DESENT: Smart Decision Support System for Urban Energy and Transportation

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1 ABSTRACT

The focus of this paper is on the DESENT project, which aims to develop, test and disseminate a comprehensive decision support system for smart energy and transport in cities. Transport energy consumption modelling, building supply and energy demand tools are combined to provide a common decision support system for appraisal of city-wide energy use. The system will be set up as planning toolbox that consists of several models and tools providing different functionalities to show actual data for energy demand and transport energy demand and furthermore allow to predict the energy demand on building and city level for future planning scenarios. Thus, the relationships between sustainability objectives, transport, spatial design of the built environment and rational use of energy are considered.

The paper describes the concept and structure of the planning toolbox and its models and tools developed so far. Furthermore, it outlines methodologies developed and the data acquisition process for the city of Weiz, which serves as one of the pilot cities in the project.

Keywords: energy demand prediction, smart city development, transport energy demand, uncertain supply, optimal energy distribution

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2 INTRODUCTION

The design of living spaces with a high quality of life is one of the core challenges of the 21st century, a century of urbanisation and rural exodus, the use of information and communication technology in almost all areas as well as the change of the demographic structure, especially in European society (Calvillo, C., et al, 2016) (Eremia, M., et al 2017). In this context one of the most important factors of government policy is security of energy supply (Brown, M.H., 2001). Therefore, concerns such as growing energy demands, limitations of fossil fuels and threats of CO2 emission and continuous climate change underpin the high demand for resource conservation and resilience in urban areas.

Today approximately 50 % of all people worldwide live in cities (for Europe it's almost 75 % of the total population) (Kotzeva, M., et al., 2016) (European Commision, 2012), and by 2050 an increase to 70 % is predicted. Urban regions are focal points of resource consumption and emissions - in Europe around 80 % of energy is used in urban areas (Nabielek, K. et al, 2016) and in 2050 cities will be responsible for 75 % of global carbon emissions (Lufkin, B., 2017). Thus, cities will in future define the need for space and infrastructure, products and services (Obernosterer, R., et al., 2012), (Grimm, N., et al.,2008), (Hammer, S., et al., 2011). As a result, the conservation of energy resources must primarily start in the cities and consider all levels of energy planning, including also the areas of spatial planning, building stock and transport, as well as the areas of economy, society, politics and administration to gain high acceptance. This will help raise awareness among the public, and in particular among different stakeholders, that are willing to invest in resource-efficient technologies and be a success factor for the "city of the future" (Chourabi, H. et al., 2012).

The design of urban areas has a significant bearing on the balance of building and transport energy use, which are the two sectors that are directly affected by urban planning (Steemers, 2003). City planning knows a wide variety of key figures that characterise neighbourhoods, districts and cities. However, which of these figures describe a city with future potential, a "city of the future", cannot be clearly defined. As a rule, urban typologies are captured in terms of their resource efficiency through quantitative values (e.g., land use, energy measures, density metrics). Although key figures regarding certain properties of urban areas allow first conclusions about resource efficiency, they do not give a complete picture without considering the user behaviour. Thus, the key elements of urban energy systems are (1) land use and activity location, (2) use pattern (peoples' behaviour), (3) built environment (buildings and transport) and (4) supply technologies and fuel (Keirstead, J. 2010).

So far, studies and models have dealt with future effects and optimisation potentials, e.g. for energy savings individually for the building, transport and energy sector (Keirstead, J. 2010) (Hegger, M. et al., 2012). There also have been multiple efforts to develop tools for urban energy systems modelling. These include for example GIS based tools for estimating the spatial pattern of energy requirements in an urban area (Girarding, L., et al 2008), or a model for the optimisation of flexibilisation technologies in urban areas (Alhamwi, A., 2017). Moreover, a model assessing the interactions of heat demand and locally available heat sources (Mori, Y., 2007), an open tool (called TEASER) for urban energy modelling of building stocks, (Remmen, P., 2018) or a model combining demand estimation with an energy-management optimisation module (Brownsword, R.A., 2005). While these applications are quite diverse, they demonstrate two important features of existing urban energy system models (Keirstead, J. 2009).

- First, such models must include a representation of the spatial and temporal variation of urban energy demand. This can lead to significant input requirements, e.g. in form of GIS data or building design information specifications, but building up the urban system from individual components allows the aggregate effects of small changes to be assessed more readily.
- Second, these models seek to explore both the supply and demand sides of urban energy use, for example by optimising provision strategies.

However, in addition to these positive characteristics, these examples also show that current practice consists largely of detailed models built for the assessment of a single aspect of existing systems. This means that these tools have limited applicability beyond the specific problem case, increasing the resources required for data collection and validation in new contexts. Furthermore, they are unable to offer a truly integrated perspective on urban energy use across all sectors and stages of the design process.

Furthermore, the increase of renewable sources for electrical and thermal energy generation will require flexible and secure supply systems (Remmen, P., 2018). In spite of the fast development of new energy solutions, current predictions of energy consumption leave much room for improvement and a sophisticated approach is required to develop smart solutions (Keirstead, J., 2009). Linking energy demand of buildings with the energy consumption for transport can be difficult as the energy consumption occurs at different times and places. An integrated decision support tool needs to consider an activity-based approach with a special emphasis on individual consumers' daily activities and trips (Arentze, T.A. & Timmermans, H.J.P, 2005). This allows to trace individual consumer's activity-travel behaviour and gives the chance to predict the energy consumption in time and space. Only thus, a holistic decision support system can provide detailed knowledge about when and where people consume energy and moreover enables to predict future energy demand based on different scenarios. Thus, the development of models that can reduce uncertainties regarding future energy demand / supply and furthermore support decision making in sustainable urban energy planning are crucial for (smart) cities.

3 DESENT PROJECT

The overall goal of the project DESENT is to develop and test a comprehensive decision support system for energy and transportation in small and medium-sized cities, that are showing a will to carry out energy plans and achieve ambitious climate goals. The specific objectives of the project are to

- create models for future energy consumption prediction at building level in different types of buildings and for transport,
- develop an integrated framework for dynamic building energy simulation at the district level,
- investigate how the developed planning tool can reduce the uncertainty on energy demand predictions and how it leads to improved energy infrastructure / service provision decisions,
- integrate the developed models into state-of-the-art simulation tools, in order to develop enhanced decision support systems which provides scientific evidence in support of policy options,
- investigate the effects of the products and services enabled by the integration of personal transportation, building energy and power services;
- test/implement the models and tools, demonstrate and evaluate the capabilities of the tools through the case studies in several demo cities.

Regarding the last point, the Austrian town Weiz near Graz, with about 11,300 inhabitants is involed as one of the three pilot cities within the project.

DESENT will aim at developing a practicable ICT solution, which will accelerate the spread of the integrated real-time transport and building energy monitoring. The planning toolbox developed will help companies and governments understand energy use behaviour and customer responses to different policies. It will capture the behavioural adaption of customers at a microscopic scale. A continuous observation of energy consumption and user responses will provide more insights into the specific roles and interactions of and between various stakeholders.

4 METHODOLOGY AND DATA ACQUISITION

During the project different programs and tools (based on Excel, MATLAB, ArcGis etc.) will be developed and merged into a comprehensive planning toolbox for descision making regarding the energy system (on building and district level) for a short- and long-term perspective.

The modular designed planning toolbox provides data that will be integrated into a geographical information system (GIS) for the analysis and evaluation of different future energy and transport policies. To predict the energy demand and transport energy demand the toolbox comprises different models on the level of single users, buildings and the overall system (city) - see Figure 1.

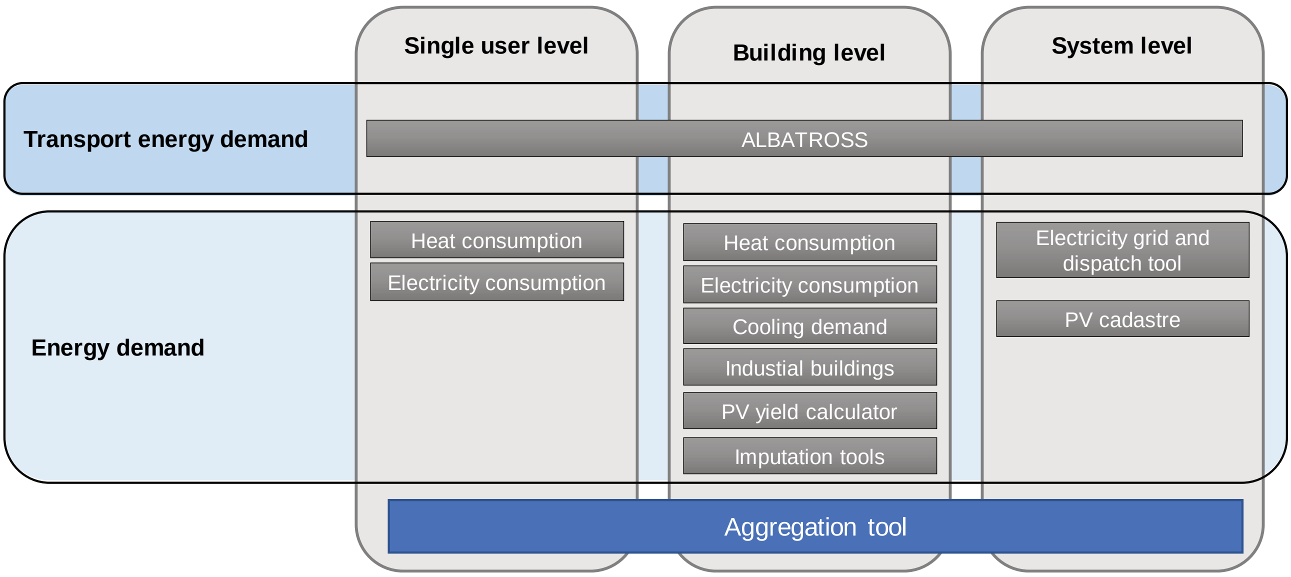

Fig. 1: Models and tools on single user, building and system level

Since testing of the support systems is a core part of the project, the city of Weiz (Austria) played a major role in the discussion of the charactaristics and functionalities of the models and tools. This also translates to the data required and furthermore provided by the tools as well as the benefits and results for different target groups/stakeholders. Based on this involvement a consensus on the structure, elements and features of the toolbox could be achieved. The models and tools rely heavily on the data provided. As such the quality of the data considered is of major importance. Further steps included the agreement on the interfaces between the tools on single-user, building as well as on system level. As part of the agreement process the necessary parameters for the tools were defined. To ensure the efficient interaction between the different tools, the data format of the tools, based on the available data, was unified.

4.1 Transport energy demand

4.1.1 Description of model

For the prediction of the transport energy demand an agent based simulation model, called Albatross, will be used. Three different versions of the model have been developed between 2000 and 2010.The first version of Albatross is a prototype of the model, examing the feasibility of key theoretical ideas and modeling approach (Arentze T.A., & Timmermans, H.J.P, 2000). The second version addressed the limitations of Albatross I and developed an approach to intergrate the stated choice models with the system. It also rederived the decision tables for a large national travel survey in the Netherlands (Arentze T.A., & Timmermans, H.J.P, 2005, 2007). Albatross III updated the decision trees with new datasets (Arentze T.A., & Timmermans, H.J.P, 2007). It more systematically redesigned decision tables about task and resource allocation.

In this project, Albatross III will be extended but less focused on the theoretical development and more on applying the model at city level. The Albatross has been extended to predict the energy demand of travel behaviour at individual level for a certain city. It includes the following three extentions.

(1) First, to reflect the possibilities of including new mobility options that have been / will be introduced in the market. Therefore, the set of transport modes that is included in the travel demand forecasting model has been expanded. The car options are now differentiated according to engine type (gasoline, diesel, hybrid, electric) to make Albatross more sensitive to differences in energy consumption and emissions.

(2) Second, to mitigate the pollution and energy consumption problem caused by conventional vehicles, it is important to predict the market penetration of new mobility tools. A stated adaptation model has been built to predict social acceptance of new technology for smart energy use, which refer to electric vehicles, car sharing and E-bike. A pivoted stated choice experiment was designed to capture the decision among car sharing, E-bike and electrical car considering life events impacts. Heterogenous behaviour across respondents in the decision-making process regarding the trade-off between shared and conventional mobility, respective to electric cars is observed. This model will be integrated into the Albatross for predicting individual energy consumption for travel by different transport modes.

(3) Third, the current version of Albatross only predicted movement based on a four-digit postcode. To predict spatial distribution energy consumption and emission by transport in a city, a traffic assignment model is needed in order to obtain the information of traffic flow on road segments. It compromises the microscopic energy consumption prediction. The activity-travel demand, which is generated using the model based on the synthesised population in demonstration cities, will be assigned on the road networks. The transport energy demand will be predicted, based on the assigned traffic flow and the energy consumption model.

The enhanced model will provide consistent information on the time use of individuals for activities and trips, which serves as information source for energy consumption prediction for transport on building level.

4.1.2 Required information and data gathering

To obtain the data required for the transportation model a two-fold strategy was implemented: On the one hand a mobility questionnaire was prepared with the aim to understand people’s energy consumption behaviour and the acceptance of households to use new energy facility and transport technologies. The survey thus involves questions about household characteristics, housing situation, availability of transport mode, life trajectory as well as attitudes and perceptions. For the prediction of the energy demand for transport based on the predicted activity-travel agenda, moreover road network data, population data and national travel survey data has been collected. On the other hand, travelling data for the micro-simulation-model will be collected by using a mobility app that allows to collect GPS-data of users.

4.2 Energy demand on single-user and building level

4.2.1 Description of tools

The main objective of the tools for the energy demand on single user and building level is to provide qualitative and quantitative information on the demand of energy services in different types of buildings. Specific objectives are (1) to develop an integrated model for dynamic building simulation that enables analyses of the energy demand in buildings and analyses of demand flexibility on basis of real time data and (2) to develop a model to predict energy demand of buildings in case of missing data. At this stage of the project real time data doesn't refer to the energy consumption in real time, but rather to real energy consumption data, e.g. the actual fuel consumption per year. In a further step it is planned to extend the tools by integrating real time values (load profile data).

Thus, the following different tools to analyse and predict/estimate the energy consumption in buildings have been developed:

- Tool Heat consumption:

The tool shows the buildings requirement for thermal heat incl. the amount of heat required for hot water and compares the data with benchmarks. It calculates the heating costs as well as the CO2-emissions of the different buildings.

- Tool Electricity consumption:

The tool shows the buildings requirement for electricity incl. the amount of electricity required for hot water and compares the data with benchmarks. It calculates the electricity costs as well as the CO_2 emissions of the different buildings.

- Tool Cooling demand:

The tool shows the buildings requirement for cooling and compares the data with benchmarks. It calculates the cooling costs as well as the CO_2 emissions of the different buildings.

- Tool PV-Yield calculator:

The tool aims at a user-friendly and validated program for different user groups. The tool determines the annual feed-in energy as accurately as possible for grid-connected PV-systems and allows a quick and precise estimation of the expected solar yield at a specific location. Based on the electricity consumption and load profiles of different building types, the tool can be used to determine the optimum design for PV systems on building level.

- Tool Industrial buildings:

The tool shows the energy consumption, based on actual consumption data to integrate the energy consumption of the building into the "Aggregation tool". It isn´t possible to predict the energy demand in all types of buildings only based on calculations. There are benchmark values for different types of buildings, but most of them refer to the total energy consumption, and the waste heat potential is rarely examined. Especially for commercial as well as industrial buildings realistic predictions without measuring the energy flows are practically impossible. The tool aims to find an easy and economical way to integrate the quality and quantity of the demand of energy services in buildings, where the energy demand cannot be assessed with the aid of the other tools.

Furthermore, different Imputation tools will be implemented that aim to complete missing data based on the ratio between existing data and statistical data e.g. missing information about the year of construction of a certain building. The usage of these tools requires a standardised address code of each building, to ensure that all existing input-data at the end of the calculation are linked to the original building. Missing data are not ignored or replaced by random data, but rather an attempt is made to replace them with plausible values.

4.2.2 Required information and data gathering

For the above described tools, the different types of buildings to be examined (single family houses, apartment buildings, multi-storey buildings, office buildings, supermarkets, schools, hotels, hospitals, industrial and other buildings) were specified, and the relevant data for these tools were defined. It was determined, that the calculations will be done on the basis of actual data (for the city of Weiz the main data

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source is the GWR[1]), or, if no data is available, assumptions (based on statistical values) within the tools will provide the required results. Where corresponding data was obtained, these data were validated and integrated into the tools. In addition to the assessment of the energy- and CO_2 emissions in individual buildings the results of the various tools are integrated into the "Aggregation tool" which is used for the functionality of investigating the effects of future developments within a city.

4.3 Energy demand on system level

The main objective of the tools for the energy demand on system level is to develop a dynamic model for optimisation and operation analysis of distributed energy infrastructure at district level. Specific objectives are (1) to simulate the interaction between grid operators, users and local infrastructure, (2) to investigate how improved predictions on the demand side will reduce the uncertainty and (3) to specify in which way improved energy demand prediction leads to improved energy dispatch. Therefore, the following tools will be developed.

4.3.1 Electricity grid and dispatch tool

The purpose of the electricity grid and dispatch tool is in a first step to calculate the strain on the distribution grid considered. Taking consumption and generation into account the tool can facilitate both a DC and an AC-loadflow (Zimmermann, R.D. et al, 2011) calculation scheme. The grid tool will be used to define whether the local electricity grid is capable of handling changes in the structure of the system, such as increases in PV-capacity, additional e-mobility, more electrical power to heat components. The tool is capable of doing both, single time-step calculations and multi-time-step calculations regardless of the given resolution of data. When it comes to using loadflow calculation the quality of data is very important, this refers to both the grid data itself as to the data about consumption and generation.

In a second step the tool will be extended by an electricity dispatch tool that will enable the user to add information on the development and changes in the energy system. Through the input of these changes and developments the tool will be able to calculate the effects which occur as a result from these inputs. With this information at hand, the future dispatch of energy can be planned.

For the grid in Weiz detailed grid data was not obtainable, only a digitalised map of the distribution grid corridors is available. Using GIS to reference the different lines and by using avaiblabe statistical data on line types in distribution grids, a surrogate grid was created. For obtaining the data for consumption and generation, the aforementioned tools will be used to create load profiles where measurements are not available. The resulting loadflows will, in the case of Weiz, thus only be an estimation.

4.3.2 PV-cadastre

This tool aims at identifying suitable surfaces in urban areas for the installation of solar photovoltaic panels (PV-panels) and should give an overview on the photovoltaic potential in the city. The calculations are based on the building stock data, as only on-roof systems will be considered. Thus, the surface area, the orientation and inclination of the building's roofs are the basis to perform the calculations. Furthermore, the solar radiation data must be collected. The tool calculates (and maps) the potential at district and city level and furthermore allows on the one hand public bodies (municipalities, local authorities) to integrate energy spatial planning in their policies and on the other hand, the grid operators to assess how much PV could be installed at secondary and primary cabin level. The main important datasets for the city of Weiz are the cadastre map, the Solardachkataster Steiermark and the solar radiation data (Kreuzer, B., 2016).

4.4 Aggregation tool

The Aggregation tool will combine all results and enables to predict future demand for various scenarios. This tool aims at collecting all the available data and calculating the required results by calling up the different tools on building level. In addition, the results will be aggregated on different resolution levels, depending on who the user is. Currently the resolutions (1) pin-point (building level), (2) block of buildings, (3) district and (4) city are being implemented. Through this aggregation tool the energy demand side will be

[1] Gebäude- und Wohnungsregister (GWR) is operated by Statistik Austria and contains site and building specific information of a municipality/city e.g. address of site, buildings, building data (year of construction, surface area, etc.) and information on construction measures.

depicted and all current information on energy demand will be made visible. Through the modular approach and the unified data interfaces, the aggregation tool can easily be modified for different cities.

5 SMART DECISION SUPPORT SYSTEM FOR URBAN ENERGY AND TRANSPORTATION

The objective of the decision support system is to assist city representatives and administrators enhance the efficiency of the energy supply while improving environmental indicators. The planning toolbox will fulfil the following functionalities that can be summed up into three stages, providing different results and insights:

(1) STEP 1 Acquisition of the current status: The goal of this step is to provide the current status of energy and transport demand for different spatial resolutions (single user, building and city level). Missing data will be imputed based on existing values and statistics. This step thus provides the necessary information on single user basis that should inform citizens about their energy performance via the usage of an app (currently under development). In addition, on district or city level, based on the existing infrastructure, analyses regarding the actual energy demand, fuel type used, CO_2 emissions, etc. of the city can be performed. This information will allow to highlight areas within the city, which are the most relevant contributors to the variable considered. This will furthermore enable city planners and developers to locate targets better for future changes in the city.

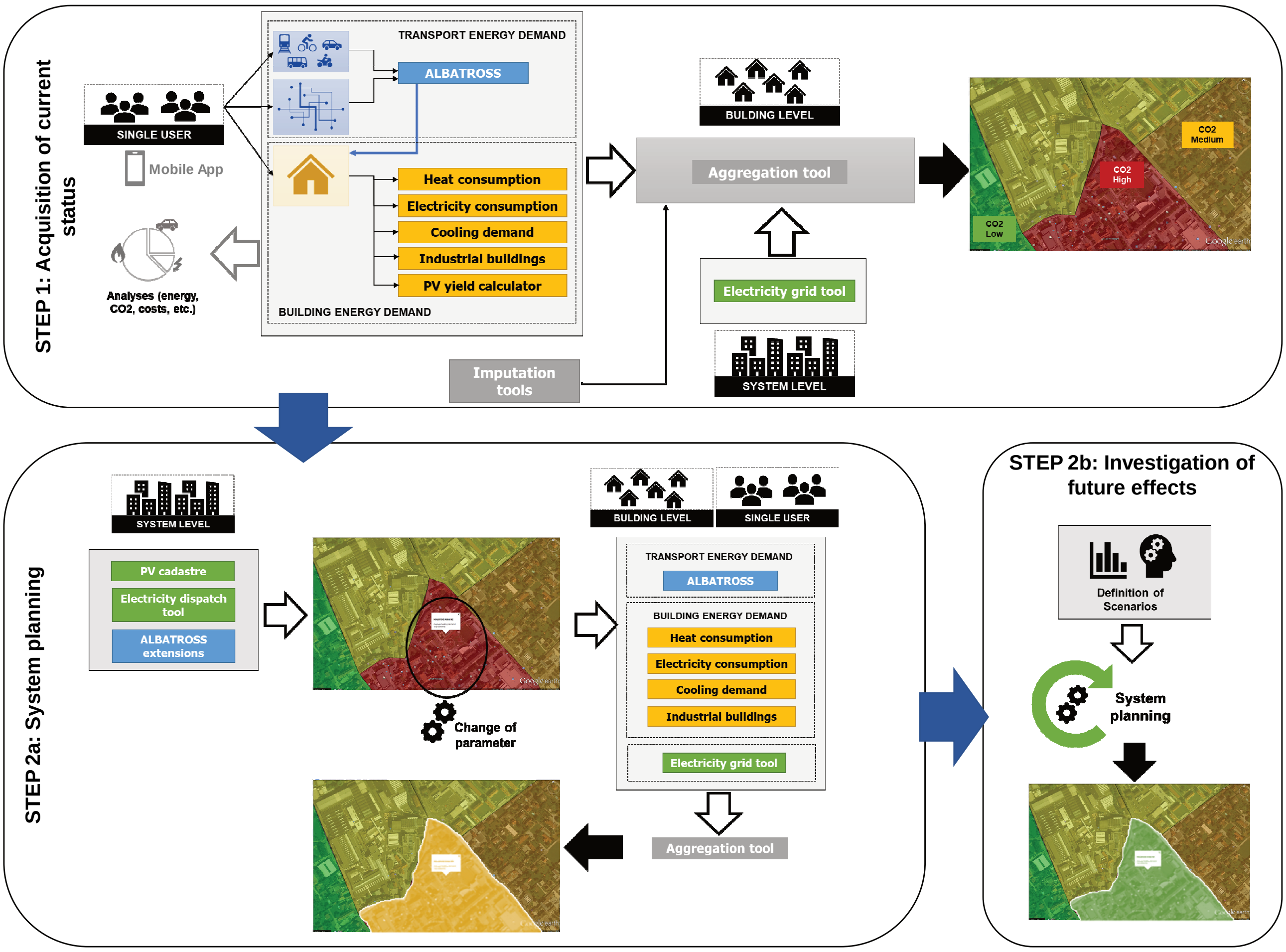

Fig. 2: Structure and functioning of the “DESENT planning toolbox”

(2) STEP 2a System planning: Adapting the system to reach future climate/energy/city goals is challenging as changes in the system need to be directed at those stakeholders which cause a “problem” in the first place. For instance, if CO_2 emissions through heating need to be reduced, one needs to know who is responsible for the emissions. This information is obtained in STEP 1. In STEP 2a this information is used and the effects of changing certain system parameters for these initial stakeholders will be investigated, for instance a change of the heating system. To do so the tools on single user and building level will be used to predict the resulting changes. Recalculating the relevant parameters under the changed conditions will highlight the effects of the parameter-change on the different spatial resolution levels. This will give the opportunity to

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specifically intervene in the city's energy and transport system, by identifying the necessary changes in the system, that will lead to the best results.

(3) STEP 2b Investigation of future effects: In a further step, the planning toolbox will allow to investigate future effects regarding the urban energy system. These are based on changes which can result from general energy policy decisions, for instance, a substitution of a percentage of oil-fired heating systems with district heating within a city, or changes in the energy behaviour, for example general increase in electricity consumption. This will permit to investigate the resulting effects on the overall system.

The overall structure and functioning of the decision support system, comprising all models and tools, is shown in Figure 2.

6 CONCLUSION

One of the innovative insights of DESENT is, the implementation of the developed tools in real cities. Thus, an integrated approach and co-creation process has been facilitated to achieve the planned goals and to understand and address the various challenges of the cities involved (Weiz, Helmond and Steinkjer). As expected, the early involvement and support of cities in helping to create the knowledge tools and data collection can best ensure the delivery of good quality work. This process ensures the transformation to a sustainable and smart city and contributes to solve major problems that come along with continuous urbanisation.

So far, the conceptual tools to analyse and predict energy consumption on building level based on annual data have been created. For this, comprehensive data of the city of Weiz has been provided. The current results show that the data quality is often not sufficient which usually requires the imputation of data with the help of statistical information. The results are combined with the grid models, that also consider a PV-cadaster tool. Moreover, Albatross is extended and comprises a traffic simulation model to predict the spatial distribution of vehicles on a specific road segment of the city network by different times of day. Currently all data and tools are being linked together to an aggregation tool, allowing future scenario predictions.

Although still under development, we believe DESENT decision support tool offers a powerful platform for the modelling of urban energy systems. The capabilities presented in this paper show that the planning toolbox allows users on the one hand to evaluate their energy consumption behaviour on single-user and building level and on the other hand to evaluate holistic urban energy strategies from the early master plan stage through assessing the impacts of a specific (future) energy supply strategy.

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