Analyses of the Long-Term Energy Demand of Vienna City and Modelling Related-Key Food-Water-Energy Nexus Effects

Ali Hainoun and Wolfgang Loibl

Abstract

Within the ongoing SUNEX project, sustainable urban FWE strategies are being formulated for the city regions of Berlin, Bristol, Doha and Vienna reflecting different climate conditions, socio-economic states as well consumption patterns and resource uses. The newly established SUNEX modelling framework is being used to conduct integrated FWE demand–supply analysis, capture main nexus effects and maximize their existing synergies. Following a participatory process involving key local stakeholders, future FWE demand and supply are projected according to consistent long-term scenarios of socio-economic and technological development of the considered city regions. The results are monitored by a set of indicators defined and linked to selected goals of UN-SDGs to ensure sustainable development paths in social, economic and environmental dimensions. This contribution dealt with the use case of Vienna city focusing on the first results of energy demand analysis and related water-food nexus along the energy end-use activities of local urban farming, food and beverage processing, transport and trading, catering and hospitality services beside home cooking and hot water provision.

Keywords

Demand–supply analysis • Future development scenarios • FWE nexus • SDGs

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1 Introduction

The growing need for inclusive and sustainable development calls for integrated approaches to address interdependencies between interacting systems, manage existing trade-offs and maximize synergistic effects to achieve an overall optimized resource uses. Within this context, food, water and energy systems occupy special position in the sustainable development agenda with profound and complex interrelation at national, regional and urban scales. Thus, applying a food-water-energy (FWE) nexus concept is essential for operationalizing such interdependent systems that have shown unsustainable development over the past decades. Urban regions, with their high population density and resource-intensive and complex life-styles, face big challenges and constraints in ensuring sustainable supply to cope with ever increasing demands on food, energy and water along the emerging urbanization (Heard et al. 2017; GIZ and ICLEI 2014). Being responsible for the main share of FWE consumption and related GHG emissions, cities are key players for achieving global sustainability. Particularly, they are considered to be responsible for about 75% of global energy consumption and 80% of GHG emissions (UN 2007). Moreover, cities are faced with inefficient supply and recycling systems, underused synergy potentials of FWE coupling, waste and rebound effects. These challenges are augmented as urban systems are heavily dependent on importing FWE from outside their physical boundaries with far-lasting environmental impacts beyond the city borders. Considering the limited land within the urban scale, the competition on the land use for energy and food production beside other urban uses makes the attainment of a sustainable urban development more challenging (FABLE 2019). Hence, for a sustainable urban transformation, cities' infrastructure need to become more productive, efficient and resilient (Pandit et al. 2017). However, cities with their concentrated activities and dense infrastructure also offer the opportunity to implement unique sustainability solutions at

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scale, where FWE intersection are best captured through a nexus approach. With this in mind, several activities are running to develop concepts and integrated modelling approaches to evaluate the FWE systems and assess their intersections at urban, regional and national scales using tools and models of different complexities and level of details (Kaplan and Kaldunski 2016; Zhang and Vesselinov 2017; Simon et al. 2017; Hussien et al. 2017; ESCWA 2015; Mirakyan and De Guio 2013; Ben Amer 2014; EPA 2017).

Within this perspective, SUNEX concept provides an integrated FWE nexus view to support the decision-making process in formulating inclusive urban FEW strategies. The applied nexus approach relies upon profound urban data, stakeholders' dialogue and consistent development scenarios to address and understand the complex interlinkages between the three systems, promote coordinated solutions and maximize their synergies. The SUNEX project follows the sustainable urbanization global initiative (SUGI) on urban FWE nexus being jointly established by the JPI Urban Europe and Belmont Forum to promote innovative new solutions to the FWE nexus challenge (SUNEX 2019). SUNEX establishes an integrated modelling framework to model and assess the FWE systems' demand and supply and capture their intersections through a nexus view that endorses sustainable and efficient solutions for urban FWE systems. The FWE nexus concept serves as central approach to ensure coherent solutions on sustainable use and management of related resources.

SUNEX is being applied in the cities of Berlin, Bristol, Doha and Vienna, reflecting different socio-economic and climate characteristics and addressing local and remote resource uses among the full FWE supply chains. Starting from the current situation identified as base year (2016) and in co-design with local stakeholders and urban policymakers, future evolution of urban FWE demand is projected based on consistent scenarios reflecting the prospective future socio-economic and technological development of the considered cities. The future FWE supply is developed based on simplified techno-economic optimization. The results of the developed FWE strategies are analysed and monitored by a set of sectoral indicators covering key nexus effects of FWE systems beside a high-level indicator aligned to the UN sustainable development goals (SDGs) covering the following goals: Goal 7 to ensure sustainable energy for all, Goal 6 to ensure sustainable management of water and sanitation for all, Goal 2 to achieve food security and improved nutrition and promote sustainable agriculture, Goal 11 to ensure sustainable cities and communities, Goal 12 to ensure responsible consumption and production, Goal 13 on combating climate change and its impacts and Goal 15 on combating desertification and halt land degradation (UN-SDGs 2016). The final project outputs will be analysed to identify possible implementation measures for improvement beside preparing policy guidelines to support city decision-making in formulating sustainable urban FWE strategies (Hainoun et al. 2019). This contribution was devoted to present the results of the business as usual (BAU) scenario on final energy demand and related key FWE nexus for the case study of Vienna city.

2 Methodology of Sectoral Energy Demand

Within the established SUNEX modelling framework, the end-use scenario-based approach of the bottom-up model, model for evaluation of energy demand (MAED), was used to project the long-term future final energy demand of Vienna city starting from the current consumption. The MAED concept disaggregates the urban energy demand by sector of consumption comprising building (household and service), agriculture, construction, manufacturing industry and transportation (of freight and passenger) (Hainoun et al. 2018; MAED 2006). Each of the energy consumption sectors is further disaggregated in various sub-sectors in respect to the socio-economic and technological determinants driving the energy consumptions and to the type of end-use activities where the intersection and synergies between energy demand and water-food consumption can be captured and quantified via selected indicators as elaborated later. The applied bottom-up approach of MAED model systematically relates the specific energy demand for producing various goods and services to the corresponding social, economic and technological factors affecting the demand for a particular energy form. These factors entail current state and future development of population, dwelling size, electrical appliances used in households, peoples' mobility and preferences for transportation modes, GDP (of the considered city or region) priorities for the development of certain industries or economic sectors, efficiency of machines, appliances and equipment and market penetration of new technologies and energy forms. The demand analysis starts with the reconstruction of a base year —chosen to reflect current energy consumption state— achieved by calibrating the established mathematical relationships between energy demand and related demographic and socio-economic and technological drivers. Following this concept, the model provides a systematic accounting framework to evaluate the impact of changes in economics, social and technological drivers on future energy demand. The expected future trends for the key determinants, which constitute the 'scenarios', are exogenously introduced. For more elaboration on the modelling approach and related data, see Hainoun et al. (2018), MAED (2006), IAEA (2009). Figure 1 shows the disaggregation of energy end-use activities by consumption sectors of agriculture, food industry, service, household and transportation within the city scale. The resulting end-use activities comprise urban farming; construction of buildings and infrastructure; food and beverage industry; catering and hospitality services as well food wholesale and retail trade; residential buildings by household type; freight and passenger transportation by different inter- and intra-city modes.

The different activities in each sub-sector are correlated to specified energy services being covered by the useful energies in the form of heat, motive power and specific electricity use. The available conversion technologies at the end-use level of consumers convert the provided final energy into the desired useful energy to cover the needed energy services. The fundamental principle of the model relies up on relating the specific energy needs for producing various services and commodities to the social, economic and technological factors driving the demand on a particular fuel (Hainoun et al. 2018).

The energy demand of Vienna city is being analysed for the current base year 2016 using official statistical data covering energy balance by sector and fuel type, demographic and socio-economic parameters and their expected future development and technological parameters related to the efficiency and penetration rate of the current end-use technologies in the different consumption sectors (Statistics Austria 2019a, b; Statistics Austria 2018; MA20 2018).

Starting from the base year energy consumption, two future development scenarios have been developed reflecting plausible trends of the expected demographic, socio-economic and technological development of the city. Beside the business as usual (BAU) scenario associated with the reference—current policy—development path, a sustainable development scenario (SDS) has been formulated reflecting sustainable development trajectories of energy demand and its interaction with food and water on the demand side. SDS focuses on transforming the city energy system towards efficient, sustainable and low-carbon future in respect to the Smart City Vienna Framework Strategy (SCWFS) and its set goals for sustainable development up to 2050 (Homeier et al. 2019).

Key Assumptions of BAU Scenario

The development of the key drivers of BAU scenario is expected to follow the recent development considering the current energy and climate policy measures in place. Over the study period 2016–2050, the development will experience moderate change in social, economic, technological and environmental scopes. This includes slight improvement of energy efficiency and switches to low carbon and clean fuel:

- Demographic and social development: following the official forecasting, the population will increase from 1.84 million in 2016 to 2.158 million in 2050. Life style and their associated energy services will experience moderate improvement in terms of comfort level in the household (family and dwelling size, heat and cool comfort, cooking habit) and interaction with service activities (visit of restaurant) and daily mobility.
- Economic development: no significant change of economic activities in term of GDP growth and distribution by economic sector. Considering the observed average annual GDP growth rate for the last period 2010–2018, it is assumed that the GDP will grow in real term with an average annual rate of 1.7% over the period 2020–2050.
  - Technological development: moderate enhancement of energy efficiency in all consumption sectors.
  - Fuel switching and electrification: moderate increase in penetration rates of electricity, biofuel, local solar thermal and heat pump (in all related end-use activities). The change will be moderately driven by energy price and applied regulation.
  - The slightly increased electrification should also account for the assumed moderate diffusion of digitalization and the expected transition to smarter solutions.

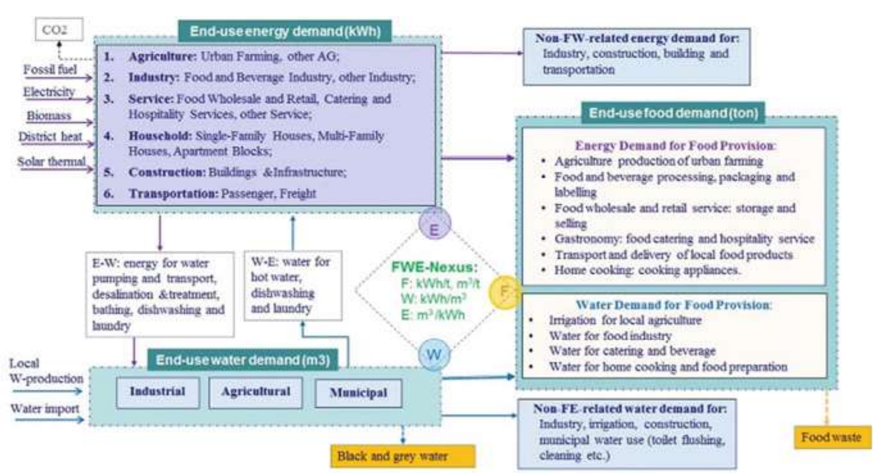

Fig. 1 Intersections of FWE demand at urban scale

– The objective of CO_2 reduction will further contribute to the switch to clean fuel—assumed to be driven by policy regulation—rather than innovative mitigation technologies and measures.

3 Results and Discussion

The future long-term final energy demand by sector and fuel type has been projected following the expected socio-economic and technological development path of BAU scenario for the period 2016–2050. Figure 2 displays the final energy demand projection by fuel type for the BAU scenario. The final energy demand will grow by an average annual rate of 0.72% from around 37.64 to 48 TWh over the period 2016–2050. The main observed changes are in the fossil fuel for thermal use and transportation as their shares will decrease from 23.4 to 20.2% and from 36.4 to 35.3%, respectively. On the contrary, the electricity demand will grow by an average annual rate of 1.12% increasing its share in the final energy demand from 21.9% in 2016 to around 25.1% in 2050 reflecting the continuous increase of electricity in the end-uses observed over the last decades. However, this trend will be more pronounced in the sustainable scenario that stresses the importance of electrification of end-use activities as a driver of sustainable energy development. Starting from the current final energy demand distributed by 36.9% for transportation, 32.5% for household, 25.3% for services and 5.3% for industry and agriculture (Fig. 3).

The adopted assumptions of BAU will lead to a slight decrease of service and Household sectors by around 1% as result of the ongoing building refurbishment. The freight transport will increase by around 1.7% compared to the base year while passenger transport will decline by around 1%. Within the industry sector—with its low contribution in a city scale—the food and beverages are dominating and will further increase their share from the current 27% to around 30%. This activity has key impact on the three FWE systems and their related nexus effects within the urban scale. Similarly, urban agriculture will slightly increase its share form around 0.4% in 2016 to around 0.6% in 2050.

SUNEX developed an approach to specify key nexus indicator (KNI) following the two categories: either applied for two systems (FW, FE, EW) or jointly by the three FEW systems.

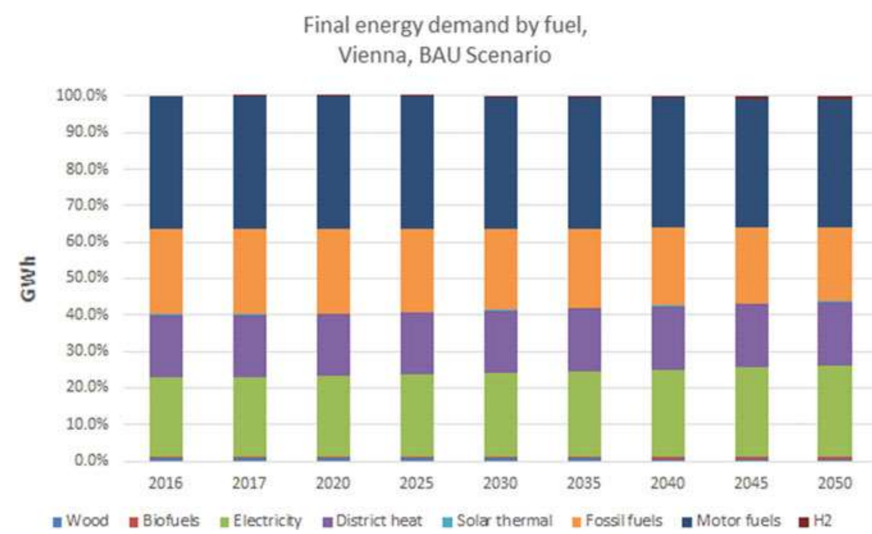

Fig. 2 Projected final energy demand by fuel type (Vienna, BAU scenario)

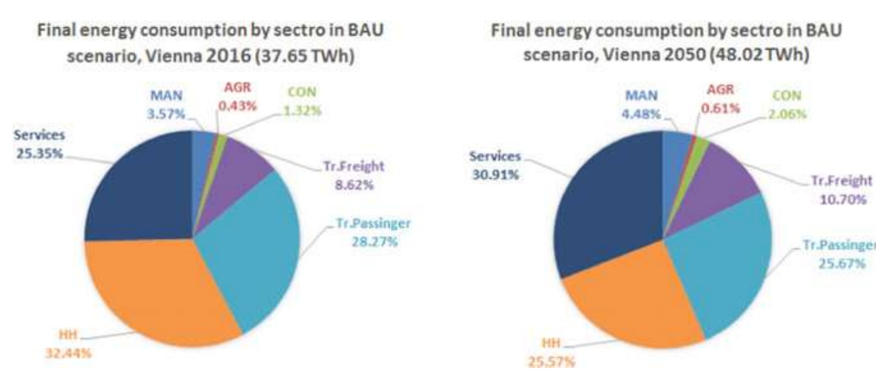

Fig. 3 Projected final energy demand by sector (Vienna, BAU scenario)

Table 1 Selected KNIs to capture intersections across FWE systems

Affected systems	Activity	Reference unit	Key nexus indicator KNI
FWE	Cooking (HH) (all cooking appliances)	Per dw	E and W per F (kWh/t, m^3/t)
FWE	Dishwashing (HH)	Per dw	E and W per F (kWh/t, m^3/t)
FWE	Agricultural production of urban farming	Per tonne or (GDP-VA)	E and W per F (kWh/t, m^3/t)
FWE	Food and beverage processing, packaging and labelling	Per tonne or (GDP-VA)	E and W per F (kWh/t, m^3/t)
FWE	Gastronomy (Ser): food catering and hospitality service	Per tonne or (GDP-VA)	E and W per F (kWh/t, m^3/t)

Key nexus effects are identified, and related key nexus indicators (KNI) are calculated showing the intersection among the three systems. For this purpose, three effects have been selected for the demand side as shown in Table 1. The indicators refer to the energy intensity per m^3 of water and kg of food associated to household cooking, food and beverages industry, food provision in gastronomy within the service sector and agricultural production of urban farming. Hot water provision in HH demonstrates a WE nexus only. Several FWE nexus effects have been specified, and their related KNIs are being under evaluation and quantification using the results of the developed future development scenarios. The results of BAU and SDS scenarios will be compared and evaluated to specify the strength of coupling the effects (nexus grade) using the newly introduced KNIs.

4 Urban Governance and Policy Implications

The first results presented in this work focus on energy demand for a city case study. It is part of a more comprehensive analysis of FWE system for the considered cities that relies on an integrated modelling framework. The outcomes focus on formulating sustainable FWE strategies that are developed following a co-creation process integrating relevant stakeholders among the different stages of future visioning, scenario development and monitoring of the results. Based on the outcomes of the developed case studies and the lessons learned during that, policy guidelines for the design of sustainable urban FWE strategies will be formulated taking into consideration cities' regulatory framework and future sustainable development plans and strategies.

5 Conclusion

The established SUNEX modelling framework covering energy, water and food demand and supply sides is a promising approach to cover FWE nexus effects and helps optimizing their existing synergies. The newly introduced KNIs provide a solid basis for a quantified assessment of existing nexus effects among FWE systems. Their future development pattern will allow for tracking the sustainable development path of urban FWE strategies. However, the so far covered research topics of the urban FWE demand analysis seems to be challenging due to the intensive data required for the applied bottom-up approaches. Alongside the official references on urban FWE systems, extensive communication and interaction with the relevant stakeholders are also essential for providing complete and consistent set of data on current FWE balances, related socio-economic and technological drivers and their expected long-term evolutions within the future development vision of the considered city.

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