the set cities' goals in the EU to become carbon neutral latest by 2050.

Accordingly, the FWE Nexus-approach provides an interesting basis for a multisectoral decision making for a sustainable FWE strategy in respect to the city's long-term development goals (Ludlow et al, 2019).

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

	Affected Systems	Activity	Reference unit	Key Indicator
	FWE	Cooking (in household and HH): (all cooking appliances)	Per dwelling	E and W per F (kWh/t, m^3/t)
	FWE	Dishwashing (HH)	Per dwelling	E and W per F (kWh/t, m^3/t)
	FWE	Gastronomy (Ser): food catering and hospitality service	Per ton of food or related (GDP-VA)	E and W per F (kWh/t, m^3/t)
	FWE	Food and beverage processing, packaging and labelling	Per ton of food or related (GDP-VA)	E and W per F (kWh/t, m^3/t)
	FWE	Agricultural production of urban farming	Per ton of food or related (GDP-VA)	E and W per F (kWh/t, m^3/t)
	FWE	Food waste treatment	Per ton of food	E and W per F (kWh/t, m3/t)
	EF	Transport and delivery of local food products	Per ton or (GDP-VA)	E per F (kWh/t) or (kWh/$)
	EF	Refrigeration (in household)	Per dwelling	E per F (kWh/t)
	EW	Hot water (in household): (for bathing and showering)	Per capita	E per W (m3/kWh)
	EW	Laundry (in household)	Per dwelling	E per W (m3/kWh)
	EW	Irrigation: urban farming, private garden, public parks	Per m^2 of irrigated area	E and W per m^2 (kWh/m^2) (m3/ m^2)

Table 1: selection of main KNIs specified along the urban FWE-supply chain (FEW: intersection of Food-water-energy systems; EF intersection of Food and energy systems, EW: intersection of energy and water systems)

4 CONCLUSION

The introduced KNIs to monitor and evaluate the FWE-Nexus prove to be a valuable approach in supporting the development of sustainable urban FWE-strategies. The KNIs-concept has been realised within the integrated SUNEX-Modelling frame being under development. It has been successfully applied to cover the urban food supply chain covering (within the city boundary) form the agricultural production of urban farming up to the food provision in the household or gastronomy. Currently the concept is being applied to track and monitor the results of long-term sustainable FWE strategy for the cities of Vienna, Berlin, Bristol and Doha.

5 ACKNOWLEDGEMENT

This work has been carried out as part of the ongoing Project SUNEX running within the SUGI on FEW-Nexus of JPI-Urban Europe and the Belmont Forum (project number 730254). The authors would like to thank the Austrian Research Promotion Agency (FFG) for funding the Austrian Team (FFG- 867102).

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