Towards energy optimized cities

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Abstract. This work deals with the application of a bottom-up and scenario-based approach to analyse the future urban energy development. For this purpose, consistent scenarios of long term socio-economic, technological and demographic developments of the considered urban area are prepared. The key development parameters focus on technology and infrastructure transformation related to EE improvement and electrification in all consumption sectors, including the shifts in mobility modes and lifestyle changes driven by financial incentives and environmental awareness. The concept systematically relates the specific energy needs for producing various services and commodities to the social, economic and technological factors that affect the demand for a particular fuel.

Keywords: Sustainable urban development, Bottom-up approach, Development scenarios, Energy services, Sector of consumptions

Introduction

The ongoing transition to a resource-efficient and low-carbon economy presents the adequate response to the perceived sustainable development revealed in the recently adopted UN sustainable development goals (SDGs). Current observations show that urban areas account for the main resources consumption and are responsible for about 70% of GHG emissions. With the projected increase of urbanization rate up to 80% by 2050, the pressure on our limited resources and related environmental implications will further increase calling for comprehensive, interdisciplinary and sustainable solutions.

Cities, as centre of urban activities, require innovative solutions to tackle this looming challenge and lead the urban transformation in a sustainable fashion to ensure sustainable cities and communities according to Goal-11 of SDGs taking into consideration Goal-12 tackling the global need for ensuring sustainable consumption and production patterns (UN-SDGs, 2016). To ensure their sustainable development in social, economic and environmental dimensions, cities need to combine economic growth with social equity and environmental congeniality, i.e. a minimum production of wastes (emissions, effluent and solid waste) (UN-Habitat, 2008; Mirakyan and DeGuio, 2013). This leads unavoidably to the integrated concept of minimizing the inputs of materials, water and energy and maximizing their recycling and reuse. The consequence for the city energy system is the successive reduction of the use of fossil fuels to the minimum possible on the way of its full replacement by renewable energies in combination with the substantial improvement of energy efficiency. Important part of this effort is the application of a nexus scheme, that implies among others energy reuse from wastes, wastewater and waste heat[1].

To respond to the interdisciplinary challenge of the ongoing urban transformation, consolidated actions are needed to ensure inclusive and integrated solutions. One of the key aspects in such effort is to ensure access to affordable and clean energy that - in accordance to Goal 7 of SDGs - enables providing reliable and sustainable energy services (like illumination, information processing, thermal comfort, mobility) which drives our intensive and highly concentrated socio-economic activities within cities. Considering its interdependency with other systems, energy system plays a vital role for ensuring sustainable urban development and thus covering the synergies between Goal-7, Goal-11 and Goal-12 (among other SDGs) during the formulation of sustainable urban energy strategies offering a suitable approach to attain energy optimized cities on the way to achieve inclusive and resilient cities.

In fact, the intensive and highly concentrated socio-economic activities within cities offer the opportunity to employ adequate measures of energy saving and harnessing of existing synergies to simulate the final energy demand by consumption sector and energy form and subsequently optimize the energy supply covering the whole energy chains from the energy resources to the final demand level. The sector-wise assessment of urban energy consumption is a very useful first approach to develop long-term energy demand projection and help to formulate urban GHG mitigation and decarbonization strategies. Besides, it serves as a benchmarking for more sophisticated spatio-temporal approaches that take into consideration the spatial distribution of energy consumption (and onsite production) within the city and surrounding areas and thus enable more accurate optimization of energy strategy within an integrated energy-demand-supply analysis[2] (Alhamwi et al., 2017; Arne and Espegren, 2016).

Methodological Approach

This work demonstrates the application of an end-use based bottom-up approach to model the future development of urban energy demand using the model MAED being traditionally used for national and regional energy demand projection. However, with some modifications the model is adaptable for application on an urban region with predefined system boundaries comprising the city and its surrounding peri-urban and rural areas. The applied concept disaggregates the urban energy demand by sector of consumption comprising building (household and service), industry and transportation (Hainoun et al., 2006). As presented in Figure 1 each of those sectors is disaggregated in various sub-sectors following the socio-economic and technological determinants driving the energy consumptions. The different activities in each sub-sector are correlated to specified energy services being covered by the useful energies in 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 ser-

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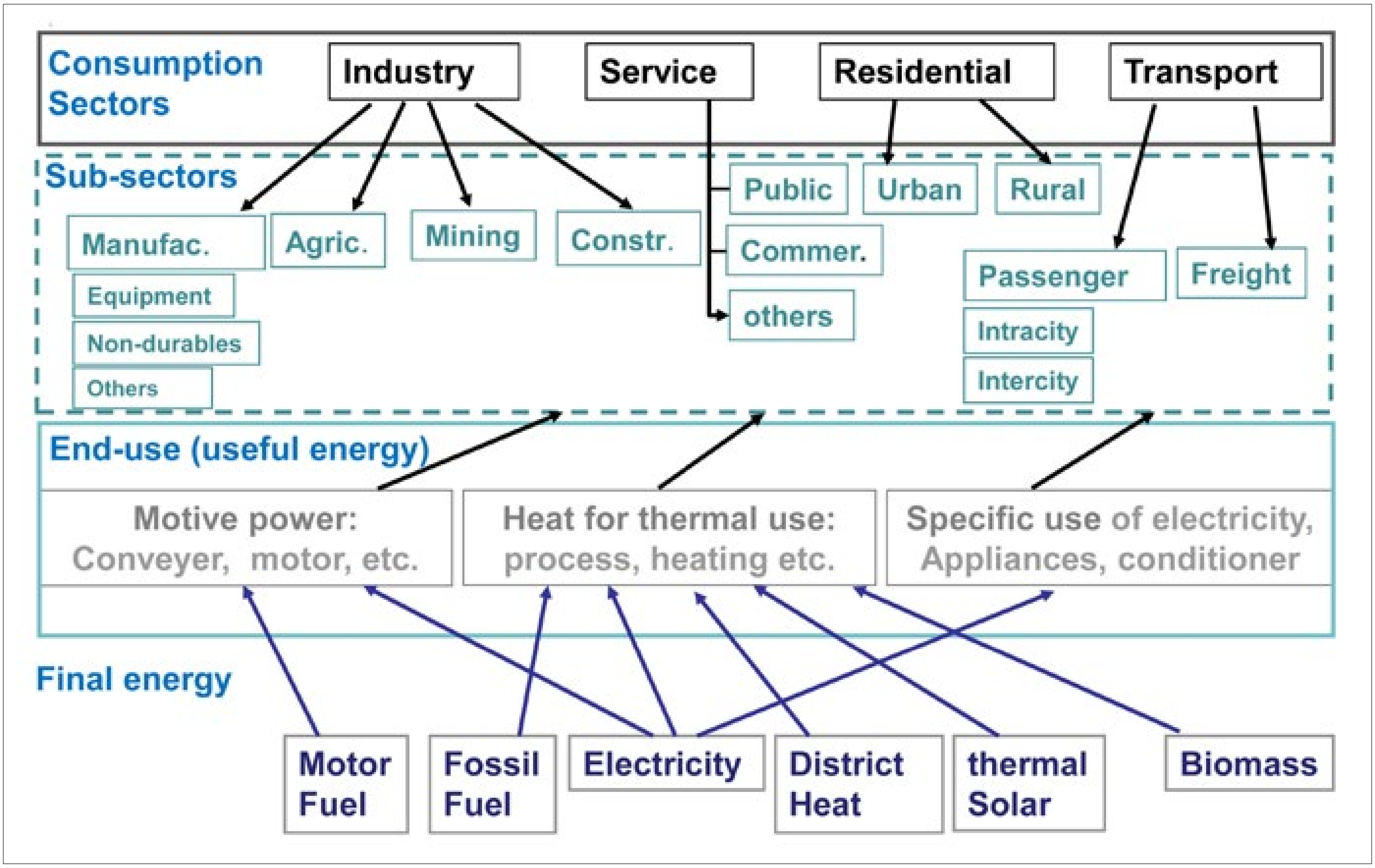

01 | Disaggregation of urban final energy by consumption by sector and energy form

vices and commodities to the social, economic and technological factors driving the demand on a particular fuel. Furthermore, it offers a flexible framework for projecting future trends and anticipating change in energy needs following alternative scenarios of socioeconomic and technological development.

Base year Energy Consumption

The starting point of the energy demand analysis is the defining of a base year reflecting the current energy consumption of the considered urban region. The base year is selected to be as close as possible to the current state and to represent the typical consumption behaviours of the considered urban region. The base year reconstruction implies establishing the mathematical relationships between final energy demand and related demographic, socio-economic and technological drivers. This process comprises the following steps:

1. Disaggregation of final energy demand of the urban region by the end-use categories for the base year 2015 by the consumption sector (household, service, industry, agriculture and transportation) and the useful energy form of heat, motor fuel and electricity for specific uses.
2. Data preparation for current final energy consumptions by sector and fuel type within the considered city-region based on available official data and additional international references. The interaction with the stakeholders via workshop organization and direct communication is essential for data collection, provision and final preparation. Moreover, the stakeholder's involvement is vital for the later stage of scenario development.
3. Identification of demographic, social, economic and technological drivers determining the demand on energy services like population, dwelling size and type, GDP value added of industry and service activities, inter- and intracity mobility of passengers and freights, penetration rate of different fuel carriers and the end-use conversion technologies.
4. Reconstruction of the base year final energy consumptions

by calibrating the established mathematical relationships between energy demand and related demographic, socio-economic and technological drivers.

Future Development Scenarios

Starting from the established base year the future final energy development is projected based on consistent scenarios reflecting the expected long term socio-economic, demographic and technological developments and the official energy policy of the considered city region. The key development parameters -for the conceived urban energy transition- focus on technology and infrastructure transformation related to EE improvement and increased electrification in all consumption sectors, including the shifts in mobility modes and lifestyle changes driven among others by financial incentives and environmental awareness (Fig. 2).
Due to the high uncertainty in developing the driving factors different development scenarios are designed reflecting different development paths of the conceived future vision. Concerning the addressed problem, the scenario is understood as an alternative image of how the future might unfold and thus represents plausible future state of a system resulting from a set of mutually consistent assumptions. Following this approach, the considered sscenarios are constructed to cover plausible range, in which urban future evolution of economy, demography, technology as well social and environmental aspects is expected to lie.
In view of the big amount of required data and the different employed disciplines in designing the future development scenarios, a co-design process is being applied that involves various local stakeholders and urban decision-makers within the development process. Within this analysis two scenarios are considered. Beside the envisaged development trend reflecting the desired sustainable urban energy development along the anticipated urban transformation, a reference development scenario reflecting the business as usual (BAU) trend is developed offering a benchmark basis to evaluate the effectiveness of the assumed optimization and transformation measures of the sustainable urban energy scenario (SUS). Furthermore, SUS should ensure integrating

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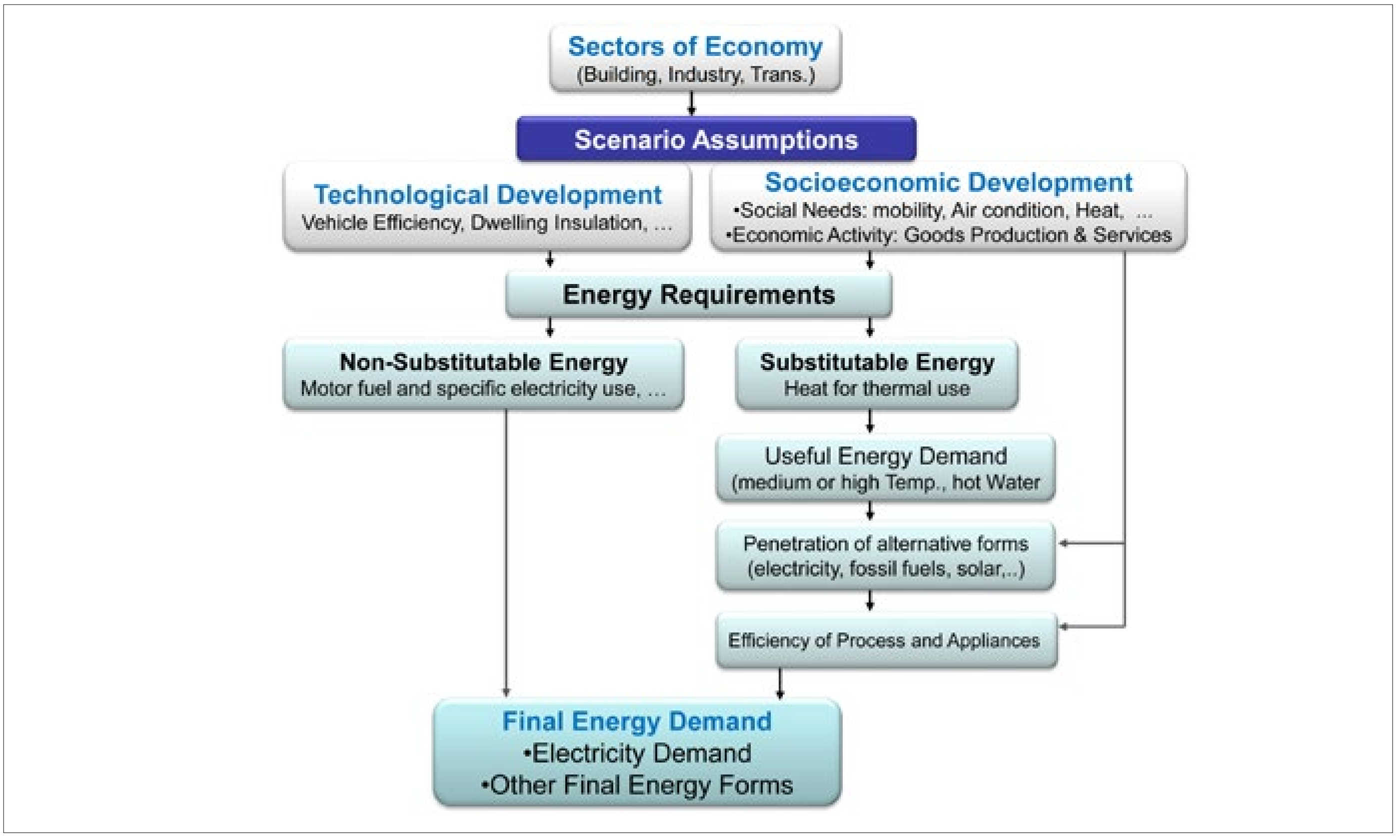

02 | Main steps of designing future development scenarios for final urban energy demand projection

the targets of Goals 7, 11, 12 of UN-SDGs. In a final stage the results of the projected final energy demand are monitored using key performance indicators (KPIs) derived from the indicators of selected SDGs beside the officially adopted energy and urban development strategies of the considered city.

Finally, the achieved results of the developed scenarios should prove to be consistent with the key assumptions and applied policies. This means that the resulting evolution of the energy demand will not lead to questioning the validity of key socio-economic and technological hypothesis of the scenario.

Final Energy Demand Projection of Vienna Region 2015-2050

The above presented approach is being applied as part of the effort to formulate a sustainable energy strategy for the region of Vienna city. Furthermore, the project will comprise the construction of a decarbonization scenario. In the following a description of the Vienna city region and final energy demand for the year 2015 is presented. The information provided, are part of an extensive set of socio-economic, demographic and technological data being under processing to design the base year and formulate the future development scenarios following the concepts described above. Very important is the Vienna energy policy adopted by Vienna City Council on Smart City Wien Framework Strategy 2050.

The results will be published in a later stage subject to further approval by AIT and different stakeholders of Vienna city.

Overview of Vienna City

The City of Vienna, is Austria's Capital with 1.87 million inhabitants, located in the northeastern Austria embedded in a larger functional urban area hosting around 3 million inhabitants[3]. Observing a net-migration of above 20.000 people per year, it is expected that Vienna will reach 2 million inhabitants latest 2025. The elevation range is between 150 and 542 m. Vienna's areal extent is 414 km^2. 50% is green space - forming with the forest areas of the hilly Wienerwald ranging from the West to the North and agricultural areas in the eastern and southern outskirts as well as nature protection areas along the Danube River the green belt around the built-up area. Inside Vienna various small to large parks and the 21-km long Danube Island (an artificial flood protection measure) support this greening strategy. Nevertheless, the green space is not evenly distributed – while the 13th district Hiezing in the southwest has a green space share of 70% while the 8th district Josefstadt near the city centre has a green space share of 1.9%. Vienna is one of the wealthiest regions in the European Union: Its GDP per capita reach EUR 47,700 per capita (2016) which is 159% of the EU average. Vienna constituted 25.7% of Austria's GDP in 2013. With a share of 85.5% the service sector is Vienna's most important economic sector. Industry and commerce have a share of 14.5%. This constitution is essential for the final energy consumption of the city. Within the service sector the tourism industry plays a considerable role hosting 15 million overnight stays and uncounted millions of day tourists. The overnight stays alone sum up to a daily average of around 50,000 people requiring accommodation with food, water and energy.

Energy Demand

Vienna's current annual final energy demand amounts to 36,800 GWh distributed by consumption sector to 30% household, 25% services, 8% by production including agriculture and 37% for transportation. Related secondary energy supply reaches about 40,600 GWh, distributed by fuel type to 36% natural gas, 13% electricity, 1% district heating (requiring solid waste through waste incineration), 11% renewables (biomass, wind), 32% oil products and 4% coal. Vienna's energy supply is like all cities very much depending on imports. 88.2% of the energy supply is imported. 12.8% comes from local sources which are renewables (8.6% - biomass, hydropower) and waste incineration 3.8% comes from reuse of waste heat.

Vienna Energy Policy

Vienna has strict energy policy guidelines:

- Conservation of the environment and resources.
- Rational and economical use of energy.
- Safe, fairly priced and need-based supply.
- Social compatibility and satisfied customers and
- Economic efficiency and competitiveness.

The Vienna City Council has adopted the Smart City Wien Framework Strategy 2050. It is a long-term umbrella strategy that is supposed to establish a conducive, long-term and structural framework in order to reduce carbon dioxide emissions from 3.1 tons per capita to 1 tons per capita by 2050, have 50% of Vienna's gross energy consumption originate from renewable sources and to reduce motorized individual traffic from the current 28% to 15% by 2030. A stated goal is that, by 2050, all vehicles within the municipal boundaries will run without conventional propulsion technologies.

The key stakeholders for the scenario development will be the Energy Planning, MA20 Vienna administration department responsible for energy strategy development, and Wien Energie - Vienna utility company responsible for energy supply.

Conclusion

This work demonstrates the application of an end-use based bottom-up approach to model the future development of urban energy demand following a predefined system boundary comprising the city and its surrounding peri-urban and rural areas. The applied concept disaggregates the urban energy demand by sector of consumption comprising building (household and service), industry and transportation. The sector-wise assessment of urban energy consumption proves to be a very useful first approach to develop long-term energy demand projection and help to formulate urban decarbonization strategies. Besides, it serves as a benchmarking for more sophisticated spatio-temporal approaches that take into consideration the spatial distribution of energy consumption (and onsite production) within the city and surrounding areas and thus enable more accurate optimization of energy strategy within an integrated energy-demand-supply analysis. The presented concept is being applied as part of the effort to formulate a sustainable energy strategy for the region of Vienna city up to the year 2050.

NOTES

[1] This approach is part of an integrated concept being established by AIT to model the urban Energy-Water-Food-Nexus with application on the Vienna urban region.

[2] Along this effort a new modelling framework is being under establishment by AIT to tackle the issue of integrated urban energy system modelling (IUESM).

[3] https://www.wien.gv.at/statistik/pdf/viennainfigures-2017.pdf

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As an urban planner working in the field of smart city development, I support activities optimizing integrated energy and urban planning. The proposed concept within the article "toward energy optimized cities" is in line with this ambition and relevant for urban energy strategies.

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