Integrated Urban-Energy Planning for the Redevelopment of the Berlin-Tegel Airport

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Abstract In order to achieve their sustainable targets, cities are today looking for better solutions for integrating infrastructure systems into their urban planning. A large variety of tools exists for decision support both in energy planning and in city planning, but few of them combine detailed multi-energy modelling and a user-centered collaborative development process in the early phases of an urban project. With the opening of the Berlin Brandenburg Airport, the Berlin-Tegel Airport (Berlin TXL) will be redeveloped as an innovative hub for cutting-edge research and industry under the umbrella of *Berlin TXL – The Urban Tech Republic* (UTR). The European Institute for Energy Research (EIFER), the energy provider

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Electricité de France (EDF), the Department of Urban and Regional Planning (ISR) of the University of Technology Berlin (TU Berlin) and the Drees and Sommer Advanced Building Technologies company for energy design started in 2014 a collaboration with Tegel Projekt GmbH, the agency in charge of the development of the site, in order to unify urban and energy planning for the redevelopment of Berlin TXL. Based on an innovative modelling approach coupling both spatial and multi-energy systems, they developed a simulation prototype illustrating the interrelation between different technologies, land uses, and planning decisions. Several collaborative workshops were conducted as *TU Urban_Labs* led by the TU Berlin in order to integrate relevant actors into the planning process. This paper describes the integrative and collaborative approach developed by the participants to answer the needs and questions of Tegel Projekt GmbH regarding the energy planning of the future redevelopment of Berlin TXL according to the spatial setting.

Keywords Integrated urban energy planning · Local energy system · Multi-energy simulation · Spatial modelling · Design thinking

1 Introduction

Cities are today facing crucial urban and environmental challenges as most of the world population lives in urban areas which generate almost 40 % of the total greenhouse-gases (GHG) emissions. In order to achieve their sustainability objectives, cities are looking for better solutions for integrating their infrastructure systems. A key leverage is seen in integrating energy issues into urban planning at various levels. A large variety of tools exists for decision support related to urban energy systems (Keirstead et al. 2012). Yet, few of them combine spatial and multi-energy modelling in the early phases of an urban development project. In addition, such approaches are often driven by an engineering approach and thus lack a collaborative process to integrate the needs of a wider group of stakeholders and future users or inhabitants.

With the opening of the new Berlin Brandenburg Airport, the Berlin-Tegel Airport (Berlin TXL—495 ha) will be transformed into an innovation hub for cutting-edge research and industry under the umbrella of *Berlin TXL—The Urban Tech Republic* (UTR). The concept combines various advanced urban technologies in energy, mobility, recycling, materials, and water management with information and communication technologies for a smarter and greener district. It aims to host more than 800 companies, a university campus, and research institutes. It is planned to create around 15,000 jobs on site. Tegel Projekt GmbH is the development agency commissioned by the state of Berlin for the management of the site.

The European Institute for Energy Research (EIFER), the energy provider Electricité de France (EDF), the Department of Urban and Regional Planning (ISR) of the University of Technology Berlin (TU Berlin), and the Drees & Sommer Advanced Building Technologies company for energy design started in 2014 a collaboration with the local agency in order to integrate urban and energy planning for the redevelopment of Berlin TXL. Based on an innovative modelling approach coupling both spatial and multi-energy systems, the consortium developed a simulation prototype, illustrating the interrelation between different supply and distribution technologies for heating, cooling and electricity, land uses, and planning decisions. Several collaborative workshops were conducted in the *TU Urban_Labs* format developed at the TU Berlin in order to integrate relevant actors, stakeholders, and domain experts into the planning process. This procedural approach enables participants to tackle the main issues related to the energy concept of the UTR and to visualize the effects of specific hypothesis on the energy demand, energy supply, potentials of use of renewable energy, and environmental impacts such as carbon footprints.

This paper aims to describe the integrative and collaborative approach developed by the consortium to answer the needs and questions of Tegel Projekt GmbH regarding the energy planning for the future redevelopment. The aim is to develop an integrated energy concept including the supply, distribution and storage of heating, cooling, and electricity of the future UTR according to its spatial settings.

2 Research Background

2.1 Interrelation Between Urban and Energy Planning

In the field of climate policy, the urban development planning takes conceptual tasks, e.g., through the development of integrated space-related energy and climate change concepts, together with relevant and appropriate professionals. These include numerous strategies and concepts for a climate-friendly and energy-efficient urban redevelopment by inventory remediation but also through new neighborhoods like *Berlin TXL—The Urban Tech Republic*. Climate protection (e.g., energy efficiency, use of renewable energy sources, and climate-friendly mobility) and adaptation to climate change (e.g., storm water management and greening) taking into account economic, social and building cultural objectives, can only be achieved through integrated and spatial approaches (Städtetag 2011). The importance of integrated approaches for urban planning is furthermore underlined by the IPCC (2014) and the Leipzig Charter on Sustainable European Cities (Leipzig Charta 2007).

As urban planning usually affects the transformation of existing spaces, buildings or usages but also the infrastructural conditions, the goal of widely carbon-free cities should be integrated into the development process of the urban infrastructure and into both urban and energy planning. Urban design plays an important role in the planning of energy-efficient cities. It determines not only the structural configuration of the city as the environment in which residents and users live and feel comfortable, but it also has significant impact on the energy balance of districts.

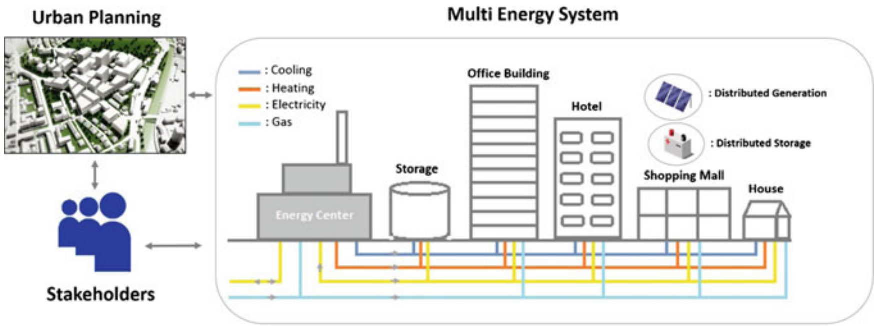

Fig. 1 Illustration of challenges faced by stakeholders regarding urban planning and multi-energy infrastructure (Ge 2015)

Recent studies show indeed that urban form can affect energy demand and production, for instance through exposure to the sun or mixing of uses (Salat 2009; Rode et al. 2014; Daab 2015). Therefore, energy and urban planning in the era of smart and resource-efficient cities are closely interrelated and must be strategically addressed in tandem at the start of any development process (Cajot et al. 2015).

Moreover, urban development processes are accompanied by an increasingly diversified array of stakeholders and demands on urban structures that are ever more complex, as well as interdependencies in almost all areas of planning. This is especially true for overlapping technical infrastructures, which were previously operated independently from one another, and their interactions with the uses of public and private urban spaces. In particular, the development of urban systems under the influence of information and communication technologies, and the resulting ever more compact collection, analysis, and networking of real-time data presents the stakeholders with new challenges (see Fig. 1).

Therefore cooperation between the people who live in the existing space and those who operate the future design as planning is essential. Collaborative planning is understood as a process in which the various actors bring together their knowledge and vision in various different communicative arenas in a process of governance (Lawrence 2000; Healey 2002). It enhances dialogue and communication between stakeholders, leading to consensus building, where planners are not only technical experts but also mediators coordinating the different stakeholders. The early integration of potential investors into the future urban concept then plays a key role. The investment decisions of private players must be involved (Siemens 2009). This cooperation among stakeholders results in a master plan that links up space, the time span of project involvement, and the development of a consistent urban energy infrastructure. The implementation of innovative urban technologies must therefore employ new methods to involve all concerned stakeholders and user groups with regard to urban co-production.

2.2 Existing Tools for Multi-energy System Modelling

In the course of the liberalization and decentralization of urban energy systems, new approaches and tools are required that can map out and visualize these highly interconnected systems (see Fig. 2).

By examining the energy system from a 'bottom-up' perspective, through which the individual as well as the systemic effects of separate objects can be represented, it is possible to analyze the overlapping interactions in the networking and energy sources of subsystems. The multi-energy system approach is an emerging field of research, whose aim is to consider different energy systems (power grids, district heating networks, gas networks, etc.) in a holistic manner, to benefit from the synergies between those systems (Stoyanova et al. 2012).

Several multi-energy system modelling tools have been developed in the last years, which mostly follow two methodologies. The first type of tools are made for specific studies (for example, integration of renewables in the mix or design of stand-alone energy systems), for which the technology mix is optimized for given energy demands (e.g., H2RES (Krajačić et al. 2009)). They are mainly used during the design phase of urban projects, and are often industrialized. However, they often do not consider land use nor using any Geographic Information Systems (GIS) and are very specific. Therefore they are hardly usable at the early phase of urban planning projects to integrate urban and energy planning. On the contrary, the second type of tools are foreseen to be used at early stages of urban planning by urban planners and decision-makers (e.g., EnerGIS (Girardin et al. 2010) or

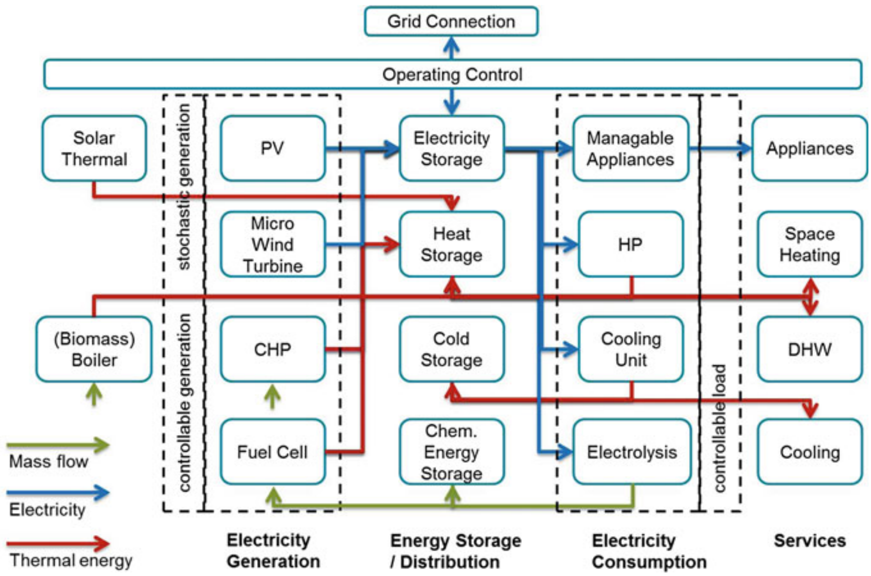

Fig. 2 Connected system components of a multi-energy system (Bahu et al. 2014)

SynCity (Keirstead et al. 2010)). They model the land use, the demand side, and the supply side of urban energy systems, and can support different types of studies.

EIFER has developed simulation approaches and methods in this field that are used to address various issues in the areas of smart grids and/or hybrid systems. Initially, an agent-based approach was proposed to the topic of smart grids, which show a large degree of heterogeneous components interacting with each other, while ensuring stability and efficiency in operation of the system. The agent-based simulation approach enabled individual representation of the various elements of the system (Kremers 2013), while coupling them and replicating them, leading to massive simulations of such complex systems. In Evora et al. (2012), an island power system with a large amount of hybrid PV and battery units at household level was represented and simulated for a period of 1 year, to test operation strategies for massive systems. The approach was then extended to include heat technologies towards the goal of being able to represent multi-energy systems in the same way. This concept is proposed in Gonzalez de Durana et al. (2014), as a technology independent, scalable, and easily extensible approach, through the use of so-called multi-carrier energy hubs. In Oldenburg et al. (2013), it was first applied to a city by implementing the energy concept at an early-phase masterplan for providing an hourly step model based on spatially-adapted load and generation profiles.

Such a shift towards intelligent multi-energy systems reflects current challenges posed by the ambitious targets of integrating high shares of renewable energies in many European countries. These strategies, which are consequently implemented at the local scale, require an increased share of flexible capacity in the electricity grid to accommodate fluctuating loads. Flexible thermal energy needs associated with electricity generation (e.g., cogeneration) or electricity use (e.g., heat pumps) have widely been identified as such additional flexibility measures (IEA 2014). By developing multi-energy system simulation methods, EIFER is looking towards tackling these challenges and considering them within the framework of a wider approach targeting closer integration of urban and energy planning.

3 Methodology

The research project approach follows two major aspects, both triggering a reciprocal update (see Fig. 3). First a digital application was iteratively designed for modelling energy demand, supply, distribution, and storage of the future UTR's urban infrastructure and for evaluating interactions between various technologies and planning decisions. The second crucial component of the project was the Urban Design Thinking Workshop process. As part of the *TU Urban_Lab*, this moderation process ensured the early involvement of stakeholders from industry, academia, and municipal bodies in the updating and refinement of the energy system model, and served to enhance preparations for planning decisions.

In the future, the redevelopment of the Berlin TXL site should use efficient and innovative infrastructure systems in the areas of electricity, heating, and cooling,

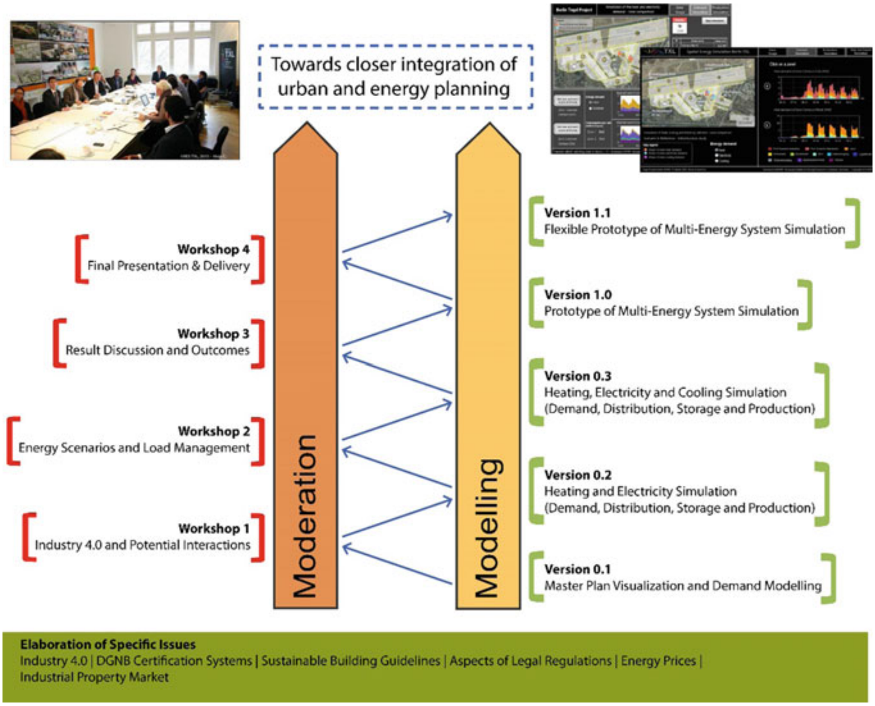

Fig. 3 The research project includes two main aspects: modelling and moderation

among others. The implementation of these new infrastructures requires the foresight to anticipate future needs in order to evaluate the effectiveness and efficiency of different decisions. Therefore EIFER developed an integrated a spatial energy system model within which the interactions of different urban technologies, uses, and planning decisions (e.g., energy efficiency measures) could be visualized and evaluated. Building on the requirements established during the planning (e.g., the masterplan, the infrastructure study conducted by Drees & Sommer, and other investigations), a simulation prototype specifically related to the UTR's future concept was iteratively developed by EIFER (see Fig. 3). Specific load profiles that could visualize future uses were developed by Drees & Sommer. The final simulation prototype is a stand-alone application that can be run on various devices.

By using prototyping and an iterative development process, the risks of missing targets in the implementation are reduced (Eberlinger and Ramge 2014). To this end, the Urban Design Thinking approach currently under development at the *TU Urban_Lab* relies on Design Thinking (Brown 2008, 2009), a method tried and tested in product development, and takes it further to develop a cooperative approach for urban development and transformation processes. The interplay between infrastructure systems and urban spaces can be mapped early on, and throughout the entire process, in order to iteratively adapt the development concepts based on the respective results.

4 Results

The Urban Design Thinking process, together with multi-energy system simulation prototyping, provided several strong value-added results.

Through a series of moderated workshops, a wide range of stakeholders from planning, energy, real estate, and various associations have been involved with the aim to advance development of the energy simulation prototype for the UTR (see Fig. 4).

The *TU Urban_Lab* served as a platform for incorporating the user perspective as well as furthering the development of specifications for the spatial energy model through dialogue between all involved stakeholders. By following the Urban Design Thinking method, the participation and interaction of the stakeholders incorporates three key points:

- *User-centered*: The evolution of urban development and transformation processes is conducted from the outset with the continuous involvement of future users, as is especially the case with Tegel Projekt GmbH. The aim is to produce innovations that are concentrated on the user and so satisfy their needs. To ensure this, the method draws on practices from the design area, which explicitly operates in a user-oriented way;
- *Stakeholder engagement*: The involvement of a large number of stakeholders in the project development enables not only that different views, interests, and approaches be taken into account. This also ensures a stronger focus on the implementation of transformation and infrastructure projects. At the time of implementing the research project, only the Beuth University of Technology had definitely decided to locate its operations in the UTR. Also the operators of technical infrastructure were not yet determined. The stakeholder participation

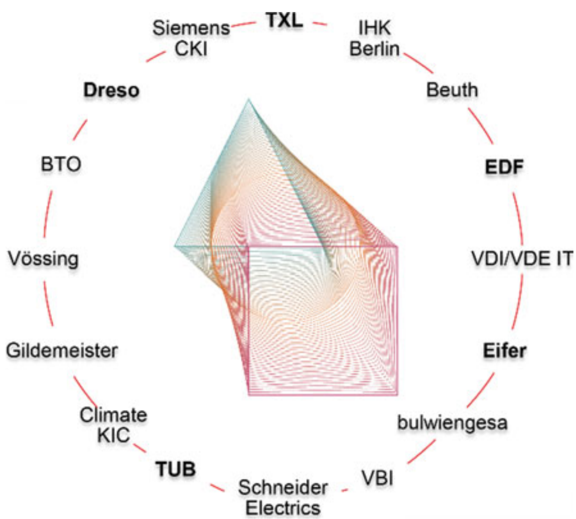

Fig. 4 Urban coproduction by collaboration of stakeholders from community, science, and economy

therefore relied on representative or exemplary organizations and existing partners. This brought experiences, concrete characteristics, and requirements of comparable projects into the research project;
- *Prototyping*: The consistent development of digital and physical prototypes enables the developed concepts to be assessed based on effectiveness and efficiency. The verification of concepts, processes, and products by building prototypes reduces the risks that user-optimized solutions will be missed, with the consequence of high costs and loss of time.

The Urban Design Thinking process is not linear, but runs rather in iterative loops of acceptance, implementation, testing, and adaptation. With specific questions from the modelers (e.g., about the energy scenario or load management) and numerous feedbacks from the relevant stakeholders, it was possible to collect reliable data and assumptions for the successful development of the simulation prototype (see Fig. 3). For example, the model has been extended so that the cooling energy demand and supply components and the simultaneity factors of the load profiles can be adjusted. Based on the spatial energy model, the simulation prototype has been continuously updated and refined to make the project's approaches to problem solving easier to experience and comprehend.

Simulation and mediation are the two pillars of the method that leads to better integration of urban and energy planning, in terms of involvement of stakeholders, goal definition, and shared knowledge on the project (see Fig. 3). Only through the use of the dialogic format were planners and modelers able to collect initial assumptions in the pilot project phase in order to test and adjust them with the aid of the tools under development and then to refine the energy concept (for instance, regarding the on-site potential for renewable energy generation). In direct exchange with the representatives of Tegel Projekt GmbH, the final prototype matched with the requirements of the UTR.

As energy planning is not only dependent on purely technical components, the structural and energy potential, as well as challenges, should be reviewed against the backdrop of prevailing concepts such as industry 4.0 developments. Industry 4.0 is characterized by a strong customization of the products under conditions of highly-flexible production with high volumes (BMBF 2013, 2015). New forms of production with a high degree of automation can possibly enable various different neighborhoods of uses in the future. Housing and production can again be spatially compatible so as to expect diminished emissions. The interactions between urban and typological measures (e.g., spatial settings, distribution of uses, or types of industry) and their influence on energy efficiency, load curves, or energy supply have emerged as key factors. Furthermore, the achievement of a set objectives in the field of energy-efficient measures strongly depends on the opportunities presented by legal regulations and requirements. Therefore the control and steering possibilities that arise from the legal framework (e.g., planning legislation, urban development contracts, etc.) were investigated and passed on as a recommendation for action to Tegel Projekt GmbH.

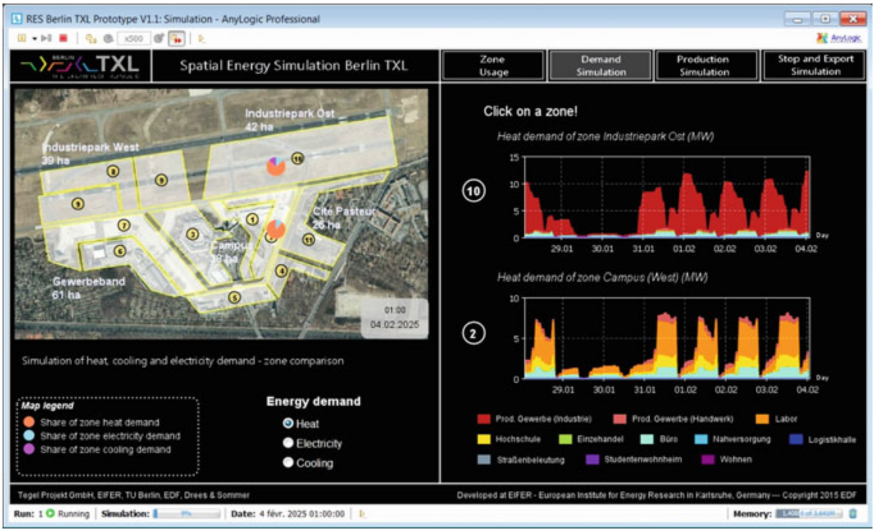

Fig. 5 User interface simulation: calculation of the hourly heat demand in selected construction zones

The spatial simulation of thermal (heating and cooling) and electrical load curves enables the user to select different planning scenarios and to visualize their impacts on the hourly energy demand and supply. In the pilot phase, various scenarios were defined according to the variation in the energy efficiency percentage (i.e., the proportion of decrease in energy demand) or in the share of renewable energy sources installed on-site. The simulation maps indicate zoning and display the system-wide effects of customized planning measures in response to mixed-use and infrastructure planning parameters (see Fig. 5).

Furthermore, these effects were evaluated based on Key Performance Indicators (KPIs) defined during the workshops (e.g., global final and primary energy use, GHG emissions, and share of renewable energy source in the heat or the electricity on-site production—see Fig. 6). The design of the interface was specifically adapted according to the requests of Tegel Projekt GmbH.

The prototype developed serves a dual purpose. As shown by the user-centered development process, the first purpose is to benefit the communication of the innovative energy concept planned for the UTR. According to the needs revealed by the review of existing multi-energy simulation tools for energy planning, the second purpose is the creation of an entirely holistic modelling and simulation approach through the summary of the already completed studies in the field of energy supply and hour-by-hour resolutions, raising then new issues concerning the networking core of the individual systems.

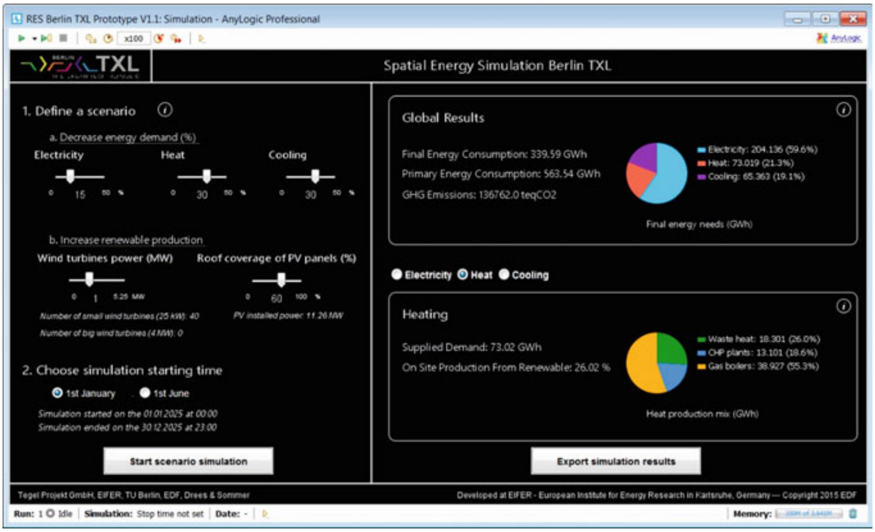

Fig. 6 User interface simulation: analysis of the simulation results based on KPIs

5 Discussion and Outlooks

Based on these different results, the research project contributes to strengthen the integration of urban and energy planning.

Through the Urban Design Thinking process, Tegel Projekt GmbH and relevant stakeholders were early integrated into the planning process. This gave the opportunity for participants to tackle the main issues related to the energy concept of the UTR and to visualize the effects of specific hypothesis on the energy demand and supply. This facilitates an early assessment of the impact of planning decisions made by planners and participating stakeholders. Thus, the iterative process enabled the definition of the specifications for the simulation prototype and the refinement of the energy concept of the UTR.

The simulation prototype provides Tegel Projekt GmbH both with decision support at an early stage and a means of communication for its development strategy. Thus, the continuous monitoring of the planning process via the spatially integrated energy system model enables:

- The visualization of interactions between energy and urban development settings;
- The simulation and visualization of energy flows for different construction sites depending on a variety of assumed uses;

- The scalable adjustment of demand and local generation of electricity, heating, and cooling;
- The observation and evaluation of different scales—ranging from the district level to specific buildings.

The visualization of the simulation results is, in turn, itself a means to communicate adjustments in the development strategy and, as such, serves as a basis for fashioning an integrated energy system model for the UTR site. The presentation of results in various levels of aggregation especially enabled to the examination of KPIs and their relevance with regard to urban planning.

Based on the ongoing development, further issues are discussed with workshop participants in order to create specifications for further development and research. Future applications should decrease the delay of model development with the objective of implementing the discussed strategies immediately in the context of ongoing *TU Urban_Lab* workshops and thus result in a real-time feedback supporting stakeholder discussions. Further issues that can be resolved using the model approach include, for example, operator models for hybrid systems as well as the integration of other technologies. In particular, geothermal energy and the intelligent use of storage technologies are discussed in the workshops. Based on the system components presented in Fig. 2, a variety of applications in an urban setting are possible. Thanks to the modular approach, the model can also be applied to other applications.

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