urbem DK
results report

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WIENER STADTWERKE Holding AG

AUTHORS

in alphabetical order

Thomas Bednar
Dominik Bothe
Julia Forster
Sara Fritz
Nadine Haufe
Thomas Kaufmann
Peter Eder-Neuhauser
Paul Pfaffenbichler
Nikolaus Rab
Johannes Schleicher
Gudrun Weinwurm
Christina Winkler
Manuel Ziegler

Urban Energy and Mobility System
Doctoral Programme

urbem DK
results report

TECHNISCHE UNIVERSITÄT WIEN

TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria

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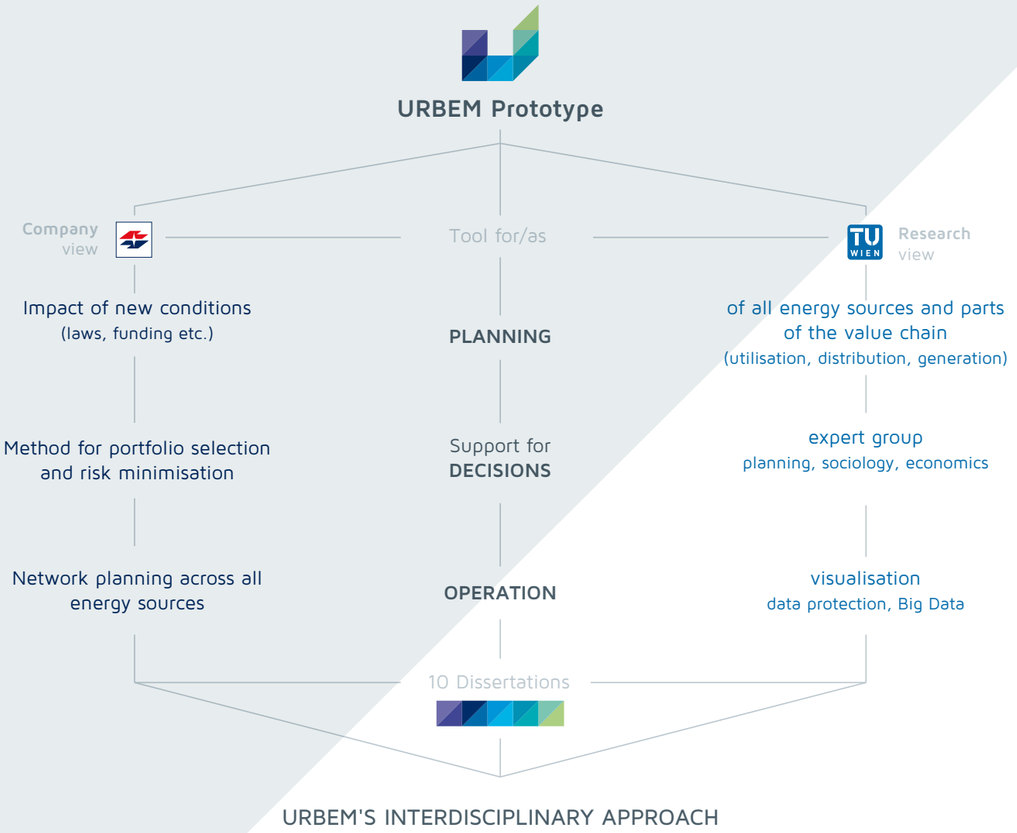
abstract



URBEM helps answer these questions from an economic, technological, social and ecological perspective. For this ten doctoral students from TU Wien spent six semesters on research in collaboration with Wiener Stadtwerke. The aim was to find methods for developing and testing strategies for a sustainable urban energy and mobility system.

What should the city of the future look like? How can a city that is sustainable and liveable tomorrow be planned today?

URBEM CARVING OUT A NEW PATH

With Vienna as an example, the URBEM doctoral programme developed a prototype of a virtual city – and validated it with real data. What arose was an IT environment in which – within the framework of data protection requirements – variations of a city of the future could be analysed more completely in scenarios. For the first time ever, changes in social structure, building stocks and mobility options as well as effects on infrastructure and energy supply were able to be considered and visualised consistently.

These pioneering methods and the URBEM prototype are presented in this report.

The central result of URBEM-DK is the prototype of an interdisciplinary decision-supporting tool which can be used for detailed planning as well as higher-level urban planning scenarios. The environment combines knowledge from ten different scientific models developed in URBEM-DK and incorporates the extensive practical knowledge of Wiener Stadtwerke.

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1

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intro

introduction

In 2030 Vienna's population will be around 2 million – about 15% higher than in 20141[1]. This growth represents a challenge particularly for the City of Vienna itself, but also for urban planning, energy and infrastructure operators and the entire building and mobility sector, and must be dealt with responsibility.

Vienna has been ranked one of the world's most liveable cities in studies such as "Quality of Living"[2] and "Global Liveability Ranking"[3].

This begs the question: how can Vienna grow so rapidly, but still maintain a high standard of living?

The trend towards urbanisation, sustainable cities and so-called "smart cities" is omnipresent in the media. Even today both national and international roadmaps exist to point out the way to sustainable and liveable cities. The numerous measures contained in them must be successively transposed and implemented. However, the complex system of a city represents an ultimate cross section and cannot be adequately described through individual scientific disciplines. An interdisciplinary and valid decision-supporting platform is required for comprehensively representing bundles of measures and various development scenarios. Only such an instrument can enable policy to take urban planning decisions with a solid scientific basis.

URBEM-DK – the doctoral programme "Urban Energy and Mobility System" is an interdisciplinary cooperation launched in 2013 between TU Wien and Wiener Stadtwerke.

The doctoral programme comprises the dissertations of nine doctoral students as well as the support from professors from six faculties at TU Wien as well as from experts at Wiener Stadtwerke and their subsidiaries.

The aim of the doctoral programme was to research and develop an interactive environment for analysis scenarios to achieve a "sustainably serviced, affordable and liveable city" using Vienna as an example and taking a holistic, interdisciplinary approach. Emphasis is on combination of economic and sociological methods with the technical consideration of buildings, heat and electricity infrastructures and mobility. Visualisation and distributed computing enable user-specific display of results or operation of the prototype.

Apart from the successful development of the interactive prototype, linking of science and practice benefits all partners, researchers and the junior scientists.

[1] MA23, Wien Wächst: Bevölkerungsentwicklung in Wien und den 23 Gemeinde- und Zählbezirken; Statistik Journal Wien: 2014.
[2] Mercer; Western European Cities Top Quality of Living Ranking – Mercer; www.mercer.com: 2016.
[3] Economist Intelligence Unit; Global Liveability Ranking 2015; www.economist.com: 2015.

why should I be interested in URBEM?

From the point of view of a company I am ...

... an urban planner

How can I represent variants for future city development in a participative process so that existing buildings, mobility and energy supply are taken into consideration?

The URBEM method also enables large groups of experts to carry out analyses of development variants by means of scenarios. In this way, all expertise can be considered and an overview retained.

... an infrastructure operator/developer

The city is changing – how can new and old city districts be connected sustainably, reliably and economically feasible to urban infrastructures?

URBEM has developed manifold methods for optimising the expansion of urban infrastructures such as energy grids and simulating the operation of such infrastructures.

... an energy supplier

What needs does the city's population have? Which tariff models can help lower greenhouse gas emissions? Which portfolio of facilities should be used for energy generation?

URBEM has researched the consumer behaviour of ten urban milieus and investigated the effect of various tariff models on customer decisions. Methods for robustly and sustainably shaping the portfolio of energy generation facilities in view of strongly fluctuating primary energy prices have also been developed in URBEM.

... a builder

Where in the future will be a possibility to build buildings in a city and which network infrastructure (district heating and natural gas) can be used?

URBEM researches the internal development potential of the city as well as possible expansion routes for network infrastructures. This allows possible future development potentials and available infrastructures to be specified and located.

From the point of view of science I am a scientist and ...

... research smart cities

How can the various disciplinary representatives involved in the design of a city develop a common understanding?

Through the interdisciplinary approach the doctoral programme URBEM laid the foundation for intensive scientific exchange between all participants and a holistic understanding of smart cities was developed. The interdisciplinary aspect is especially well reflected in Johannes Schleicher's dissertation describing a new method for management of complex and distributed processes for information processing for common analysis was developed.

... research urban mobility

Where will the population groups most likely to use electromobility live? What will be the electricity consumption in 2050 due to electromobility?

Nadine Haufe's dissertation not only clearly shows the milieus with an affinity to electromobility, but also localises the results within Vienna. Based on these results, the research report of Paul Pfaffenbichler provides an outlook for urban mobility in 2050. Julia Forster's dissertation impressively demonstrates how complex and location-specific results can be represented spatially.

... research actual energy consumption in buildings

How well can the energy consumption for heating, hot water, and household and operating electricity be predicted based on a milieu approach?

Manuel Ziegler's dissertation reveals how easily modelled the energy consumption can be. The results also show the key factors that influence the energy consumption profile. Future heating requirements scenarios can be found in Sara Fritz' dissertation. The dissertation of Nikolaus Rab derives possibilities for optimising the economics of the power plant park of a district heating generator.

... research the energy grid and infrastructure of a city

How can the equipment load in large hydraulic or electricity networks be determined?

The dissertations of Dominik Bothe and Thomas Kaufmann examine the network infrastructure load in various scenarios based on the energy consumption profile. Due to the high temporal and spatial resolution of the investigation the operating status can be determined for each network section.

... research smart grids

Which measures help improve the security of smart grids? Which topologies are especially advantageous in this regard?

In his dissertation, Peter Eder-Neuhauser developed an extensive list of measures for improving the robustness of smart grids as well as limiting the possible damage caused by malware.

2

urbem methods development

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methods development

2

Within the scope of the doctoral programme URBEM an environment in which questions related to development of urban energy and mobility systems could be analysed holistically was developed.

For this, the models existing in the various disciplines were developed further and new methods were researched and formulated in such a way that within the scope of prototype implementation the application and functionality could be demonstrated. In this chapter the background for the development of the individual models is explained. Chapter 3 "URBEM – Prototype" builds on this by showing how an interdisciplinary understanding can be achieved and how the aspects of data protection can be incorporated into model validation, model parameterisation for a concrete city and joint analysis of variants.

Six faculties and ten doctoral students from TU Wien and a large number of experts from various disciplines don't necessarily speak the same language. That's why URBEM has always emphasised awareness of the languages used in the other disciplines.

2.1
16

The city – a complex system

Supply of clean energy at affordable prices is an important prerequisite for the positive development of economically and demographically expanding cities around the world.

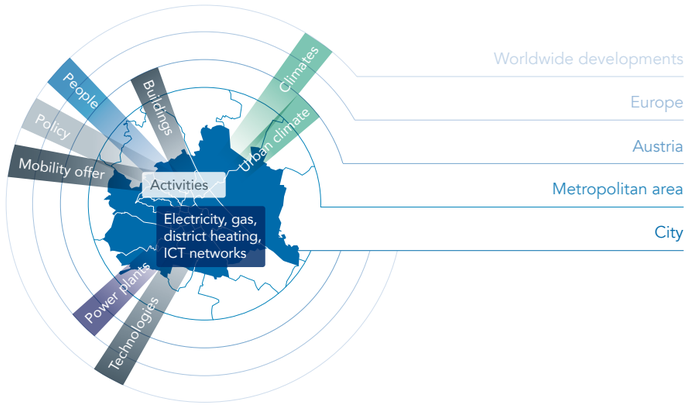
Urban spaces are growing rapidly worldwide. The reliable functioning of urban infrastructures 24 hours a day 365 days a year is a prerequisite for positive social and economic urban development. Equal access to clean, affordable energy and mobility services forms the basis for equal opportunities for citizens and improvement of the quality of living.

Integrated strategies which consider the technological developments as well as the social and economic relationships are needed to achieve these goals.

With cooperative planning between politics, administration, society and enterprise, it is not always easy for those involved to understand how measures taken at one location affect other parts of the complex system. For development of sustainable strategies which also take into account the interactions in the overall urban system new integrated methods of system analysis are required.

It is important to look beyond the city's borders and consider the effects of the surrounding area. Vienna is influenced in manifold ways by Austrian, European and global developments. One example of this is the global climate change and the targets for limiting it set forth in the Paris Convention.

Figure 1
The urban energy and mobility system is influenced by numerous interactions with the metropolitan area, Austria and the rest of the world. The methods for analysis of possible variants must be able to represent these effects consistently.
© URBEM/TU Wien



The City of Vienna and metropolitan area as an example

2.2
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Vienna was used as an exemplary city within URBEM to enable methods to be developed on the basis of a concrete example with concrete data.

With around 1.8 million[4] inhabitants, Vienna is one of the largest cities in Europe. Within the scope of large participative processes, the City of Vienna is developing targets and strategies for improving the quality of living of its citizens, strengthening the business and scientific location and developing its forerunner role in the transformation to a sustainable city (Smart City Wien Rahmenstrategie[5]).

For developing consistent methods for analysis of the mobility system the models' geographical reference is much more important than the city itself due to the daily traffic flows.

Figure 2
Due to the mobility of the population the represented metropolitan area should be considered in addition to the city in the analysis of variants for future developments.
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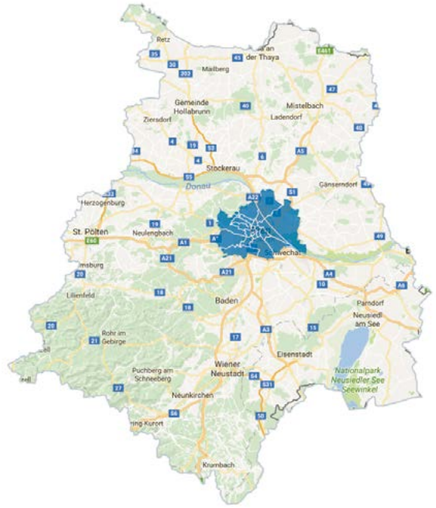


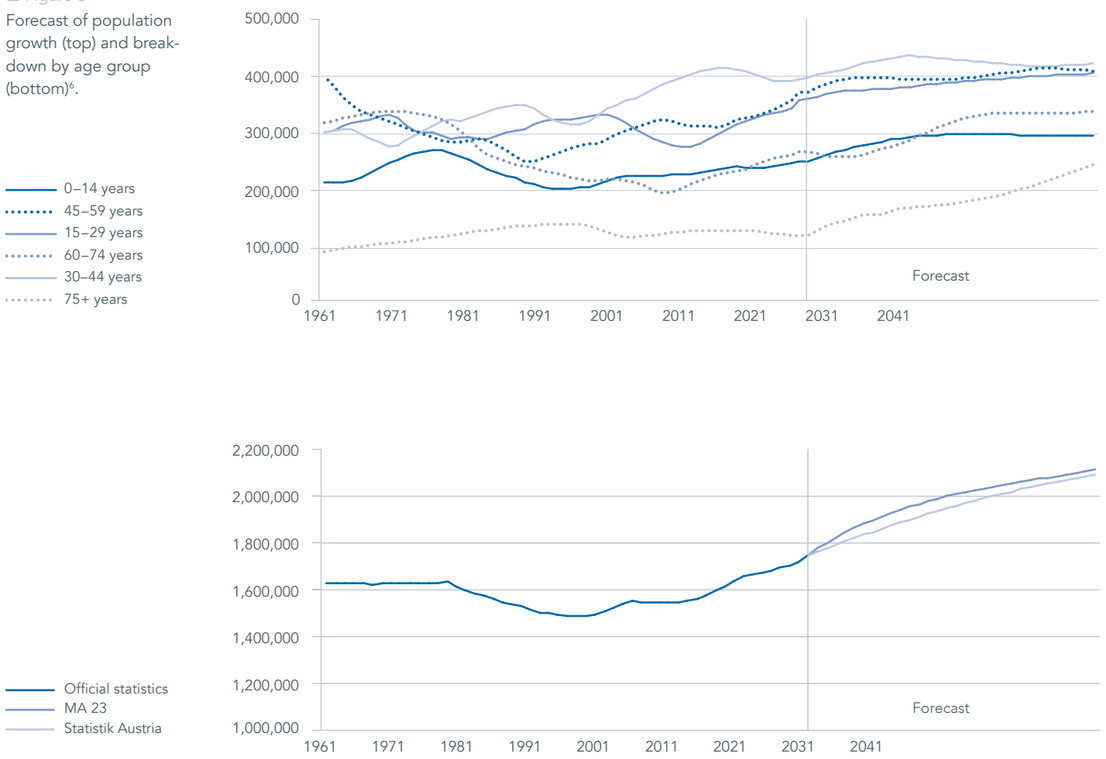
[4] Statistik Austria; population statistics in accordance with § 9 paragraph 9 of FAG 2008 (reporting date: 31 October). Created on 16.9.2016
[5] www.smartcity.wien.gv.at

2.2.1 POPULATION GROWTH

Mobility and energy demands are closely related to the number of people and their activities. For Vienna the next few decades will see growth of some 20,000 people per year.

Vienna's population grew to around 2 million people by 1910, dropped to 1.6 million by 1990 and has been growing steadily since 1991.

Figure 3
Forecast of population growth (top) and breakdown by age group (bottom)[6].



[6] Statistik Journal Wien 1/2014; Wien wächst … Bevölkerungszahlen in Wien und in den 23 Gemeinde- und 250 Zählbezirken; MA23: 2014. ISBN 978-3-901945-15-1

2.2.2 BUILDING STOCK

Because of the changes in the Viennese population a majority of the buildings were built before WWII. Until 1970 construction methods utilising a high level of prefabricated elements were developed for post-war reconstruction and being able to offer living spaces at affordable prices. With the building regulations that were in place after 1970 reduction of energy consumption became an increasingly important topic due to the oil crises.

A similar picture is yielded when various construction methods are differentiated according to useable floor space. In addition the useable floor space can also be assigned to a particular use.

Figures 4 and 5 show the uses (or useable floor space) relevant in an urban context.

Figure 4
Number of buildings in Vienna as a function of construction method[7]. The affordability of living spaces was supported by construction methods utilising a high level of prefabricated elements (Camus system, prefabricated construction).
© URBEM/TU Wien

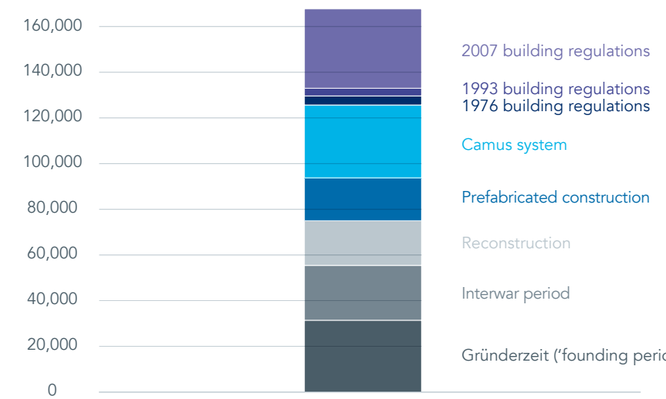
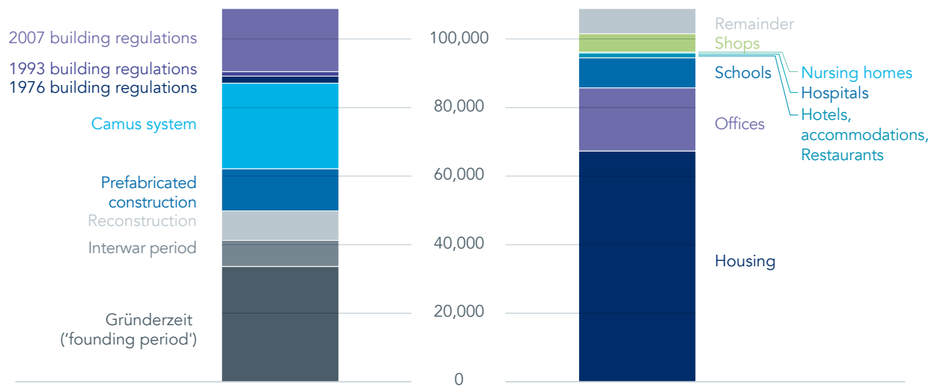


Figure 5
Breakdown of useable floor space in Vienna's buildings according to construction method (left) and use category (right)[8]. A large part of the useable floor space in Vienna is assigned to housing; 30 % of the useable floor space is assigned to buildings erected before WWII.
© URBEM/TU Wien



[7, 8] Wärmekataster Wien (construction period- and needs-based) 2011/12 MDE and MA 39: 2012

2.2.3 MOBILITY BEHAVIOUR

There are large daily and seasonal traffic flows across Vienna's city limits. Every day around 0.6 million people join the approx. 1.8 million inhabitants of Vienna for work or leisure activities. These traffic flows are counted regularly – the results for 2015 are shown in Figure 6.

In order to assess the energy consumption and the associated greenhouse gas emissions for the various routes taken into Vienna it is important to conduct surveys to estimate the shares taken up by routes on foot, by bicycle, using public transport and with private vehicles or motorcycles. The so-called modal split can be derived from these surveys.

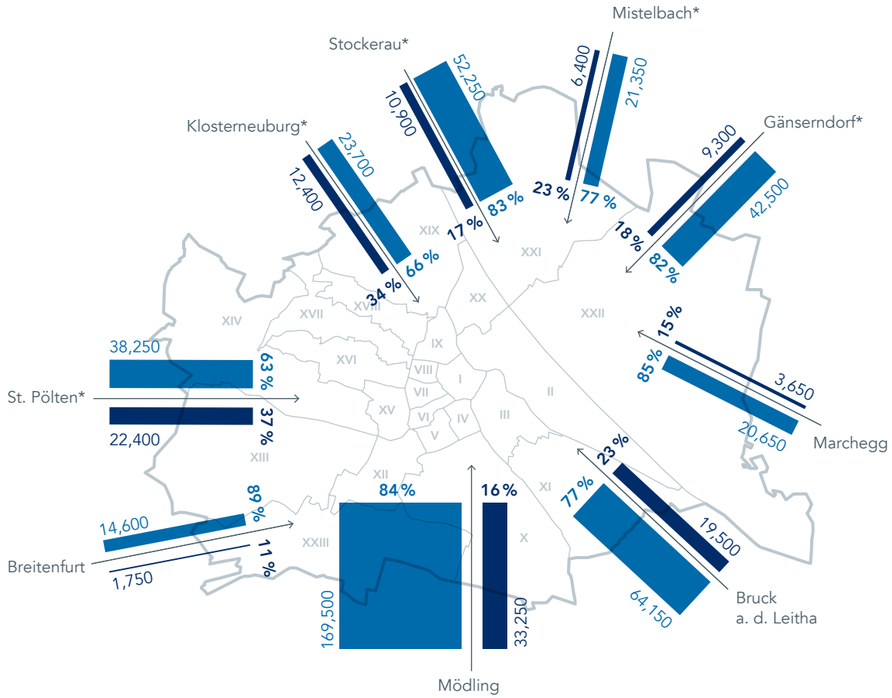


Figure 6
Modal split according to entry corridors into Vienna. On any given working day around 450,000 people drive into Vienna with cars or motorcycles and around 120,000 with public transport[9].
© URBEM/TU Wien

[9] 2015 corridor survey

The modal split for the Viennese population clearly shows that use of public transport has the largest share. Use of private vehicles is roughly the same in terms of per cent as routes taken on foot. Routes taken by bicycle make up the lowest share by far in the modal split, although this group has been steadily rising since 2011 (Figure 7).

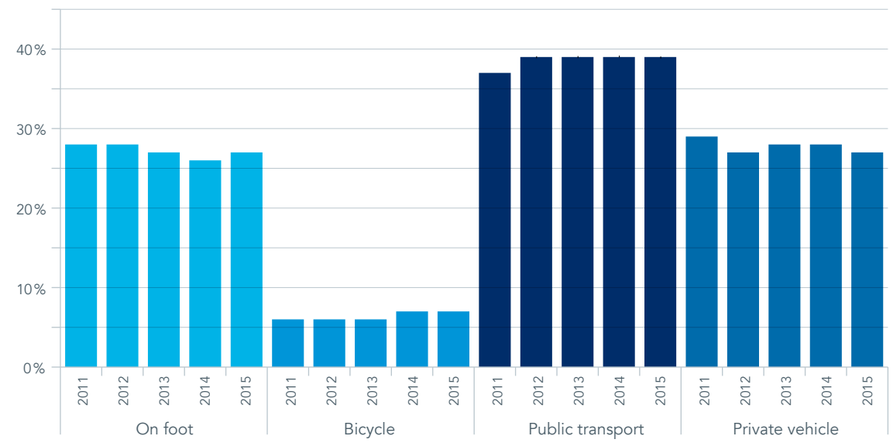


Figure 7
Comparison of trends in transport mode breakdown for Viennese population from mobility surveys in 2011–2015. The choice of motorised private transport shows a slightly falling tendency.
© URBEM/TU Wien

2.2.4 ENERGY CONSUMPTION

Energy is employed in the form of various energy sources for various end uses via a wide range of conversion technologies to support diverse human activities. Based on consumption data as well as models Statistik Austria regularly breaks down the end consumption of energy into the various sectors, end uses and states. The following figure shows the changes in and the sector breakdown of electricity consumption in Vienna. In Vienna the largest share is taken up by electricity for public and private services as well as in private households. The amount used for trams, the underground, railways and other means of transport requiring electrical energy is much lower.

For 2014 this results in an annual electricity consumption of around 4,600 kWh per capita. Of this, approx. 80 % can be traced back to private households as well as public and private services.

Vienna's district heating network supplies the Viennese population with heat for space heating and hot water. Here as well the largest users are public and private services as well as private households.

The statistics show a clear increase in end consumption of district heating energy since 1990. The consumption in 2015 shows a share of about 95 % for private households as well as public and private services.

Figure 8
Electricity consumption in Vienna has risen dramatically over the last few years. However, consumption has been stagnating since 2006.
© Statistik Austria 2015

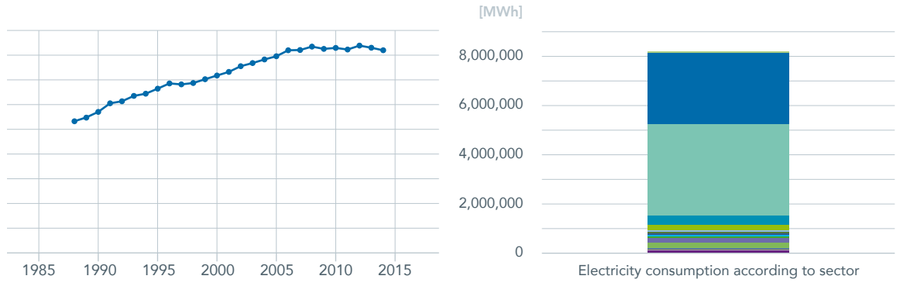


Figure 9
District heat consumption has risen steeply over the last ten years.
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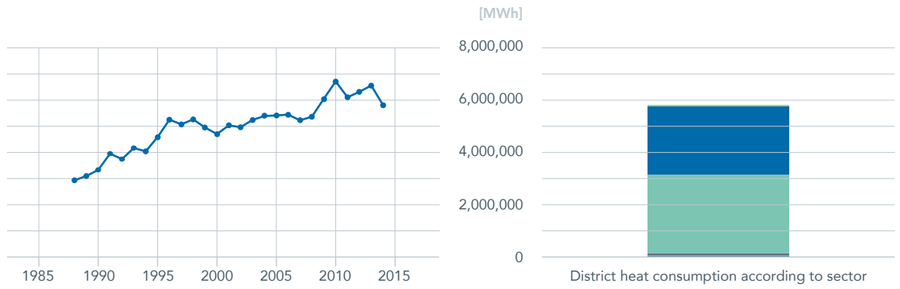


Figure legend 8–11:
- Agriculture
- Private households
- Public and private services
- Air traffic
- Inland shipping
- Transport in pipelines
- Other land-based transport
- Railway
- Other manufacturing area
- Textiles and leather
- Construction
- Wood processing
- Paper and printing
- Food, beverages and tobacco
- Mining
- Mechanical engineering
- Automotive
- Stones and clay, glass
- Nonferrous metals
- Chemicals and petrochemicals
- Iron and steel products

Natural gas plays a key role for space heating and hot water generation in Vienna. Here private households in which natural gas is used for cooking dominate the consumption. The food, beverages and tobacco sector is the second-largest consumer of natural gas.

For 2014 the per-capita end consumption of natural gas was around 3,900 kWh/year, 90 % of which could be traced back to the private households as well as public and private services sectors.

The consumption of fuels for mobility is determined by means of the amounts sold in each state. In the last 20 years the sales of diesel in Vienna has risen greatly, whereas petrol consumption has dropped steadily. The sold amounts for 2014 were around 7,200 kWh per capita. Conversion of sold amounts to energy amounts is done with the lower calorific values.

Figure 10
Consumption of natural gas shows a slightly falling tendency.
© Statistik Austria 2015

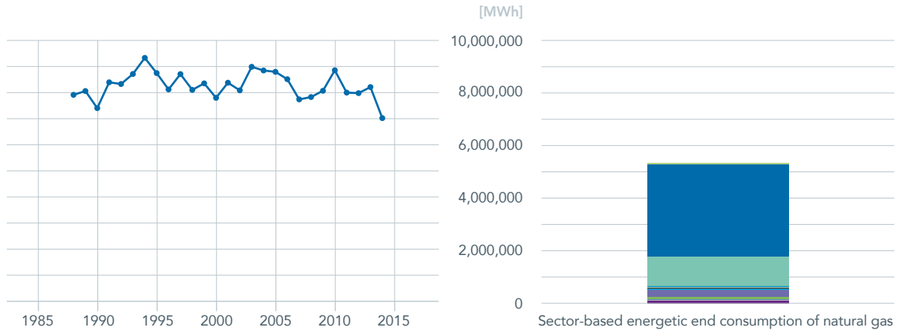
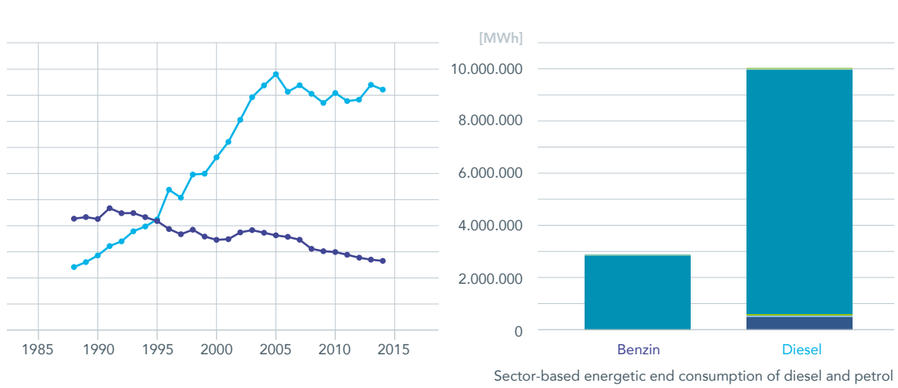


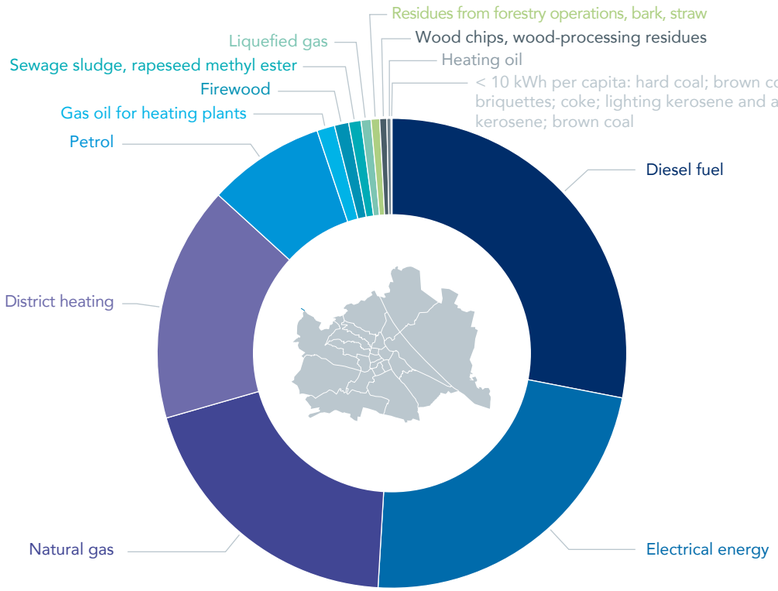
Figure 11
Consumption (sales) of diesel in Vienna has risen drastically in the last ten years. Consumption (sales) of petrol has clearly dropped.
© Statistik Austria 2015



Apart from the energy sources listed, biomass and other energy forms are used in Vienna.

Diesel, electricity, natural gas, district heating and petrol together currently represent 94 % of total consumption.

Figure 12
Shares of different energy sources in the total consumption of energy in 2014.
© Statistik Austria 2015

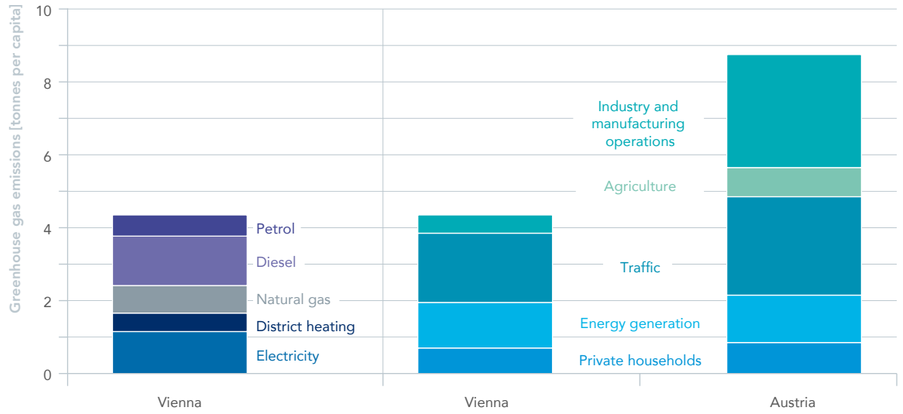


2.2.5 GREENHOUSE GAS EMISSIONS

At the UN Climate Conference in Paris in 2015 it was decided to limit global warming to less than 2 °C, or if possible even less than 1.5 °C. The global emissions of greenhouse-relevant gases are decisive for the global climate. For Austria the greenhouse gas emissions are determined once a year.

Figure 13 shows that relating greenhouse gas emissions to human activities requires a well-thought-out accounting system. For example if electromobility replaces diesel vehicles the emissions from use of diesel are reduced, but at the same time the emissions from electricity use change. Emissions from electricity use are related to the type of primary energy source used for the generation of electricity. Thus a complex system in which the energy supply and the mobility are strongly connected is yielded. Which measures have which effects on the overall system must be examined in a holistic manner and the entire chain in the energy system must be considered.

Figure 13
Breakdown of greenhouse gas emissions for Vienna and Austria for 2013. For Vienna the emissions from traffic, energy generation and private households are decisive. For Austria as a whole the emissions from industry and manufacturing operations as well as agriculture are also important. Broken down according to energetic end consumption, the emissions from use of diesel come before use of electricity, natural gas and district heating in Vienna.
© Umweltbundesamt 2015, Statistik Austria 2015, URBEM/ TU Wien



2.2.6 SMART CITY OF VIENNA FRAMEWORK STRATEGY

The URBEM targets are in line with the targets of the Smart City of Vienna Framework Strategy. The three main pillars of the Smart City of Vienna Framework Strategy can thus also be found in URBEM-DK:

- Quality of living: social inclusion, health and environment
- Resources: energy, mobility, infrastructure and buildings
- Innovation: education, business, research, technology and innovation.

URBEM is developing a method for analysis of scenarios for achieving a liveable, affordable, sustainably serviced city and represents them in a comprehensive interdisciplinary prototype. The requirements that must be met by the prototype as well as the display of specific scenarios are heavily based on the targets of the Smart City of Vienna Framework Strategy.

The key targets within the Smart City of Vienna Framework Strategy are summarised below.

Energy target

- Increase in energy efficiency and reduction in end consumption of energy per capita in Vienna by 40 % in 2050 (cf. 2005)
- Reduction in primary energy consumption per capita from 3,000 W to 2,000 W
- More than 20 % of Vienna's gross total consumption of energy in 2030 and more than 50 % in 2050 from renewable sources

Mobility target

- Strengthening of CO_2-free modes (on foot and by bicycle) and maintenance of the high share of public transport as well as reduction of the motorised private transport share to 20 % by 2025, 15 % by 2030 and much below 15 % by 2050
- By 2030 the largest possible share of motorised private transport shifted to public transport
- By 2050 the entire share of motorised private transport within the city limits accomplished without conventional drive technologies

Buildings target

- Cost-optimised low-energy building standard for all new buildings, extensions and conversions from 2018/2020 as well as further development of heating supply with greater climate protection
- Comprehensive restoration activities leading to reduction in the energy consumption in existing buildings for heating, cooling and hot water by 1 % per capita per year

Infrastructure target

- Maintenance of the high level of Vienna's infrastructure
- Vienna the most advanced European city in all aspects of open government by 2020
- Pilot projects with ICT companies

These targets are long-term goals. Framework conditions may change over time. The URBEM prototype is a planning and decision-supporting tool for assisting in the development of strategies and measures for achieving these targets even with uncertain framework conditions.

2.2.7 AVAILABILITY OF DATA ABOUT THE CITY

The data made available within the scope of Open Data of the City of Vienna make up a core part of the URBEM environment. Successful development would not be possible with this treasure chest of data sets.

However, data are of top priority not just for the development, but also for calibration and validation purposes.

Future scenarios for methods development – WIFO

Development of the Viennese energy and mobility system is strongly influenced by numerous factors outside of Vienna (climate, energy prices, EU climate protection policy etc.).

To identify the effects of these factors on possible variants of the future city development, it was necessary to develop suitably formulated and represented scenarios for all scientific disciplines in the model formation. Nikolaus Rab (energy industry) and Christina Winkler (mobility) led this participatory process in URBEM. Three very different manifestations of the exogenous influencing factors were formulated for checking the completeness of formulation of the scenarios for the model formation in the various scientific disciplines. In the formulation of such scenarios it is important to understand the relationships between the various factors and to avoid use of unrealistic or improbable temporal profiles in the analysis of the impacts of urban development variants.

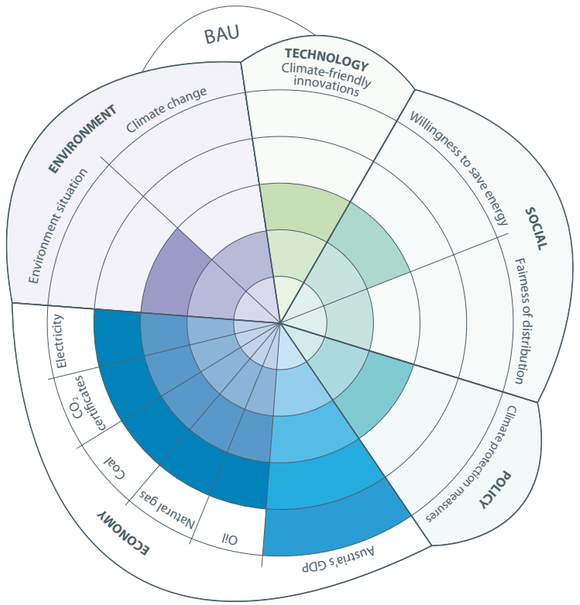
These URBEM scenarios for the exogenous influencing factors cover the period from 2015 to 2050. Quantitative factors especially include the demographic changes in Vienna's population as well as the changes in the energy and electricity prices. Qualitative factors are technological advances as well as socio-demographic, socio-economic and socio-cultural aspects.

Existing scenarios applied in the smart city research for Vienna were used where possible as a basis in determining the qualitative and quantitative forms of the scenarios. The central building block was formed by the WIFO[10] study for which the energy price scenarios and their interactions with politics and the Austrian economy were based on the disaggregated macro-economic model DEIO.

In the following sections the scenarios considered in URBEM are described and key factors such as population growth[11], renovation rate[12], annual mean temperature[13], greenhouse gas emissions[14] etc. were quantified for each scenario.

The formulated scenarios can be changed in the URBEM environment for each time period under consideration. The results – e.g. the influence of energy prices on heating demands in 2030 – can thus immediately be displayed visually and quantitatively. This capability enables the URBEM prototype to be subsequently used as a decision-supporting tool on the basis of solid, validated scientific methods and further developed.

[10] Kratena, K., Sommer, M., Eysin, U., & Rose, K. (2014). Energiepreisszenarien 2050 – Herausforderungen an die österreichische Energiewirtschaft. Wien: Österreichisches Institut für Wirtschaftsforschung
[11] Statistik Journal Wien 1/2014; Wien wächst ... Bevölkerungszahlen in Wien und in den 23 Gemeinde- und 250 Zählbezirken; MA23: 2014. ISBN 978-3-901945-15-1
[12] S. Fritz; Economic assessment of the long term development of the building heat demand and the grid bounded supply; dissertation; Technische Universität Wien: 2016
[13] L. Kranzl et al.; Power through Resilience of Energy Systems: Energy Crises, Trends and Climate Change; Austrian Climate Research Program – ACRP; Wien: 2014
[14] Conversion factors according to OiB RL6: 2015



Scenario:
Business-As-Usual (BAU)

The reference scenario corresponds to a "business as usual" approach for climate protection policy and describes existing developments further. A governmental climate protection policy with limited incentives is established such that market stimuli still play a major role in the energy and mobility sector.

Table 1
Quantitative factors for the business as usual (BAU) scenario.
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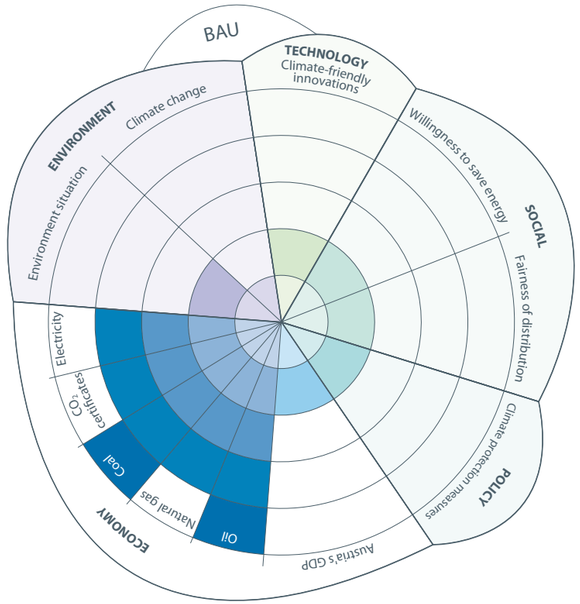
	2015–19	2020–24	2025–29	2030–34	2035–39	2040–44	2045–49
Population growth in Vienna [people/year]	20,912	14,601	10,507	7,696	6,722	6,639	6,639
Annual mean temperature [°C]	11.98	12.06	12.16	12.30	12.44	12.56	12.72
Renovation rate [%]	0.7	1.0	0.8	0.7	0.7	0.7	0.7
Mean base load electricity price on EXAA [euros/MWh]	36	51	60	69	72	75	86
Mean Austrian import price of natural gas [euros/MWh]	23	27	28	29	29	29	28
Greenhouse gas emissions from electricity mix in Austria [g/kWh]	209	194	179	164	149	134	119

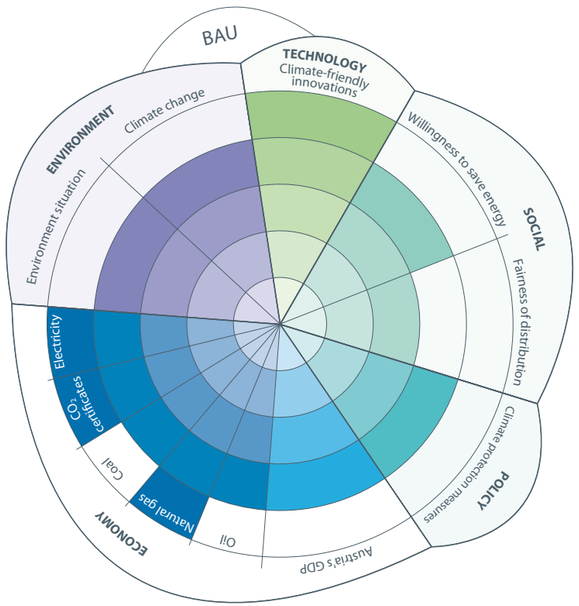


Scenario:
Stagnation

The global economy is stagnating. Climate protection measures are only carried out if they do not interfere with increasingly more important economic interests.

Table 2
Quantitative factors for the stagnation scenario.
© URBEM/TU Wien

	2015–19	2020–24	2025–29	2030–34	2035–39	2040–44	2045–49
Population growth in Vienna [people/year]	20,912	14,601	10,507	7,696	6,722	6,639	6,639
Annual mean temperature [°C]	11.98	12.06	12.16	12.30	12.44	12.56	12.72
Renovation rate [%]	0.7	1.0	0.8	0.7	0.7	0.7	0.7
Mean base load electricity price on EXAA [euros/MWh]	36	51	60	69	72	75	86
Mean Austrian import price of natural gas [euros/MWh]	23	27	28	29	29	29	28
Greenhouse gas emissions from electricity mix in Austria [g/kWh]	209	200	191	182	173	164	155



Szenario:
Climate protection

Climate protection measures have top priority in the EU and are seen as major goals worldwide as well. Heavy investments are being made towards this in new technologies which are causing great cross-sector economic impulses.

Table 3
Quantitative factors for the climate protection scenario.
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	2015–19	2020–24	2025–29	2030–34	2035–39	2040–44	2045–49
Population growth in Vienna [people/year]	20,912	14,601	10,507	7,696	6,722	6,639	6,639
Annual mean temperature [°C]	11.98	12.06	12.16	12.30	12.44	12.56	12.72
Renovation rate [%]	1.3	2.0	2.0	1.6	1.7	1.9	2.1
Mean base load electricity price on EXAA [euros/MWh]	36	56	67	77	82	86	99
Mean Austrian import price of natural gas [euros/MWh]	23	28	31	34	37	40	43
Greenhouse gas emissions from electricity mix in Austria [g/kWh]	209	185	161	137	113	90	66

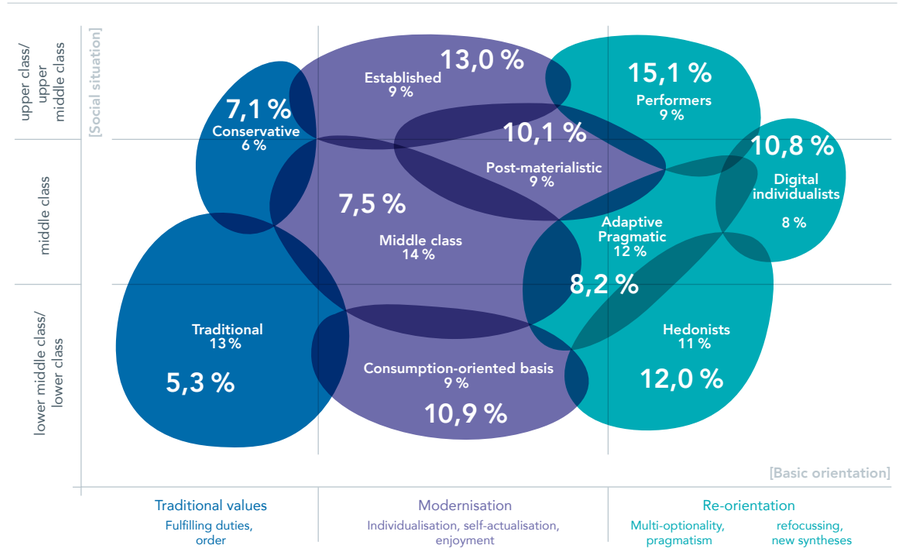
Population

Traditional segmentation features such as class, household type, income etc. alone are no longer sufficient for describing and explaining differences in behaviour.

Social differentiation and social change are leading to the need for new approaches for segmentation of the population into distinct behavioural groups. Socio-cultural approaches, that is, attitudinal approaches from the social sciences and market research are increasingly being applied. This raises the question of the method of segmentation to be used: should it be done on the basis of specific fields of action or needs, but dependent on random samples (lifestyles), or by models (milieus) across different action fields? In addition, spatial aspects also strongly influence the course of action and must be taken into account in the description and explanation of behavioural differences.

On the basis of a survey conducted in Vienna on the energy consumption behaviour of private households, data differentiated on the basis of social environments were collected and two milieu-based segmentation approaches were tested. A total of 977 responses were evaluated. Using these data it is not only possible to gain more detailed insights into the nature and extent as well as the motivation of the Viennese population's mobility and housing energy consumption habits, but also to improve traffic modelling and energy simulations in general. By integrating user behaviour it is also possible to improve the forecasts used for decision support.

Figure 14
Percentage-based distribution of Sinus milieus in Vienna (large numbers; survey by Nadine Haufe) and Austria (small numbers; Integral 2015)
© URBEM/TU Wien



Sinus milieus – a segmentation approach taken from market research – were used for identifying homogeneously behaving groups in Vienna. The milieus are determined on the basis of socio-cultural characteristics of nationally defined societies and are regularly updated to reflect social changes. The current Sinus model for Austria comprises ten social milieus. As can be seen in Figure 14, the percentages of the milieus differ markedly in part between the overall population of Austria and the population of Vienna due to milieu-specific preferences regarding place of residence. The largest milieu group in Vienna is the Sinus milieu of "Performers", making up around 15 % of the population.

The survey results generally show that the Viennese milieus exhibit radically different energy consumption behaviour patterns, sustainability potentials and residential location conditions (see Tables 4, 5, 6, 7, 9 and 10 for individual milieus).

The means of transport used for different purposes of travel not only for the entire Viennese population, but also for the 10 Sinus milieus, were determined, thereby contributing to a better understanding of mobility behaviour. The Viennese most commonly purchase Purchasing of daily necessities is most commonly handled on foot by the Viennese. The share of motorised private transport is the lowest for this purpose in comparison with other purposes. The Viennese population generally uses public transport to get to work or training. In addition to public transport, the car or motorcycle is often used for leisure activities at weekends.

However, the various milieus differ significantly in their use of transport modes. The "post-materialistic" Sinus milieu, a Viennese milieu with generally more energy-saving behaviour (see Table 5), uses public transport for the journey to work or training much more frequently than other Viennese milieus.

Figure 15
Use of transport modes for various activities for the milieus with the largest and the smallest share of motorised private transport as well as for the overall population.
© URBEM/TU Wien

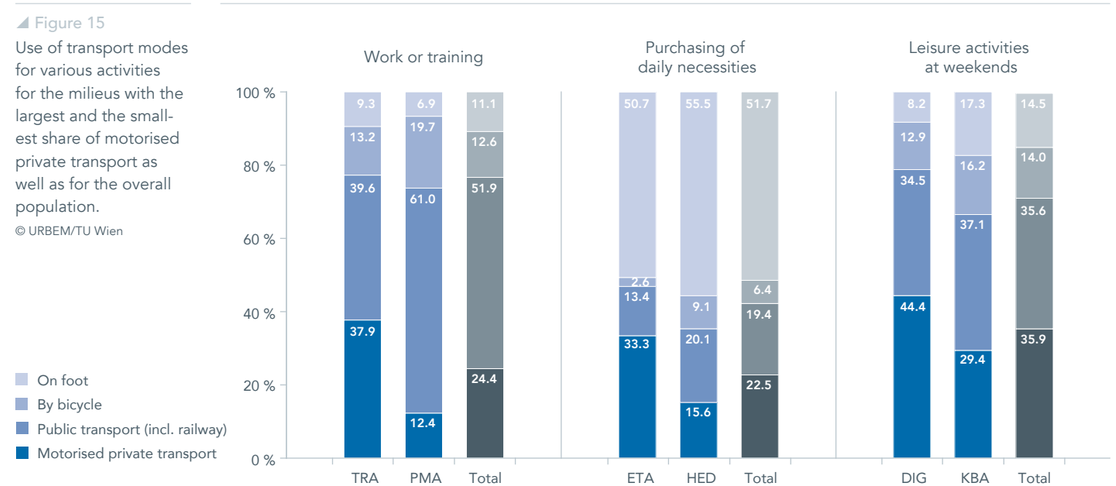


Table 4
Summary of survey results for the Sinus milieu of "Performers".
© URBEM/TU Wien

PERFORMERS [PER] – 15,1 %

Flexible and globally oriented performance elite of Austrian society – individual performance, efficiency and success have top priority; high business and IT competence.

General characterisation

Middle-aged, male, frequently with *Matura* school-leaving certificate, frequently employed

Living situation

· Household size: 2.1 people
· Per capita living space: approx. 48 m²
· Dwelling location: frequently city centre

Energy consumption

· Average number of devices and appliances overall (11.3 %) & high number of ICT devices (7.3 %);
· Lowest duration of use of television, average use of washing machine;
· Heating requirements higher at night, low during the day;
· Average use of public transport (39.9 %);

Sustainability

· Rarely concerned about environmental conditions;
· Often frequent use of environmentally-friendly transport modes (80.2 %);
· Rather frequent use of green electricity (26.1 %) and frequently also conceivable in the future (63.3 %);

Table 5
Summary of survey results for the Sinus milieu of "Post-materialistic".
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POST-MATERIALISTIC [PMA] – 10,1 %

Open-minded social critics – well-educated; most diverse interests; strong cosmopolitan orientation; critical attitude towards globalisation; often engaged in environment or social issues, try to live their daily lives as sustainably as possible.

General characterisation

Middle-aged, more often than not female, frequently with *Matura* school-leaving certificate, frequently employed

Living situation

· Household size: 2.5 people,
· Per capita living space: approx. 41 m²
· Dwelling location: frequently districts in the west

Energy consumption

· Rather low number of household appliances and ICT devices overall (10.3 %);
· Low duration of use of television and average use of washing machine;
· Heating requirements lower overall;
· Lowest motorised private transport (21.1 %), frequent use of public transport (40.9 %) & most frequent bicycle use (16.1 %);

Sustainability

· More frequently concerned about environmental conditions;
· Very frequently increased use of environmentally-friendly transport modes (91.4 %);
· Rather frequent use of green electricity (26.6 %) and frequently also conceivable in the future (60.2 %);

The Sinus milieus "established" and "digital individualists" use motorised private transport for purchasing daily necessities and going to leisure activities at weekends much more frequently than other Viennese milieus. Based on the survey results there are two Viennese milieus exhibiting less energy-saving behaviour overall.

Current behaviours as well as target groups and potential for future developments, e.g. for smart home devices, can be identified through the comprehensive survey. Especially the Sinus milieu "digital individualists" prove to be the most interested in using smart home devices. The Sinus milieu "consumption-oriented basis" is currently the least interested in using smart home devices.

Table 6
Summary of survey results for the Sinus milieu of "Established".
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ESTABLISHED [ETA] – 13 %

Performance-oriented elite – highly traditional anchoring; clear exclusivity and leadership claims; pronounced class consciousness, but also strong sense of responsibility.

General characterisation
Older, more often than not female, more often than not employed, less often with *Matura* school-leaving certificate

Living situation
· Household size: 2.3 people,
· Per capita living space: approx. 46 m²
· Dwelling location: distributed evenly over the city

Energy consumption
· High number of household appliances and ICT devices overall (11.7 %);
· Average use of washing machine and television;
· Heating requirements higher overall;
· Most frequent use of motorised private transport (37.9 %), lowest use of public transport (30.9 %);

Sustainability
· More frequently concerned about environmental conditions;
· Less frequently increased use of environmentally-friendly transport modes (66.4 %), but frequently conceivable in the future (24.4 %);
· Rare use of green electricity (19.2 %), but frequently conceivable in the future (60.5 %);

Table 7
Summary of survey results for Sinus milieu of "Digital individualists".
© URBEM/TU Wien

DIGITAL INDIVIDUALISTS [DIG] – 10,8 %

Individualistic, networked lifestyle avant-garde – mentally and geographically mobile; online and offline; strong focus on one's own ego and own abilities; constantly looking for new experiences, long-term ties rather the exception.

General characterisation
Young, male, more often than not with *Matura* school-leaving certificate, frequently employed

Living situation
· Household size: 2.5 people,
· Per capita living space: approx. 41 m²
· Dwelling location: more frequently in the city centre

Energy consumption
· Highest number of appliances and devices overall (13.7 %) and highest number of ICT devices (9.2 %);
· Most intensive use of television and washing machine;
· Heating requirements higher overall;
· Frequent use of motorised private transport and below-average use of public transport (public: 36.1 %; private: 33.2 %);

Sustainability
· Least concerned about environmental conditions;
· Rather frequently increased use of environmentally-friendly transport modes (91.4 %);
· Frequent use of green electricity (30.1 %);

The survey results also should potential for changes to more sustainable behavioural patterns for the different milieus. Amongst the milieus, the Sinus milieu of "Performers" shows the highest future interest in buying an electric or hybrid car (Figure 16 on page 36). The least interested in owning an electric or hybrid car is the "Traditional" Sinus milieu.

The comprehensive survey enables current behavioural patterns of the Viennese population, rebound effects, potential for changes in behaviour and starting points for energy-saving measures to be shown for Vienna as a whole as well as differentiated by milieu in URBEM. The far-reaching effects of the different energy consumption behaviours of the various milieus on the urban energy and mobility system will be described in greater detail in the following chapters for selected aspects.

Table 8
Statements pertaining to interest in smart home device applications. The results show large differences between the milieus with a high statistical significance.
© URBEM/TU Wien

Managing heating and electricity in the household with mobile phone, tablets etc. is interesting to me.

[%]	Total	KON	TRA	ETA	PER	PMA	DIG	BÜM	PRA	KBA	HED
True	**41.1 %**	31.6 %	17.4 %	50.7 %	51.4 %	40.1 %	**66.1 %**	32.4 %	39.1 %	14.7 %	42.8 %
False	**58.9 %**	68.4 %	82.6 %	49.3 %	48.6 %	59.9 %	33.9 %	67.6 %	60.9 %	**85.3 %**	57.2 %

Table 9
Summary of survey results for the Sinus milieu of "Consumption-oriented basis".
© URBEM/TU Wien

CONSUMPTION-ORIENTED BASIS [KON] – 10,9 %

Materialistic, resigned lower class – pronounced fears for the future, resentments and feeling of discrimination; striving to keep up with the consumer standards of the middle class.

General characterisation
Middle-aged, male, frequently with *Matura* school-leaving certificate, frequently employed

Living situation
· Household size: 2.1 people
· Per capita living space: approx. 47 m²
· Dwelling location: frequently city centre & west

Energy consumption
· Rather low number of appliances and devices overall (9.7 %);
· Average use of washing machine and television;
· Heating requirements lower overall;
· Average use of public transport and more frequently bicycle use (public transport: 38.5 %; bicycle: 14.0 %);

Sustainability
· Rather frequently concerned about environmental conditions;
· Rather frequently increased use of environmentally-friendly transport modes (78.5 %);
· Rather rare use of green electricity (23.0 %) and rather frequently conceivable in the future (55.5 %) ;

Figure 16
Responses to the question regarding the purchase of an electric or hybrid car. A large part of the Viennese population can imagine acquiring an electric car. However, the relationship between milieu and response is not statistically significant as the responses vary too much.
© URBEM/TU Wien

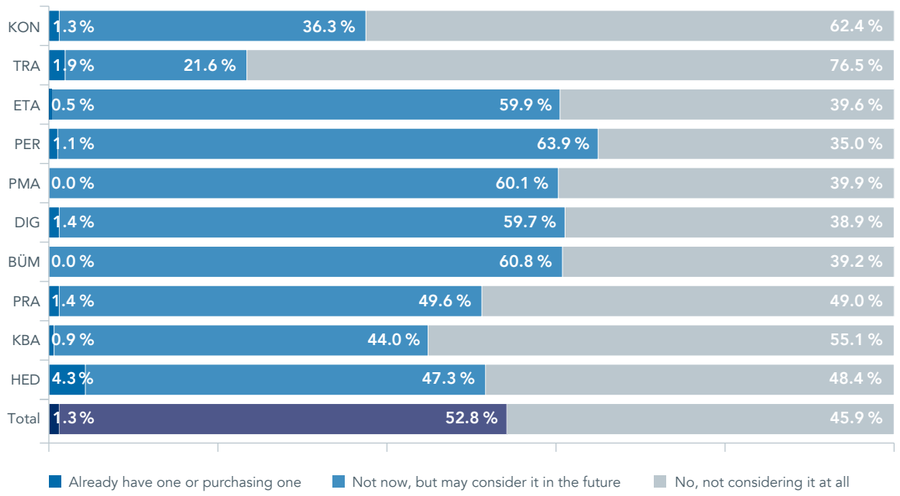

Table 10
Summary of survey results for the Sinus milieu of "Traditional".
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TRADITIONAL [TRA] – 5,3 %

Group of people focussed on security, order and stability – sceptical to rejecting of change; strong roots in the old world of the petite bourgeoisie, traditional working class culture and the traditional rural environment.

General characterisation
Relatively old, female, rarely employed, rarely with *Matura* school-leaving certificate

Living situation
· Household size: 1.9 people,
· Per capita living space: approx. 47 m²
· Dwelling location: distributed evenly

Energy consumption
· Lowest number of household appliances (3.7 %) and lowest number of ICT devices (3.7 %);
· Lowest duration of use of washing machine, average use of television;
· Heating requirements low overall;
· Frequent use of public transport (41.4 %);

Sustainability
· Rather frequently concerned about environmental conditions;
· Frequently increased use of environmentally-friendly transport modes (87.5 %);
· Rather frequent use of green electricity (28.3 %), but also frequently not conceivable in the future (37.8 %);

Detailed information about methods and individual milieus as well as further results can be found in Nadine Haufe's dissertation.[15].

[15] N. Haufe; Energiekonsum, Stadt und soziale Milieus; dissertation; Technische Universität Wien: to be published

Changes in building stock

Through technical developments and legislation triggered by oil crises the energy efficiency of residential buildings with regard to space heating has risen steadily over time.

As can be seen in Figures 4 and 5 (page 19), a large part of the existing buildings in Vienna were erected during the Gründerzeit. Buildings are continuously being renovated and thus are changing the energy requirements. The renovation rate as well as the legal provisions over the course of time have a major effect. At any time, in the last few years more and more buildings meeting the criteria of low-energy buildings according to EU building directives can be found in Vienna. Plus energy buildings have been tested since 2014.

Figure 17
Temporal profile of legal changes in relation to building standard. Photos from www.gründerzeitplus.at as well as from Passivhaus Utendorfgasse and plus energy office high-rise at TU Wien off Getreidemarkt.
© URBEM/TU Wien

Knowledge of the building stock is just as important as are the assumptions about the factors that will influence the further changes in the building stock, because the population of Vienna is growing. The additional space requirements for living, working and leisure activities can be achieved through:

- conversion or extension of existing buildings and
- erection of new buildings.

In the scenario development for the future energy and mobility demand the modelling of this change is of prime importance.

Up to now area reserves for urban densification have been carried out using digital tools (LISA, tiris, Raum+ etc.) and manual procedures. Automated access for estimating and gaining an overview of the densification potential was missing. To be able to carry out a strategic internal development in a holistic manner and derive recommendations for further actions in the future, an interdisciplinary approach that can be integrated into the decision-supporting tool is needed. The utilisation of the floor area potential, the building area potential and the extension buildings can be estimated for various scenarios on the basis of detailed geometric models of the city in relation to buildings and infrastructure.

Further results and detailed information about methods can be found in Julia Forster's dissertation[16].

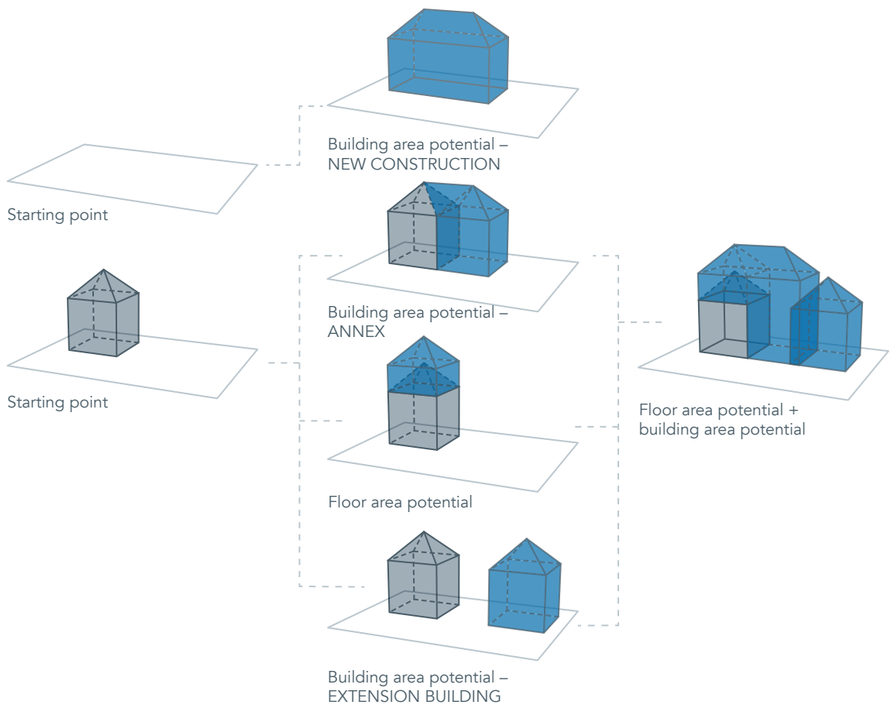

Figure 18
Possibilities of extended utilisation of a property through new construction, annexes, addition of storeys and/or extension buildings.
© URBEM/TU Wien

[16] J. Forster; Strategische raumbezogene Visualisierung; dissertation; Technische Universität Wien: 2016.

Figure 19
Use of the floor area potential in the BAU and in the climate protection scenario. Due to the higher renovation rate in the climate protection scenario the space requirements of the population are much more strongly met through exploitation of the floor area potential than is the case for new buildings or annexes.
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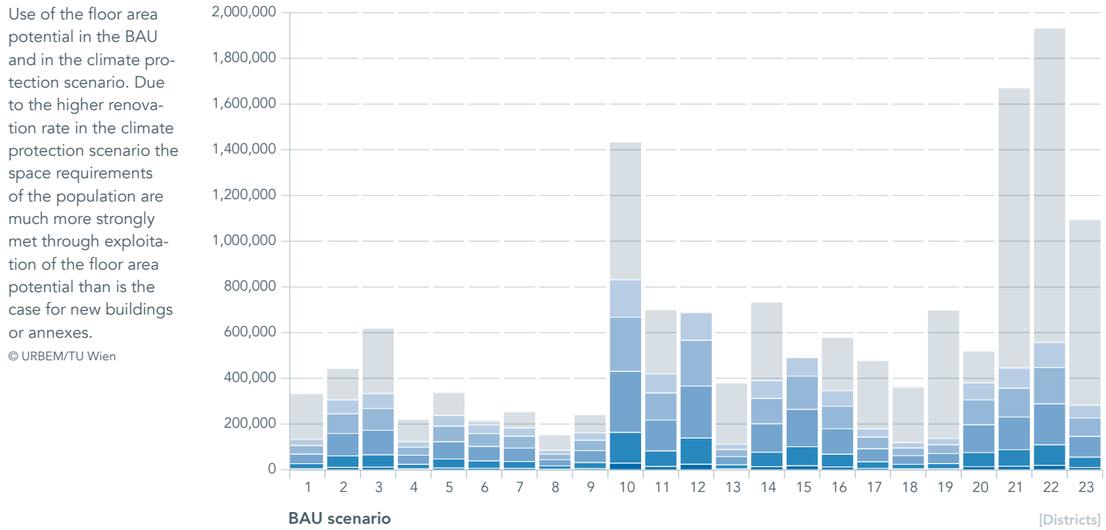
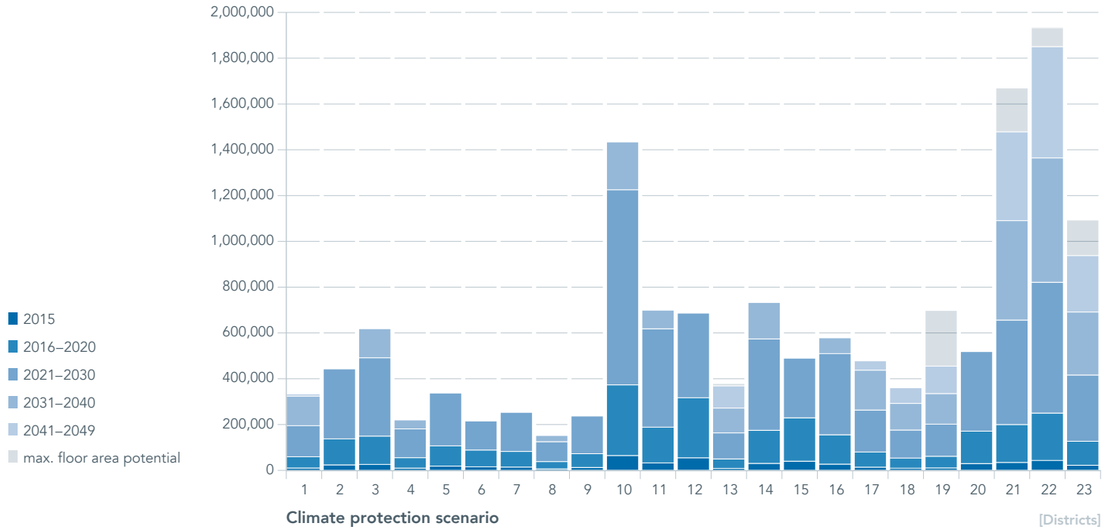




Mobility

In standard traffic planning practice traffic models are used for predicting the modal split and the traffic count.

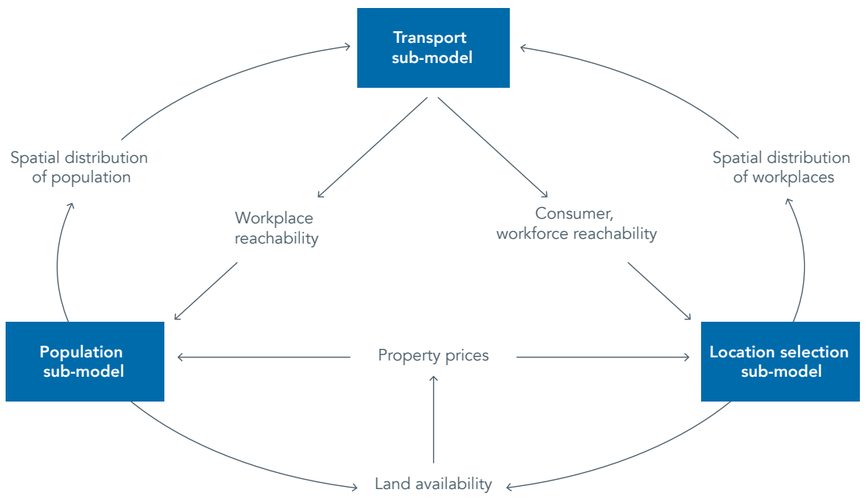
The models used are generally static, meaning predictions are only made for the status in a target year, not the path taken to reach the target. Moreover there is usually no feedback loop linking capacity changes and traffic demand. Fleet models for prediction of market share for alternative drive technologies do exist, but are rarely used in practical traffic planning.

A relatively new approach is the use of dynamic models and superposition of land use, traffic and fleet models.

Dynamic models of this type simulate the interactions in the settlement and traffic system at discrete time steps until a defined time horizon is reached. Models of this type take feedback within and between the observed systems including capacity changes and traffic demand into account. This procedure also enables detailed analysis of the cause-effect relationships underlying the observed changes in mobility behaviour. The relationships and structures within the simulation model MARS used are shown in Figure 20.

Figure 20

Basic structure of the dynamic integrated land use and traffic model MARS[17].



[17] P. Pfaffenbichler; The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Acitivity Relocation Simulator) – Development, Testing and Application: Dissertation; Technische Universität Wien: 2003.

The socially differentiated consideration also allows results for mobility to be displayed in a milieu-specific manner. Figure 21 shows the distance travelled per person in km per year for motorised private transport.

The deviations of the individual milieus from the mean value are very large. However, the standard deviation per milieu also allows a large bandwidth. At any rate it is clear that the socially differentiated consideration becomes much more significant, particularly when it comes to reducing the share of motorised private transport with specific measures (as shown in the example of motorised private transport in Figure 21).

Use of a dynamic model and the principles and methods of systems analysis lead to a better understanding of the system of the city and the mobility of the population. In particular it is possible to identify (longer-term) feedback loops and unintended effects of measures and policies.

Figure 21

Distance travelled per person in km per year for each milieu including standard deviation.

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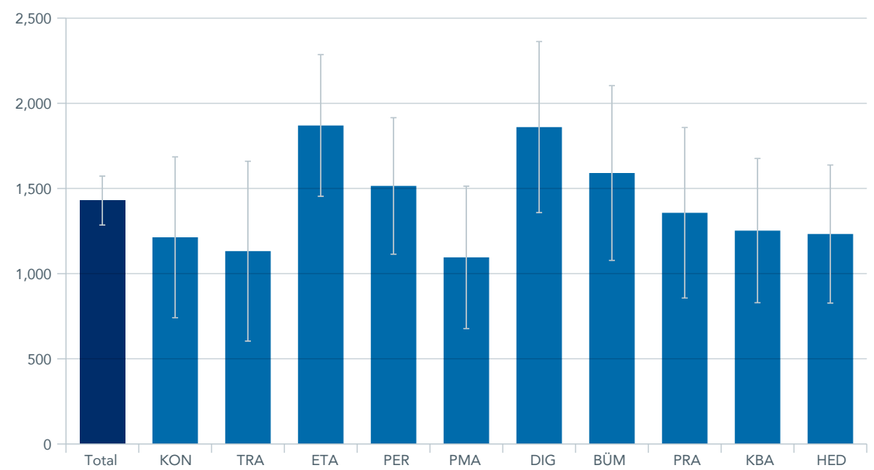

Figure 22
Distance travelled per person in km per year for each milieu including standard deviation.
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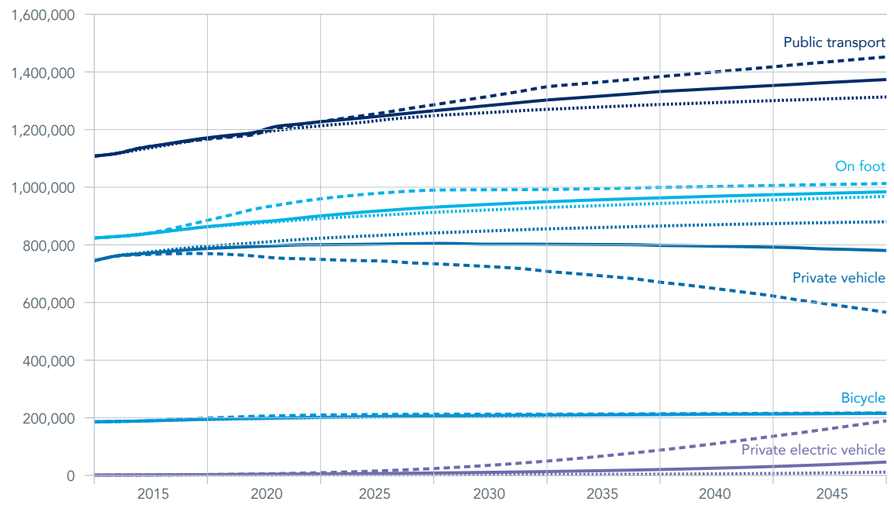


Detailed information about the methods and the simulation model MARS as well as further results can be found in Paul Pfaffenbichler's results report[18].

The MARS model can be used as a planning and decision-supporting tool. For example, measures required for achieving targets can be evaluated. Testing of different variants also considers the possible change in framework conditions or portfolios (for example: autonomous driving, e-mobility, underground vs. tram vs. bus vs. cableway etc.).

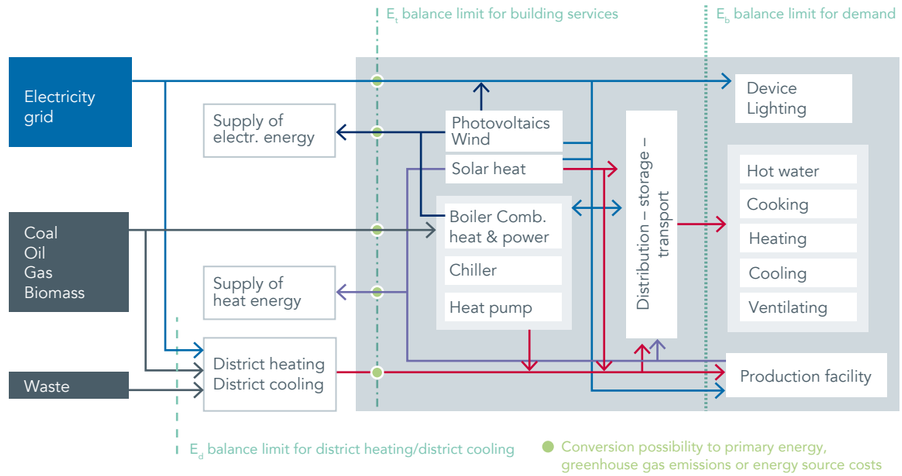
[18] P. Pfaffenbichler; Strategische Modellbildung des Wiener Personenverkehrs in einer wachsenden Stadt – Folgen ausgewählter Maßnahmenbündel für Modal Split, Stadtentwicklung und Energiesysteme; research report from doctoral programme URBEM, Technische Universität Wien: 2016.

Existing building heat and electricity load profiles

When which performance is required of the energy system by a building depends on numerous factors.

Basically it is the needs of the people for food, air, light, a certain room climate, security and activities (office work, household appliances, production facilities) that generate the requirements. For space heating this yields, together with the quality of the building technology, a specific heating requirement and, together with the building services, a time-dependent output and the annual energy requirement. Electricity can be used directly or indirectly via heat pumps as well as natural gas, district heating, biomass etc. Conversion of solar energy and wind energy and local storage of energy on the building change the demanded output and the annual consumption. Comparison of measured and predicted annual energy consumption can usually be performed with the energy meters installed in nearly all buildings which are primarily used for the annual energy statements.

Figure 23
Schematic diagram of modelling of the energy demand in buildings and the balance limit between demand (E_b) and building services (E_t) analogously to Annex 53[19]. The behaviour of the building users already influences the energy demand at the limit E_b just as the building technology does. The effect of the building services is only recorded at the balance limit E_t. As a rule the energy demand is measured at this balance limit for all buildings.
© URBEM/TU Wien



[19] H. Yoshino et al.; Final Report Annex 53, Total Energy Use in Buildings: Analysis and Evaluation Methods; International Energy Agency: 2013. ISBN: 978-4-9907425-0-8

In URBEM the method for creating scalable load profiles was also designed analogously to Figure 23. A comprehensive upstream simulation process creates more than 3,500 different load profiles as a function of building standard, building services and building use. The latter differentiates not only between office and residual use, but also according to milieu in the area of living[20].

The precise and time-resolved building energy consumption and the associated peak network load can currently only be determined through complicated and in part coupled simulation models. Usually standardised use profiles from the literature with no relation to the milieus existing in the city are employed.

Through the precalculated n-dimensional load profile matrix the creation of any load profiles, on an hourly basis for heat and electrical energy, without the need for simulations is made possible. A further innovation is the consideration of physical building and building service parameters as well as social differentiation in the time-resolved load profiles.

Detailed information about methods and the simulation model as well as further results can be found in Manuel Ziegler's dissertation[21].

Figure 24 shows the effect of the different milieus on a standardised electricity load profile. Marked differences can be seen particularly during the day when the electricity load profile is differentiated according to milieu.

Figure 25 shows the effect of the building standard on a standardised heating load profile. The differences reflect the importance of differentiating between different building standards. Through the improved thermal performance of new buildings (BC8-1) effects such as internal loads or solar inputs are very noticeable in the load profile. In contrast, these same effects are less visible through the low thermal mass and poorer thermal performance in the load profile of an old building (BC1-1).

Figure 26 shows the effect of building services on a standardised weekly heating and electricity profile. If one and the same building is heated with a heat pump rather than via district heating, the heating and electricity load profiles merge to form one electrical load profile. Through this a new load profile characteristic arises, brought on only by replacement of the energy supply. In addition it is clear that the load profile changes not only qualitatively, but also quantitatively.

Figure 24
Effect of the consumption behaviour of different milieus on residential electricity load profile.
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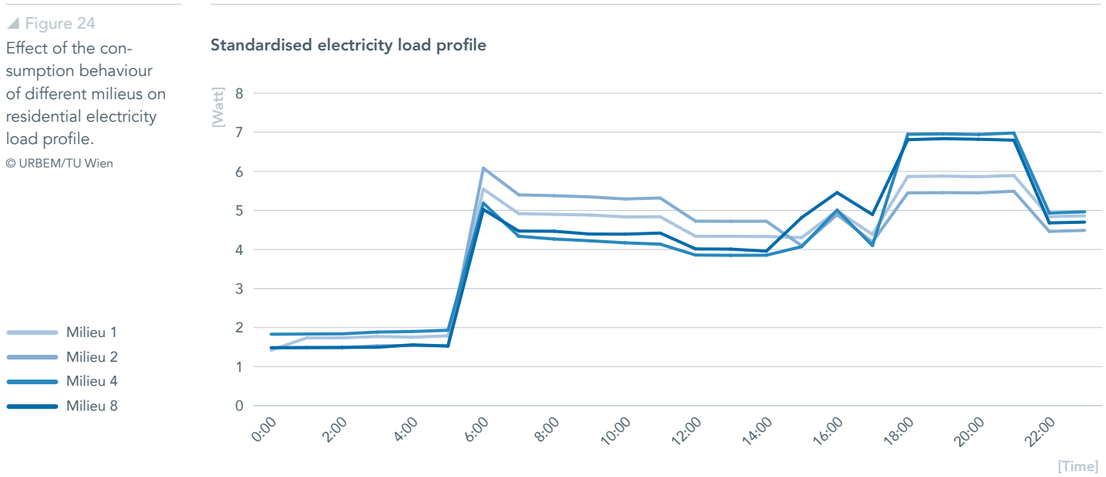


[20, 21] M. Ziegler; Methode zur Erstellung skalierbarer Lastprofile für Wohn- und Bürogebäude in Abhängigkeit zur Bau- und Haustechnik sowie der Einfluss sozialer Differenzierung für eine urbane Simulationsumgebung; Dissertation; Technische Universität Wien: 2016.

The new peak loads in the weekly profile thus also have an effect on the energy infrastructure.

Different load profile scenarios with different building types, building services and uses can be created and used, even without a solid background. The results can be immediately applied and aggregated in any way (building block, district or city level).

Through the newly developed method the time for determining the load profiles for 180,000 buildings can be reduced from years to hours.

Figure 25
Effect of different building standards on demand profile for heat for space heating (BC1-1 – Gründerzeit ("founding period") BC8-1 – new building).
© URBEM/TU Wien

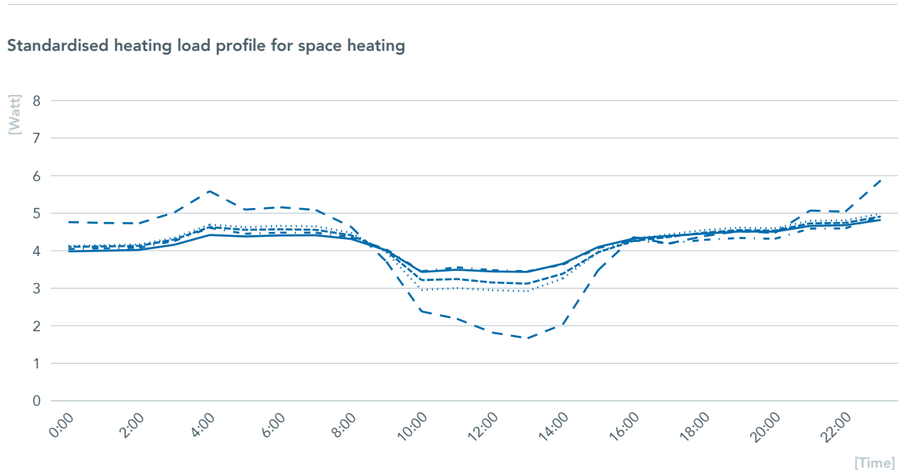
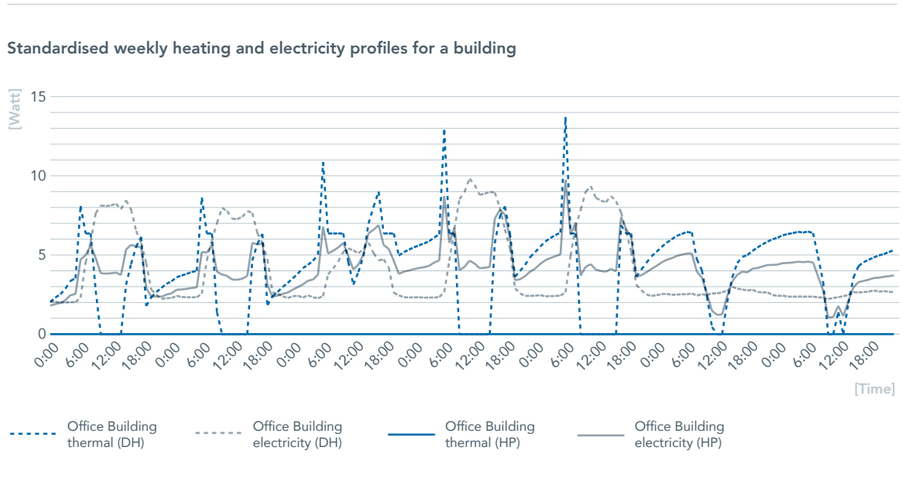


Figure 26
Differences in load profiles for an office building for two different building service solutions for energy supply. Coverage of the heating requirements by district heating (DH) results in a clearly different profile for the electricity grid than that yielded for a building in which the heating requirements are met through heat pumps (HP).
© URBEM/TU Wien



Changes in energy demand and effects on infrastructure

ENERGY DEMANDS IN BUILDINGS AND PIPELINE-BASED SUPPLY

Optimisation of the expansion of districting heating and gas networks is increasingly becoming the focus of analyses, although the changes in the demand side (space heating and hot water demands) are usually assumed to be exogenous and are not treated explicitly.

The heating system selection and renovation activities carried out on the existing building stock as a function of diverse building owner structures flow into the analyses and the effects of individual building classes are aggregated for the network expansion. This forms the basis for economic investment decisions of the network operators regarding expansion or reduction of the network.

The basis for all calculations is a simulation model which maps the building stock and endogenously simulates the future, long-term changes in energy requirements and applied technologies depending on factors such as energy prices or political conditions. All assumptions and results regarding the changes in building-related energy requirements are always aggregated to a building block. On the basis of the simulated changes in heating requirements and the information on the selection of energy source, the potential for district heating can be determined over time. With an optimisation model, investment plans for the network operators can be derived by means of the information on how far each building block is from the district heating network or the gas network.

Through this research work within the framework of URBEM it was possible to analyse in which areas the expansion of district heating and in which the expansion of gas networks is advantageous. This analysis helps to avoid doubly and multiply installed infrastructure and thus reduce distribution costs.

The role of regulatory frameworks in this context could influence energy demand in the building stock as well as the expansion of the existing network infrastructure and was included in the analyses.

Figure 27 shows the predicted reduction in heating requirements for 2015, 2020, 2030 and 2050 for each of the three URBEM scenarios. It can be seen that in the example shown the average distribution costs in euros per megawatt-hour (MWh) will increase for Viennese districting heating and for the gas network until 2050. This can mainly be attributed to the fact that the expected heating sales will drop, but the costs for maintenance of the infrastructure will continue to be incurred. Additionally, especially for district heating from 2035, reinvestments for maintaining the district heating network will increasingly be anticipated.

Figure 28 shows a breakdown of individual cost components. In the climate protection scenario greater investment costs in the buildings area are expected because higher renovation rates co-financed through higher funding (public costs) can be observed. However, through these increased investments the annual energy costs can be reduced from the level in the BAU scenario even though the climate protection scenario is based on higher energy prices.

Optimised district heating and gas expansion plans are applied for analysis of networks prior to implementation for determining how a reduced energy demand affects distribution network costs and CO_2 emissions. The analyses show how reinvestment costs due to doubly installed infrastructure can be lowered.

Detailed information about methods and modelling as well as further results can be found in Sara Fritz' dissertation[22].

[22] S. Fritz; Economic assessment of the long term development of the building heat demand and the grid bounded supply; Dissertation; Technische Universität Wien: 2016.

Figure 27
Changes in heating demand to 2050 in the various scenarios (left) and prediction of changes in distribution costs in the gas and district heating networks in the reference scenario (right).
© URBEM/TU Wien

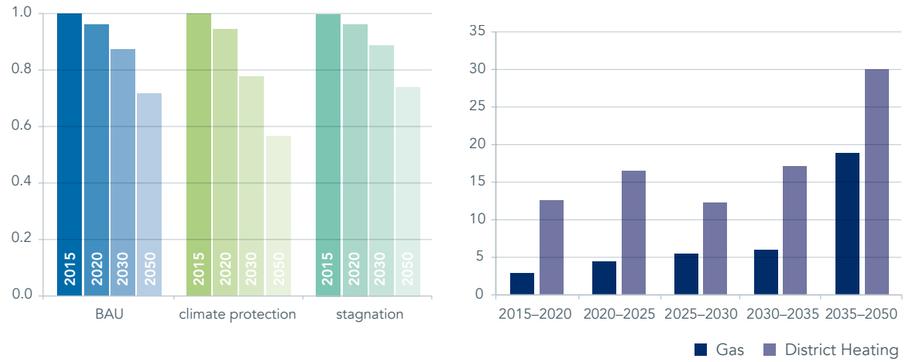
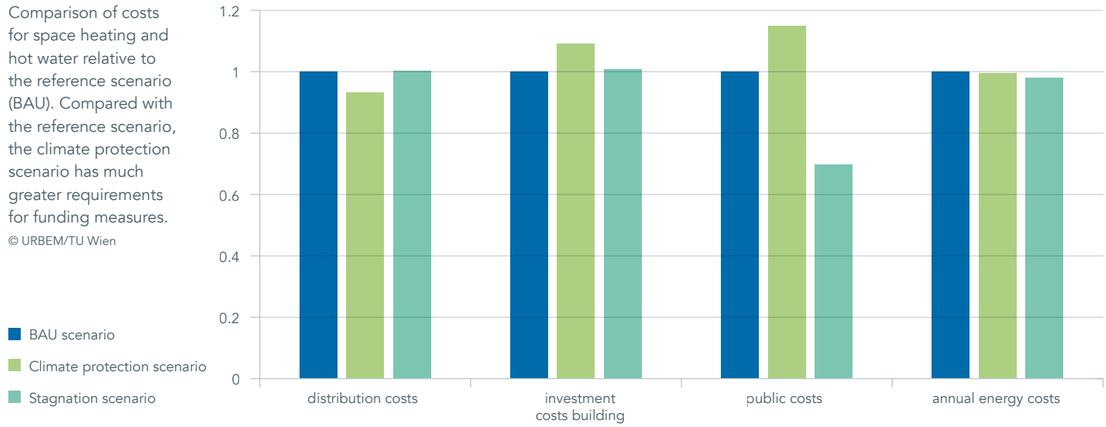


Figure 28
Comparison of costs for space heating and hot water relative to the reference scenario (BAU). Compared with the reference scenario, the climate protection scenario has much greater requirements for funding measures.
© URBEM/TU Wien



ENERGY DEMANDS RESULTING FROM MOBILITY

The following assumptions were made based on the Compett[23] project for determining the electric vehicle share in the three URBEM scenarios of BAU, stagnation and climate protection:

- The developments defined by the climate protection scenario correspond to those of the Delight scenario and the results of the logistic growth model. There is a mutually stimulating and intensifying interaction between political measures to promote e-mobility and technological developments. This leads to rapidly sinking purchase prices for electric vehicles, increasing range and strongly increasing model variety. Subsidies and exemptions remain valid for much of the observation period. The share of electric vehicles increases accordingly in Vienna to around 20 % and in the surrounding area to somewhat more than 25 % in 2050.
- The stagnation scenario is characterised by stagnation of the global economy and withdrawal of national climate measures. Moreover it is assumed that no societal preferences for energy-saving technologies can be identified and the poor investment climate hinders their development. These circumstances essentially correspond to the assumptions made in the Oblivion scenario in which there is a vicious circle between political negligence and lack of technological progress in e-mobility. Subsidies and exemptions are rolled back, purchase prices for electric vehicles drop only slightly, an increase in range is stalled and the offered model variety stagnates. The share of electric vehicles increases in Vienna and in the metropolitan area by no more than 1 %.
- The reference scenario BAU operates between these two poles. Today's trends persist in the climate protection policy. New developments in technology are funded primarily from the EU side. For the BAU reference scenario it is assumed that the annual growth rates correspond to the mean growth rates of the Delight and Oblivion scenarios. The share of electric vehicles nearly reaches 4 % in Vienna and nearly 8 % in the surrounding area.

Figure 29 shows the changes in electricity demands due to charging of electric vehicles to 2050 analogous to the increasing share of electric vehicles. It is clear that much higher electricity demands can be expected primarily in the climate protection scenario.

The results for greenhouse gas emissions for motorised private transport in consideration of all three URBEM scenarios shown in Figure 30 are similar. Here as well the climate protection scenario has by far the greatest impact.

[23] N. Fearnley, P. Pfaffenbichler, E. Figenbauer, R. Jellinek; E-vehicle policies and incentives – assessment and recommandations, Compett deliverable 5, Oslo: 2015.

Figure 29
Changes in demand for charging current energy.
© URBEM/TU Wien

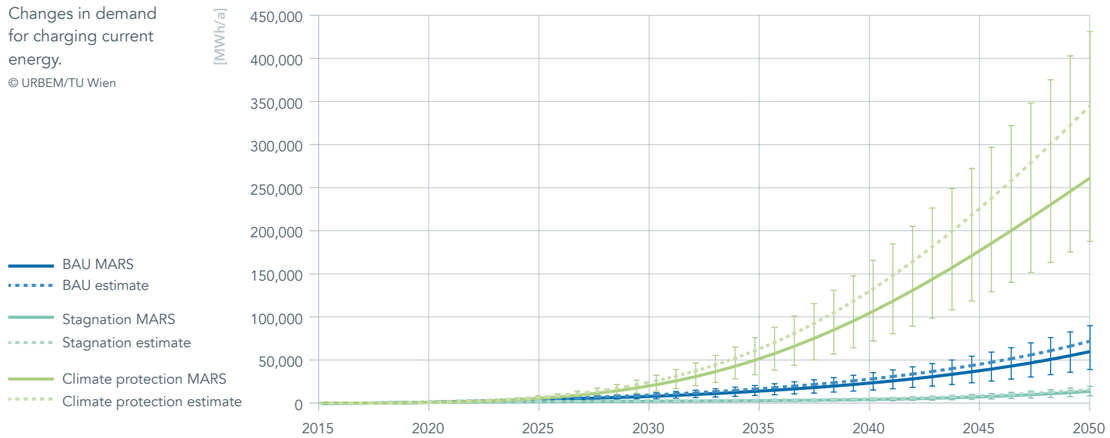
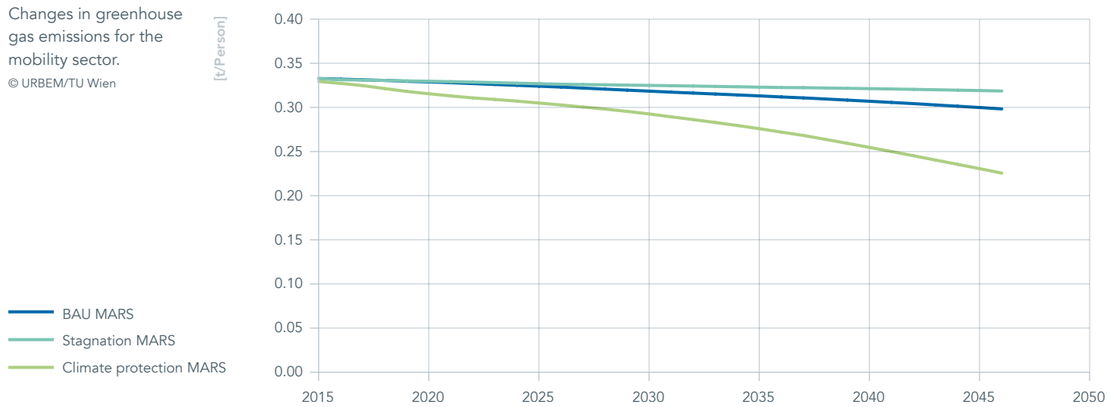


Figure 30
Changes in greenhouse gas emissions for the mobility sector.
© URBEM/TU Wien



2.9
50

Heating networks – gas network

Development of the currently fastest analysis tool for large gas and district heating networks

Commercial calculation programs for analysis of operating states of district heating and gas networks are already available. Thermohydraulic and compressible-hydraulic calculation methods for large mesh district heating and gas networks represent a new approach. In combination with the grid calculation for electricity grids, it enables network analysis across all energy sources and the results are displayed in a comprehensible manner via localised visualisation of the networks. The load profiles developed in URBEM provide input as a function of the building structure. This represents a major advancement because previously only standard load profiles were considered for this.

Through the new calculation methods potential bottlenecks ("constraints") and reserves can be quantified and localised both in the existing infrastructure and in the scenarios. Direct evaluation of different scenarios is thus enabled and questions pertaining to energy supply of potential urban expansion areas can be answered long before implementation is commenced.

The effects of the three URBEM scenarios on the differential pressure in the primary network of the Viennese district heating system and on the operating pressure in the low-pressure gas network are shown in Figure 31.

Detailed information about the methods and the simulation model as well as further results can be found in Dominik Bothe's dissertation[24].

◢ Figure 31
Changes in the differential pressure in the primary district heating network (top) and in the operating pressure in the low-pressure gas network (bottom) for the BAU, climate protection and stagnation scenarios for 2050 in relation to the loads in the reference year of 2013.
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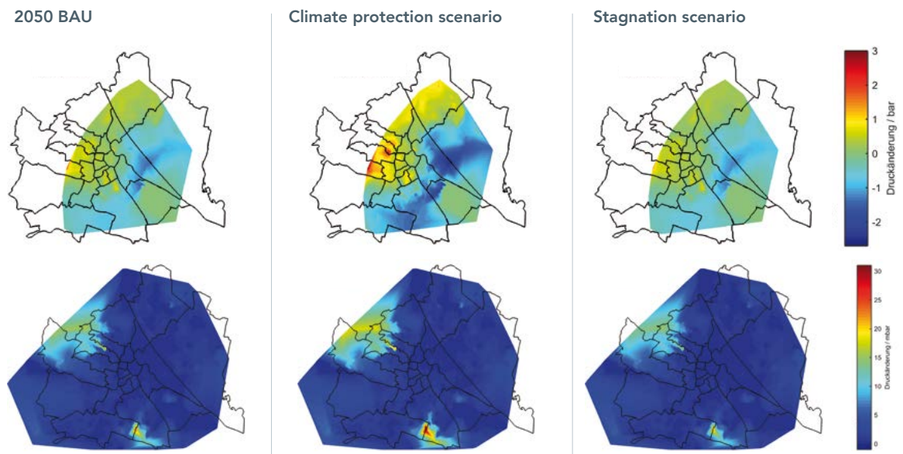


[24] D. Bothe; Modellierung und Simulation von weit verzweigten, vermaschten Netzen für thermische Energie und Gas; dissertation; Technische Universität Wien: 2016.

2.10
51

Electricity grids

Development of the fastest algorithm for load flow calculation in urban electricity grids and identification of potential for increasing flexibility through energy nodes

Numerous commercial and freely available tools exist for electricity grid calculations. The URBEM development consists in adapting the existing methods and procedures such that they can be used in a context spanning all energy sources and with numerous interfaces to other infrastructures.

The electricity grid model developed in URBEM feeds load flow calculations for service areas from geographically localised substations into a calculation method embedded in the Python software environment. Energy source-spanning analyses are additionally carried out for all supply networks existing in the area under consideration. The calculations are based on the load profiles developed within the scope of URBEM and differing from the previous standard load profiles.

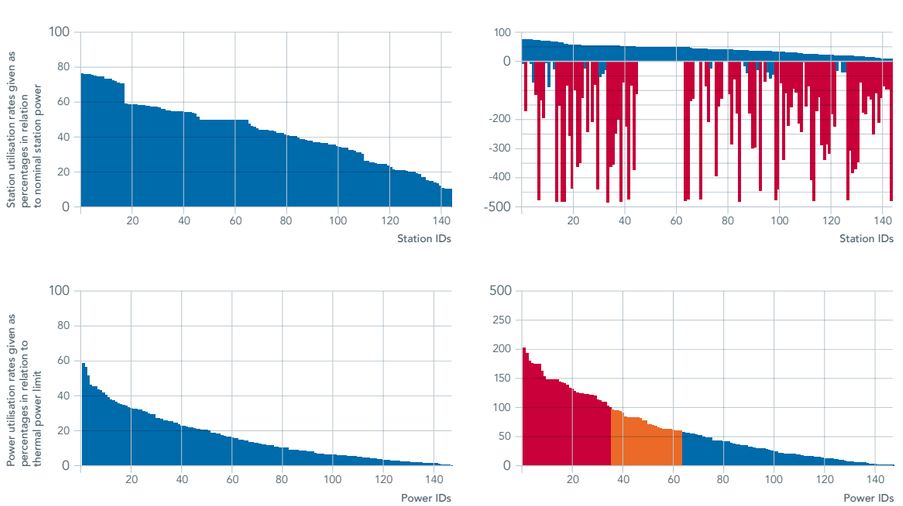
Statements regarding grid expansion variants for urban development areas can be made based on all energy sources existing at the location and different scenarios can be rated. For example the analysis of electricity grid capacities for taking up thermal loads in the case of downsizing of gas or district heating networks is possible. The effects of expansion and incorporation of renewable energies into the electricity grid operations can also be tested.

Figures 32a and 32b show the equipment utilisation rates in consideration of the solar energy potential for the suburban medium-voltage grids of two substations. In each case the base year 2015 is compared with the theoretical maximum solar energy use.

Detailed information about the methods and the simulation model as well as further results can be found in Thomas Kaufmann's dissertation[25].

◢ Figure 32a
Equipment utilisation in suburban medium-voltage grid of KAG substation for base year 2015 (two figures to the left).

Equipment utilisation in suburban medium-voltage grid of KAG substation for theoretical full exploitation of solar energy potential(two figures to the right).
© URBEM/TU Wien



[25] T. Kaufmann; Modellierung und Simulation von urbanen Stromversorgungsnetzen in einem multiskalaren Gesamtmodell; Dissertation; Technische Universität Wien: 2016.

Figure 32b

Equipment utilisation in urban medium-voltage network of KAU substation for base year 2015 (two figures to the left).

Equipment utilisation in urban medium-voltage network of KAU substation for theoretical full exploitation of solar energy potential (two figures to the right).

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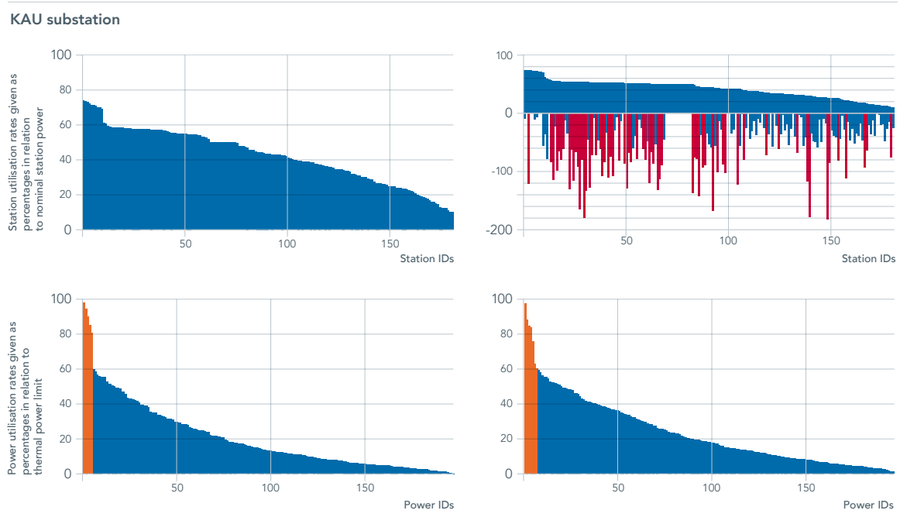

Communication network for smart grids

"Smart" technologies are already being used in the energy sector – one example is the smart meter which communicates bidirectionally, can be switched off remotely and will be implemented in the next few years.

The technically possible security suffers under cost pressures from large-scale roll-outs. Use of security concepts depends on the purchase price on the one hand and the state of the art of the technology on the other.

Already now a social threat scenario exists due to attacks on critical infrastructure (e.g. electricity grids) by malware (computer viruses, worms, Trojan Horses etc.) with a simultaneous lack of awareness by decision-makers. There are already precedence cases in which multiple electricity grids in the Ukraine were directly affected (see BlackEnergy attack in December 2015[26]). Several hundred thousand people were cut off from the power supply in the winter. To date, the automated operation of the affected electricity grid control systems could not be restored either due to lack of availability of destroyed components or because of lasting damage. The electricity grids will be operated rudimentarily by hand until they are completely repaired.

A simplified representation of a procedure for a generic cyberattack is given in Figure 33.

Thus, for example, a power failure in Vienna could result in economic losses amounting to about 250 million euros already on the first day (exponentially increasing). According to estimates society already starts degenerating after four days and the consequential effects worsen steadily. Security gaps cannot be categorically ruled out – endangerment scenarios that cannot be imagined today can still occur in the future. Hence it is necessary to erect hurdles and prevent a large bandwidth of cyberattacks. Architecture and topological security are critical factors in achieving this.

Figure 33

Procedure taken by an attacker during a generic cyberattack (kill chain).

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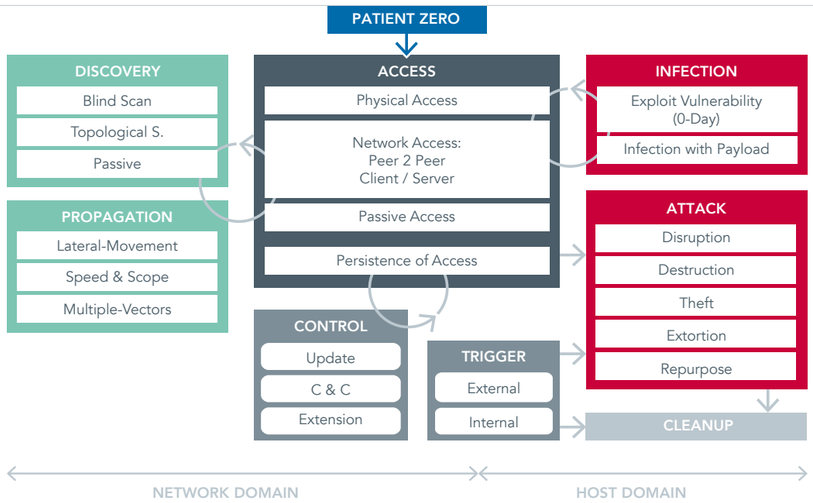

[26] Robert M. Lee, Michael J. Assante, and Tim Conway. Analysis of the Cyber Attack on the Ukrainian Power Grid: 2016, sowie F-Secure Labs. BLACKENERGY & QUEDAGH – The convergence of crimeware and APT attacks. White Paper 1030745, F-Secure Labs, Helsinki: 2014.

Only through the combination of multiple security measures can attacks be hindered ("Malware containment in smart grids"). An optimised strategic plan can be determined through analysis of various architectures. Only when an understanding of how malware behaves in different network architectures is gained in the research stage can conclusions regarding effective countermeasures be drawn. These flow into the resilience criteria and into a resulting catalogue of measures which serves as a tool for real implementation.

By developing countermeasures in the field of topological security and combating malware, it is possible to avoid the immense costs incurred by grid failures. This concerns, for example, economic losses on a macroeconomic scale as well as social upheaval in the event of a sustained power failure. The usual reliability of the power grids and other critical infrastructure is an important basis for our habitual way of living.

These attack and failure scenarios can be calculated through simulations and estimates. The costs of ensuring the security of critical infrastructure are relatively low in relation to the potential losses. However, the probability of loss is low.

Measures increasing network resilience include the following:

- Organisation
- Provisions for administration
- Provisions for passwords
- Initial and further training of operators
- Development of a response/recovery plan
- Provisions for data security
- Implementation of the correct network topologies
- Prevention of network penetration

Detailed information about the methods and the simulation model as well as further results can be found in Peter Eder-Neuhauser's dissertation[27].

Figure 34
Simplified representation of network topologies.
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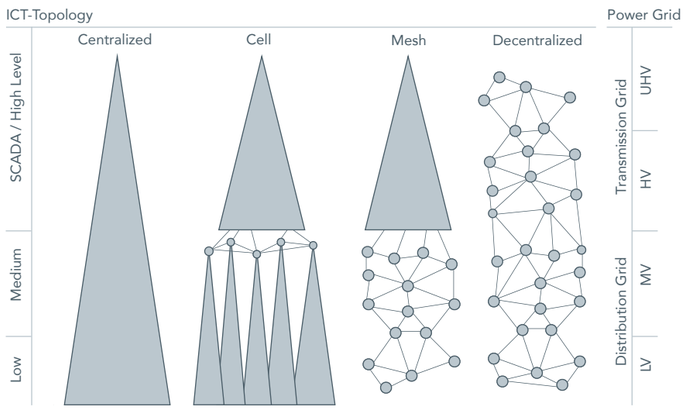


[27] P. Eder-Neuhauser; A model for malware containment and resilience in smart grid communication systems; Dissertation; Technische Universität Wien: to be published.

Optimised district heat generation

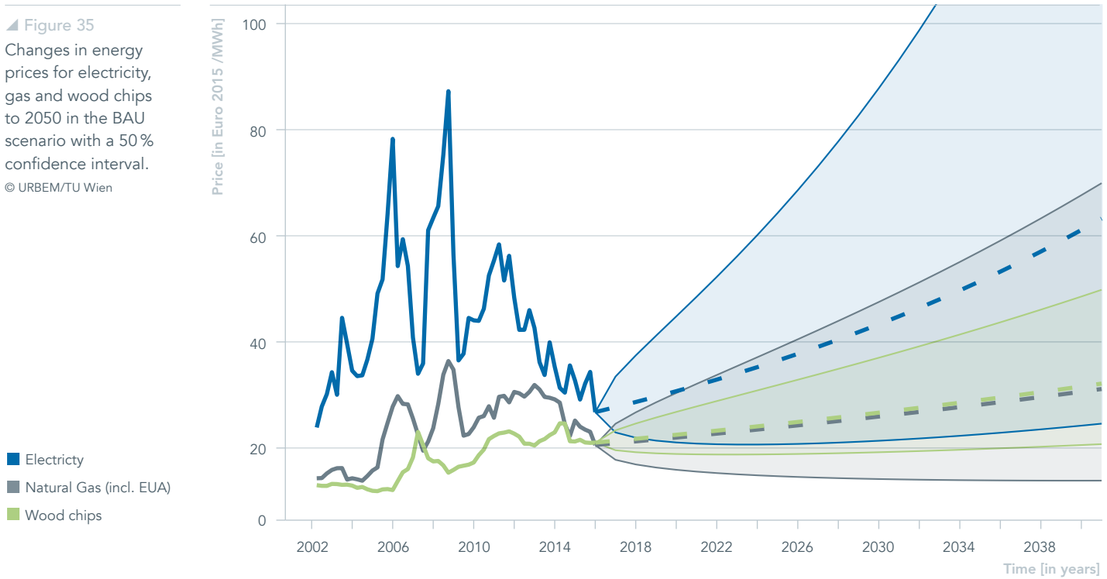
The cost-optimised compilation of power plants in a district heat generation portfolio is usually carried out with future energy price assumptions.

For heat generation technologies there are high cost risks due to strongly fluctuating energy prices (particularly natural gas and electricity). Low-cost technologies today can become the most expensive after just a few years. For this reason consideration of energy price risks for long-term investment decisions (25- to 35-year operating period for power plants) is essential.

Because the various technologies are suitable to various degrees for base load coverage or peak load coverage, the shape of the load duration curve (see Figure 36) affects the investment decision regarding a new power plant portfolio. Following from this, optimised district heating generation portfolios were determined using a stochastic optimisation model for various levels of investor risk aversion.

Detailed information on the methods and the simulation model as well as further results can be found in Nikolaus Rab's dissertation[28].

Figure 35
Changes in energy prices for electricity, gas and wood chips to 2050 in the BAU scenario with a 50 % confidence interval.
© URBEM/TU Wien



[28] N. Rab; Modern portfolio theory applied to district heating generation expansion planning; Dissertation; Technische Universität Wien: to be published.

In the URBEM approach the compilation of this type of optimised district heating power plant park is carried out with cost and risk optimisation, as shown in Figure 37.

By considering the optimised portfolio diversification it is possible to perform strategic planning with cost and risk optimisation. How district heating operators can safeguard their investments in district heat generation capacities in light of negative developments in the energy market can thereby be shown.

Figure 36
Load duration curve for district heating and distribution of district heating demand base load, intermediate load and peak load for Vienna between 2012 and 2014.
© URBEM/TU Wien

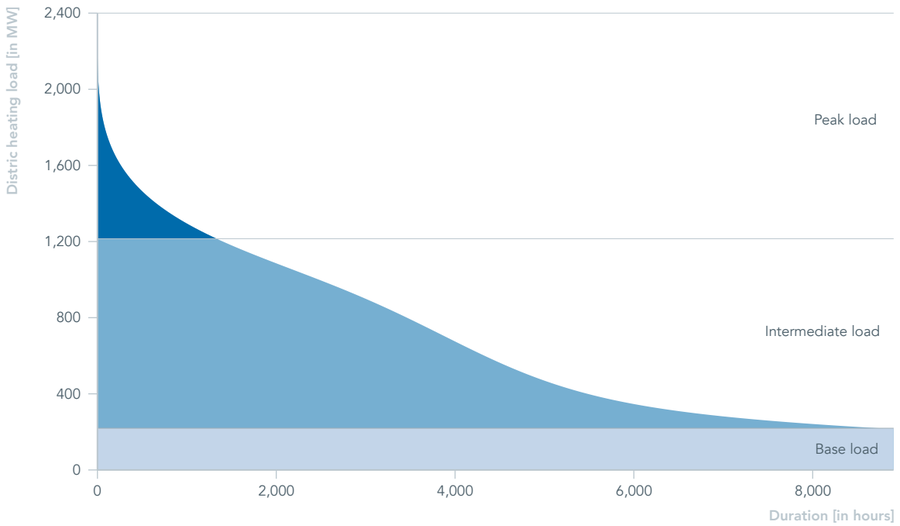


Figure 37
Risk associated with district heating production costs for optimised portfolios in the BAU scenario for cost-optimised compilation of the Viennese district heating power plant portfolio for a given risk preference.
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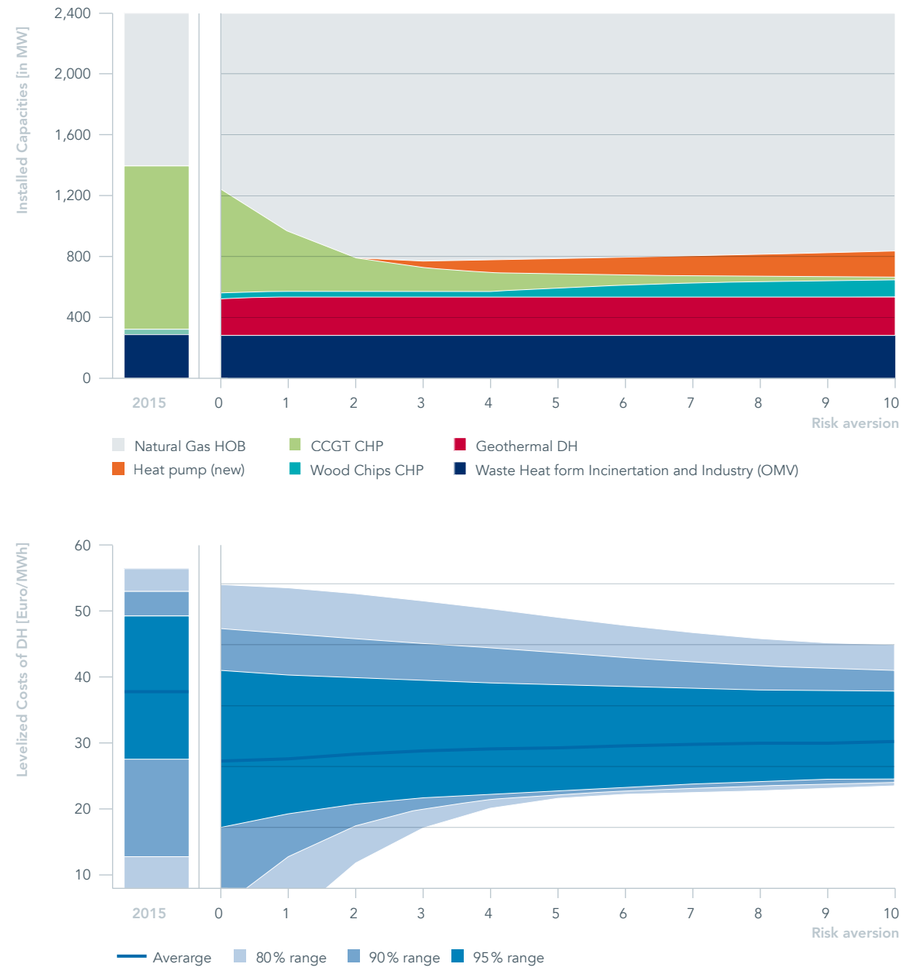

3

urbem
prototype

3

urbem prototype

In this section the prototype developed in the course of the URBEM-DK project is presented. Through the close cooperation with Wiener Stadtwerke some of the models could be calibrated with real data from the City of Vienna. All developed models were also validated and integrated uniformly into the URBEM prototype.

Der URBEM prototype is an interactive environment which unites the sub-models of all doctoral students and visually displays the results.

Detailed information about the model development and the validation process for individual models can be found in the dissertations or research reports. A further focal point is the securing of interoperability and data protection. The interdisciplinary approach resulted in the development of not only a new method for merging the sub-models, but also methods that make all sub-models interoperable as a whole.

The visual representation of the results in real time makes the URBEM prototype interesting for several stakeholder groups. On the one hand, detailed network computations can be carried out as a function of the actual building stock and, on the other hand, effects can be represented by different urban development possibilities.

Therefore, in addition to detailed calculations, superordinate questions can also be answered. In addition, all results are subject to certain scenarios which have been defined and documented in advance.

This makes the URBEM prototype flexible in terms of the scope and the time horizon under consideration. The prototype was developed and calibrated using data from the City of Vienna. Therefore, there are also confidential data in the background which are necessary for various calculations. The issue of data protection is therefore a sensitive issue which has been carefully dealt with within URBEM. Depending on the stakeholder, data or results are displayed in aggregated or detailed form.

Vienna Smart City Operating System – VISCOSE

Complex demands are placed on various systems (buildings, transport modes, electricity, gas and district heating networks etc.) by diverse decision-makers within the scope of analysis of development variants.

These requirements may not only conflict with one another, but also change dramatically over time. Due to the high dynamics and complexity that result from this, the efficient design, development and function of such systems become more and more demanding. Current decision support systems do not allow for holistic integration of all relevant elements in order to provide an integrated view that is essential for planning.

The system developed in URBEM allows a holistic as well as customised look at the problems through a new integrated view. It enables the development of smart city applications that help experts from different disciplines quickly and easily present significant results to provide effective support for decision-making processes.

The interdisciplinary decision-making and planning support tool has been developed for holistic urban planning and management. It is a cloud-based system that integrates and links the different research areas of the individual participants of URBEM.

The system allows a unique holistic and integrated view of many complex facets based on models developed by different experts to support complex decision-making processes. In doing so, the relevant aspects regarding compliance and data protection were explicitly taken into account.

Figure 38 shows the structural design of the operating system.

Figure 38
Schematic diagram of software architecture and other relevant components of the URBEM prototype. The Constraint Manager plays a key role in data protection by ensuring compliance with data protection rules, among other things.
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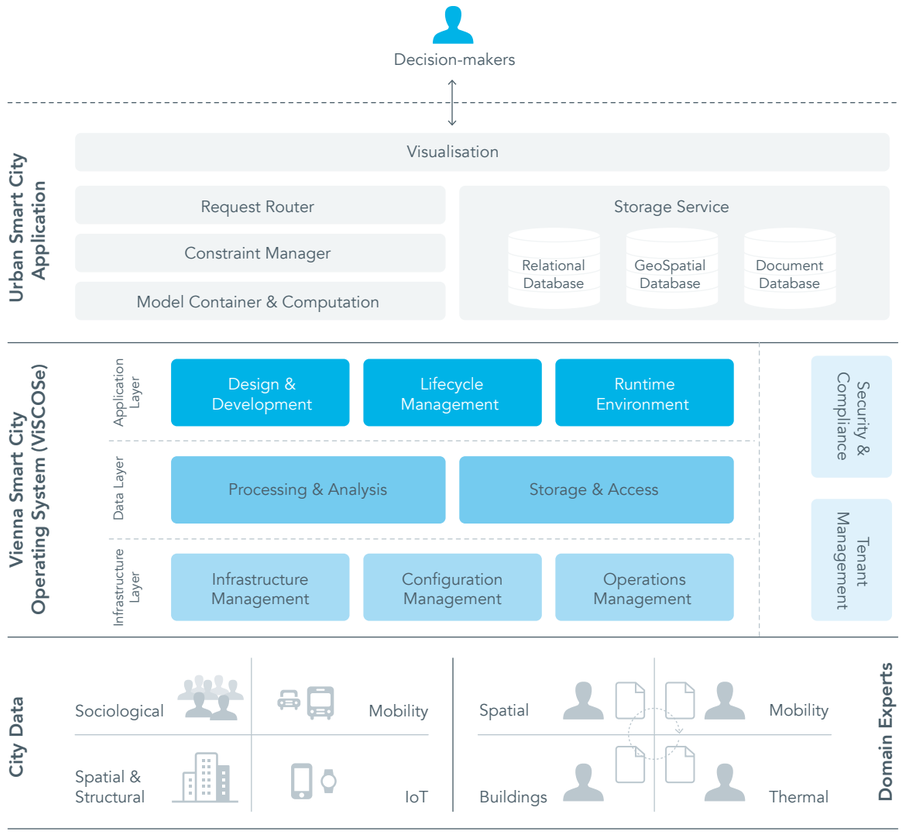

Data protection during use

The key steps in the analysis of development variants are:

- creation of scenarios and development variants for analysis
- conduction of analyses – creation of predictions
- visualisation of results without compromising data protection interests

In the process of analysis data must be processed by various parties possessing the respective permissions to view the data in detail. In the analyses other individuals use these data indirectly or, given the required permissions, directly.

The interactions between stakeholders and data providers run via the request router. Before the data exchange can take place, the Constraint Manager checks which access restrictions the logged-on user has. A user can simultaneously be a data provider and a stakeholder. The data and model requests are compared with the data and model access permissions of the user. If no conflicts exist, the request is routed to the Layer Infrastructure & Resource Management of the Smart City Operating System (SCOS) to request the resources..

If, however, the request does not match the authorisations, the security & compliance layer attempts to redirect the data and model service streams using NOMADS (Schleicher 2015) such that the request can be answered without impermissible information exchange. A brief example can provide a better understanding: Provider P2 needs information from Provider P1 on behalf of P3. However, P2 does not have the permission to request this information. P1, however, is authorised to request information and services from P2. Therefore, P2 sends information and services to P1, the data is processed by P1 and the result is then delivered directly to P3.

If the attempt to request the specific data is not successful, a rough estimate is calculated based on the statistically representative data according to the user permissions. The Model Container & Computation component together with the Storage Service ensure the correct application of the expert models. They are deposited as a so-called container – meaning the program and all required data and environment parameters. A container can create an instance at any time and be run in another environment. The only requirement for this is that a platform[29] supporting creation and running of containers exists.

The application runtime & management layer checks permissions when containers access data. This occurs when input data are sent to the container and when output data are retrieved and stored in the Storage Service. An example of this is shown in Figure 39. The representation is adapted specifically to the stakeholder and enables a detailed and localised display.

Unlike in Figure 40, the representation selected here applies only to one district and does not allow any detailed or confidential information to be displayed.

Detailed information about the methods and the model as well as further results can be found in Johannes Schleicher's dissertation[30].

[29] z. B. Docker (www.docker.com) oder Rkt (github.com/coreos/rkt).
[30] J. Schleicher; Engineering and management of heterogeneous smart city application ecosystems; Dissertation; Technische Universität Wien: to be published.

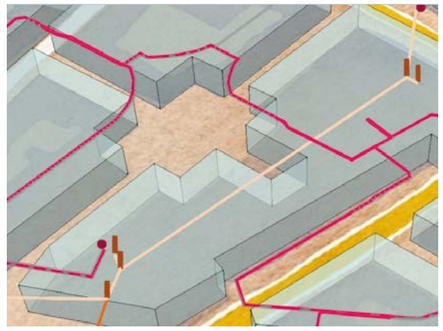

Figure 39
Detailed display of network data – colour coding could be used e.g. to indicate the utilisation rate of equipment. This view is only available to network operators.
© URBEM/TU Wien

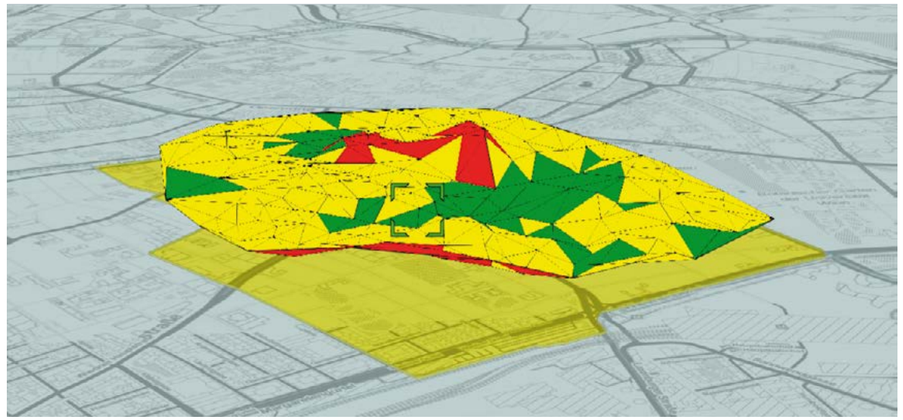

Figure 40
Display of network data with colour filling – colour coding could be used e.g. to show a problematic equipment state in a district. This infrastructure view is available to everyone analysing a development variant without detailed knowledge of the infrastructure position.
© URBEM/TU Wien

Visualisation of results

The URBEM visualisation provides a graphical overview of the various domains of the expert group – technology, planning and sociology.

The decision support tool thus yielded facilitates communication during the planning processes, information localisation and detailed information allocation. Through this information can be viewed in various contexts. The user interface is shown in Figure 41.

The various content levels of the visualisation prototype are shown in the following table. The outline shows the countless parameters available at the display and content levels.

Figure 41
URBEM visualisation prototype user interface.
© URBEM/TU Wien

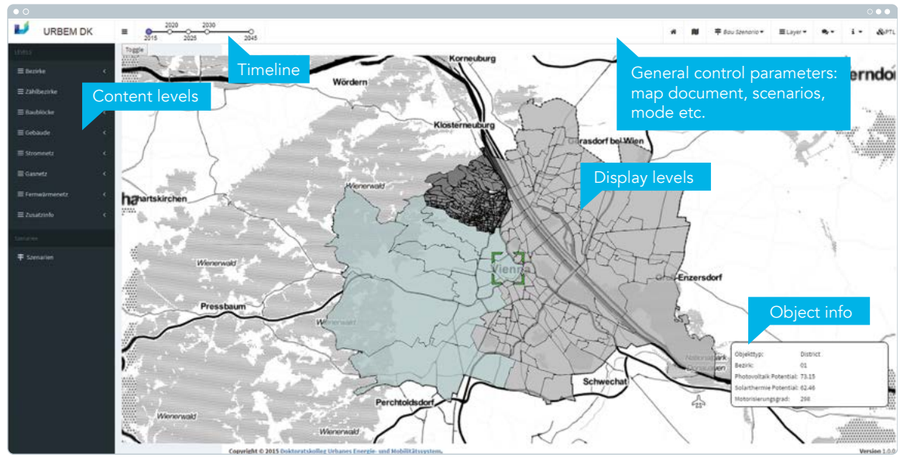

Table 11
Overview of content levels in the URBEM visualisation prototype.
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Display level	Content level	Description
District	Milieus/Population composition	The Sinus milieus group people with similar lifestyles and ways of living, i.e. basic values and general attitudes towards work, family, leisure time, money and consumption (group of like-minded individuals).
	Milieu localisation	Distribution of Sinus milieus in Vienna according to district.
	Modal Split	The modal split between public transport, bicycle transport, transport on foot and motorised private transport at the district level.
	Traffic count	The morning traffic flows for various traffic modes per district.
	Photovoltaics	The output of the installed photovoltaic systems at the district level.
	Solar heat	The output of the installed solar heating systems at the district level.
Enumeration district	Renovation rates	The determined annual renovation rates for all building categories within an enumeration district.
	Floor area potential	The possible floor area potentials (e.g. addition of storeys to buildings) at the enumeration district level.
	Building area potential	The possible building area potentials (e.g. annexes, extension buildings and new buildings) at the enumeration district level.
Block	Local energy requirements	The calculated total energy requirements for space heating and domestic water, aggregated for the individual blocks, based on the results from the simulation model.
	District heating energy requirements	The total energy requirements for space heating and domestic water covered centrally through district heating, aggregated for the individual blocks, based on the results from the simulation and investment optimisation model.
	Energy requirements in %	Share of total heating requirements taken up by total energy requirements for district heating, the percentage share of the total heating requirements for domestic water and space heating taken up by district heating.
	Gas connection	Indicator for whether a block is connected to the existing gas network.
	District heating connection	Indicator for whether a block is connected to the existing district heating network.
Building	Floor area potential	The possible floor area potentials (e.g. addition of storeys to buildings) at the building level.
Electricity grid	Electricity grid	The electricity grid utilisation rates for stations and lines at the block level.
Gas network	High-pressure network	Velocities and pressure in existing lines at the block level for the high-pressure network.
	Niederdrucknetz	Geschwindigkeiten und Drücke in Bestandsleitungen auf Baublockebene für das Niederdrucknetz.
District heating network	Low-pressure network	Velocities and temperature in existing lines at the block level for the primary network.
	Return network	Velocities and temperature in existing lines at the block level for the return network.
Power plant park	Power plant park	Total power plant park portfolio.

As an example, Figure 42 shows the distribution of milieus at the district level using the district display level and the milieu content level. The user interface thus provides a comprehensive overview and rapid access to detailed information.

The modal split can also be shown at the district level. As can be seen in Figure 43, the necessary information is shown in high resolution for the district under consideration.

Figure 42
Milieu distribution at the district level.
© URBEM/TU Wien

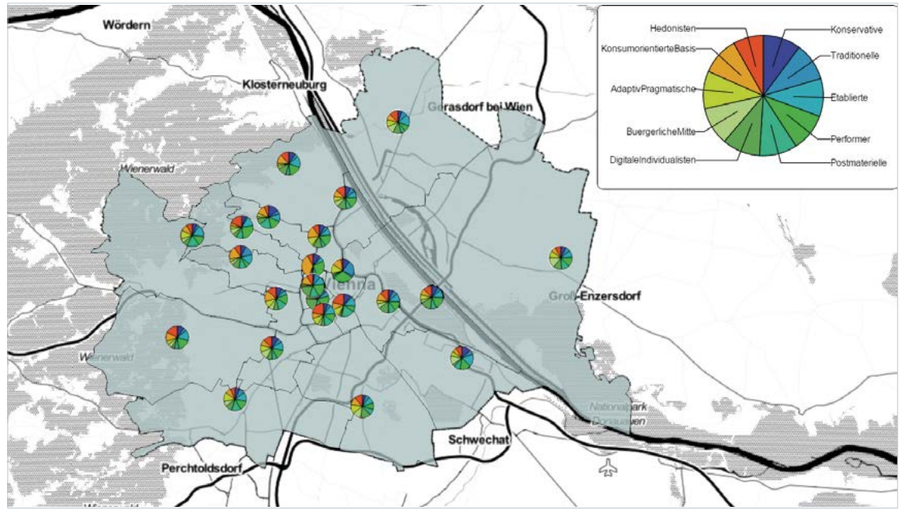
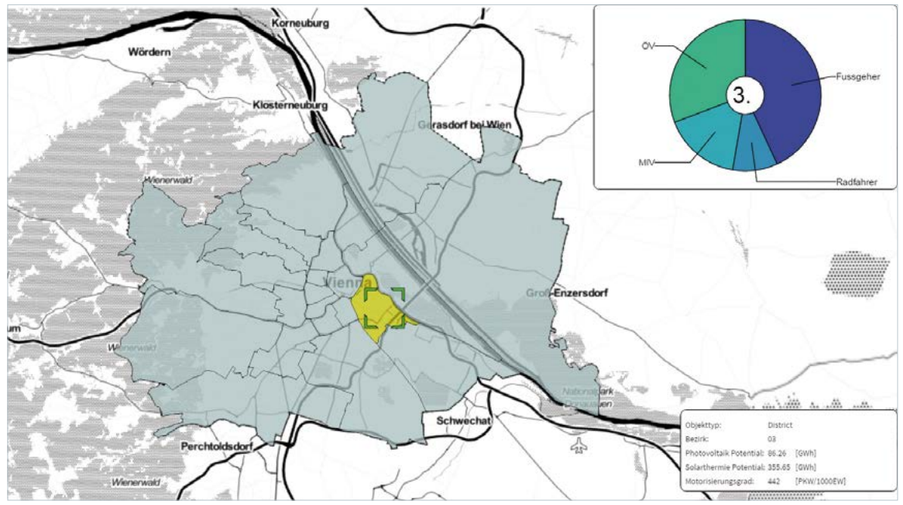


Figure 43
Modal split at the district level.
© URBEM/TU Wien



Building from this, it is also possible to display the traffic flows from a particular district. Line sizes and colours can be shown in a legend for visually displaying results in a qualitative and quantitative manner – see Figure 44.

A similar approach is also shown in the illustration of floor area potentials at the enumeration district level. The surroundings allow an informative presentation of the complex results of a whole city on a district level (Figure 45).

Figure 44
Morning traffic flows for various transport modes.
© URBEM/TU Wien

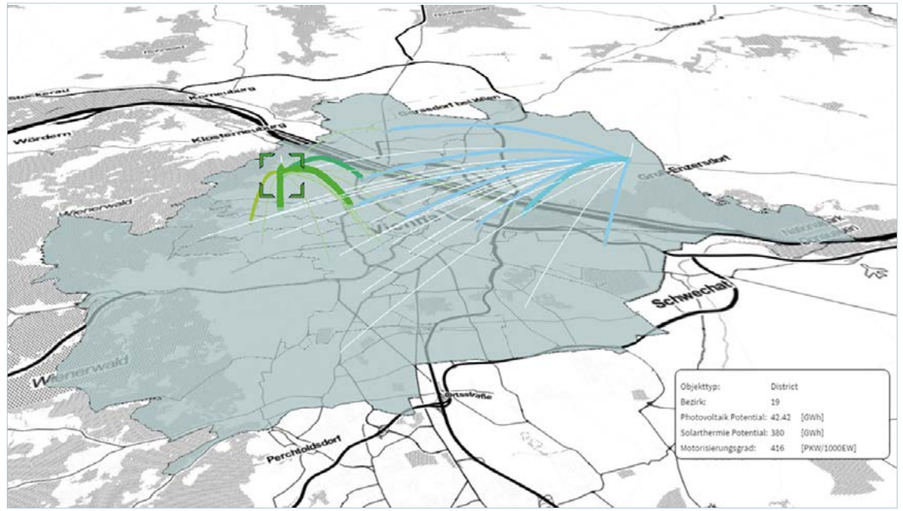
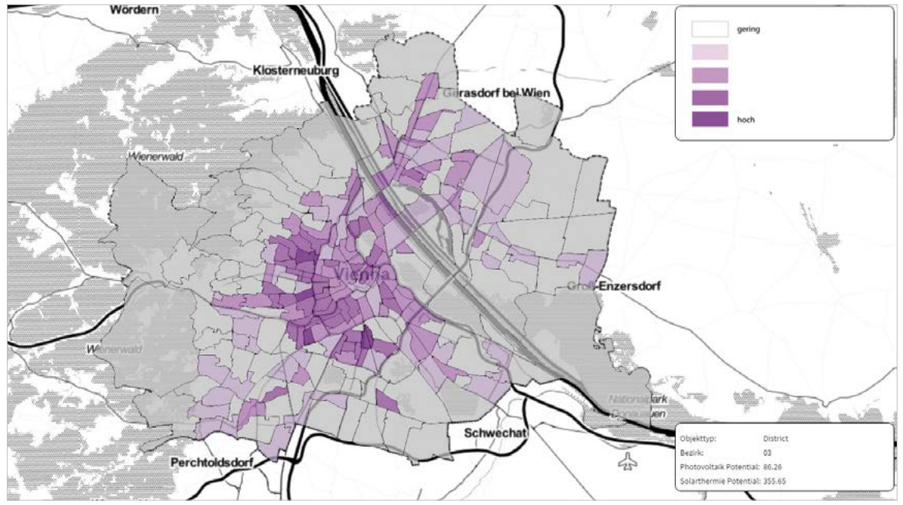


Figure 45
Floor area potential at the enumeration district level.
© URBEM/TU Wien



Building on the display of the floor area potential at the enumeration district level in Figure 46, the detail level can be raised to the building level.

Figure 46 shows how to switch from a global two-dimensional display to a detailed three-dimensional display.

Both figures showing the floor area potentials can be supported by colour legends. This not only provides a fast and comprehensive overview for all of Vienna, but also rapidly supplies detailed results at the building level.

Due to the high interdisciplinary requirements within URBEM, however, it is necessary to provide visualisations across multiple disciplines. Only in this way can relationships be represented within a single decision support tool. Figure 47 shows an example of the superimposition of the floor area potential on the network infrastructure.

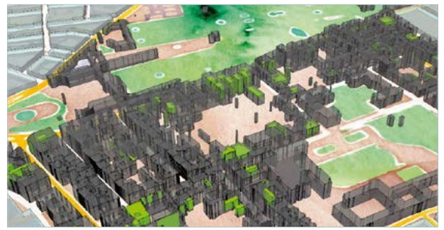


Figure 46
Floor area potential at the building level.
© URBEM/TU Wien

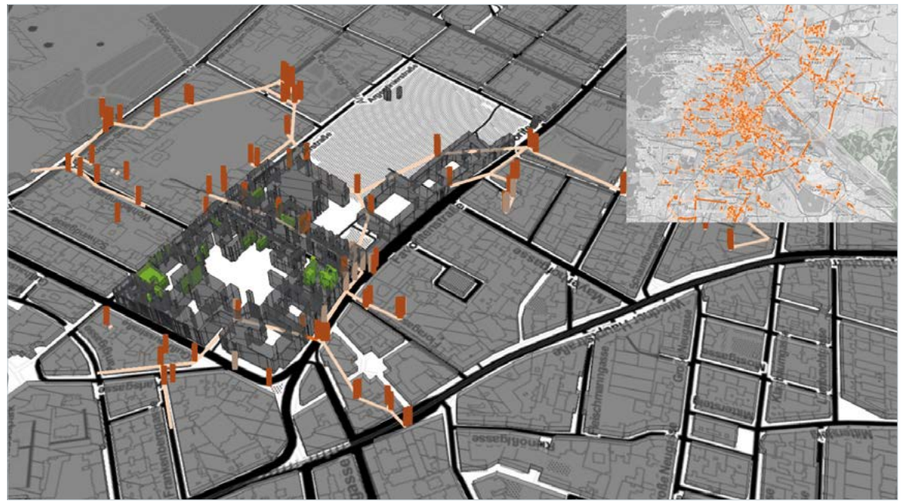


Figure 47
Floor area potential and network infrastructure (top right) at the building level – 2D site plan.
© URBEM/TU Wien

Detailed information about the methods and the visualisation model as well as further results can be found in Julia Forster's dissertation[31].

[31] J. Forster; Strategische raumbezogene Visualisierung; dissertation; Technische Universität Wien: 2016.

Answering questions with URBEM

Stakeholders pose exemplary questions to the URBEM environment to enable the complexity and interdisciplinary nature of the questions to be demonstrated. A custom team of experts from URBEM is put together to handle each particular question in a logical manner. This process is described here by means of a sample question.

How will changes in building heating demands impact the loading of the future district heating network (gas network)?

Such a question cannot be answered by individual experts due to its high complexity. Moreover new questions arise during the process of answering of the question. It is important to ensure that comprehensive preliminary information (e.g. which people from which milieus live in which buildings with which building standards) is available and that the results can be displayed stakeholder-specifically after the problem is successfully solved – see Chapter 3.2.

Figure 48 shows the flow of information from the beginning to the end with the same chronological order as is found in URBEM for the corresponding research question. The path to be taken for comprehensively answering the interdisciplinary question is yielded from this.

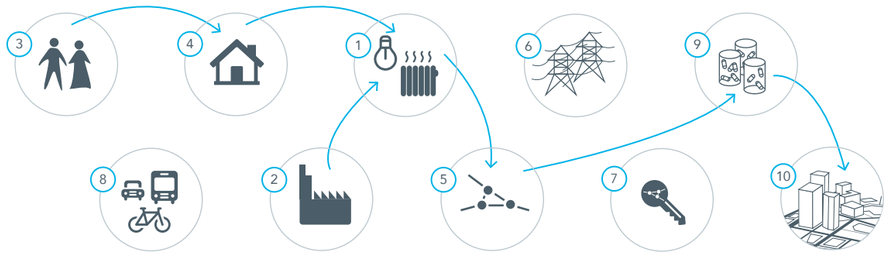


Figure 48
Flow of information between the URBEM disciplines in the URBEM planning test run for investigation of different supply variants. The numbers correspond to the respective dissertation topics – see Chapter 5 URBEM Contributors on page 94.
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The URBEM scenarios (see Chapter 2.3) have a major impact on future changes in demand. Figure 49 illustrates the district heating requirements from 2020 to 2050 for two selected scenarios.

It can clearly be seen that the district heating requirements are strongly dependent upon the selected scenario, although both scenarios are climate protection scenarios.

For the adapted climate protection scenario the previous legal framework conditions were adapted such that the pipeline-based heat supply was guaranteed, whereas the choice of pipeline-based energy source could be made by the network operator.

Furthermore the district heating requirements have a significant effect on the future changes in infrastructure. Using the results shown in Figure 49 as a basis,

Figure 49
Comparison of district heating requirements in the period 2020–2050 for the climate protection scenario and the adapted climate protection scenario.
© URBEM/TU Wien

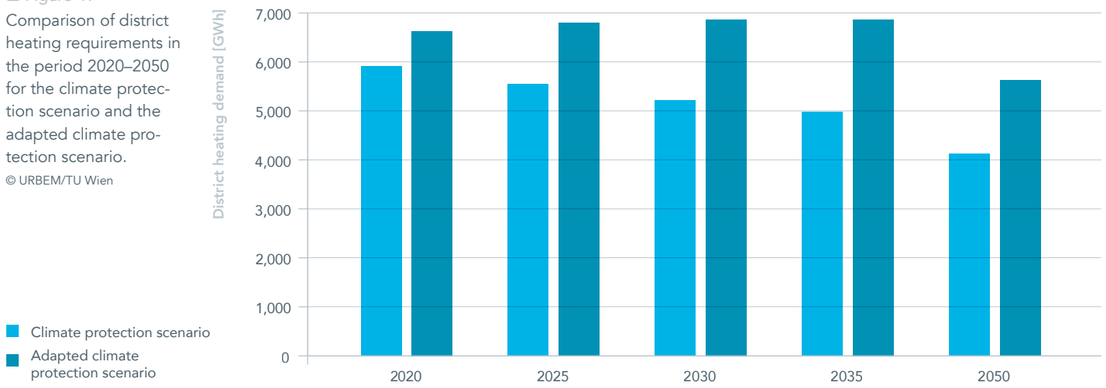

Figure 50
Enumeration districts in Vienna and distribution between Viennese district heating and gas connection for the climate protection scenario (left) and the adapted climate protection scenario (right). The districts in which the gas share exceeds the district heating share of the heating requirements in 2050 are shown in blue. The hatching represents the district heating share.
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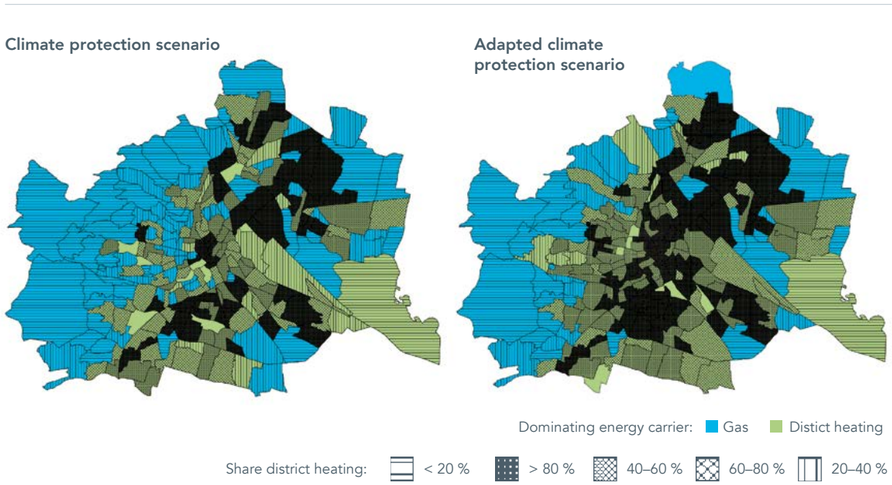


Figure 50 shows the distribution between the Viennese district heating network and the gas network for the two scenarios.

It is clear that, depending on the scenario, the gas network or the district heating network in Vienna can cover most of the heating requirements in different enumeration districts. The differences are similarly marked when the CO_2 emissions of all scenarios are compared. The reduction of CO_2 emissions for both climate protection scenarios amounts to approx. 75–80 %.

On the other hand, neither the BAU nor the stagnation scenario achieves a reduction of 60 %. The choice of scenario thus shows a clear influence on the changes in demand to 2050.

As a further example, the urban development area around Vienna's Westbahnhof is available as an URBEM test planning area – see Figure 52.

Figure 51
Changes in greenhouse gas emissions for space heating and domestic water in the three scenarios.
© URBEM/TU Wien

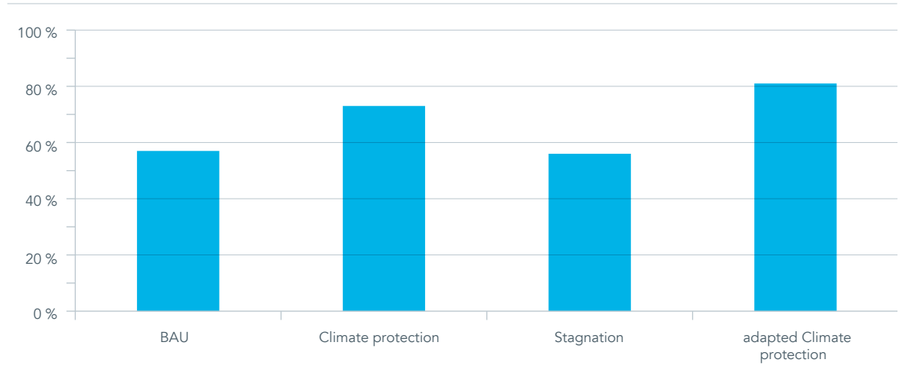
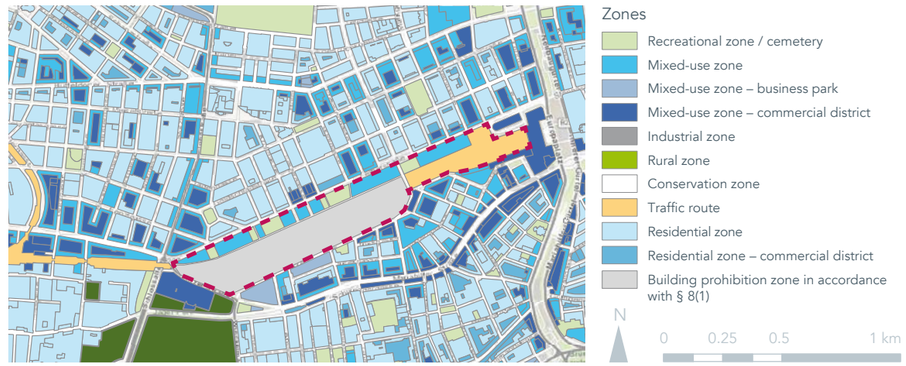


Figure 52
Current zoning in Vienna's Westbahnhof district.
© URBEM/TU Wien



Based on the current zoning dedicated planning steps for developing city districts (Figure 52) can be used to initiate and later also display the subsequent steps.

The planning steps are based on a series of sub-models from multiple experts from URBEM. Only in consideration of multiple models can solid recommendations be derived for the URBEM test planning area around Vienna's Westbahnhof. A sample master plan is shown in Figure 54.

With the master plan comes the question of energy supply. The information flow between all involved URBEM experts for the examination of various supply variants for the URBEM test planning area is shown in Figure 55.

The effects on the electrical infrastructure of the planning area can be presented by means of the building stock, floor area potential, population growth, distribution of the milieus and load profiles of all buildings. Based on the buildings in the blocks with their energy consumption and solar potentials, different supply possibilities for the urban expansion area are compared by means of predefined network expansion variants. If the extension of district heating and gas is not implemented in this area and a purely electrical supply is selected it can be seen that no valid operation is possible with the specified network expansion variant. However, if district heating is extended in the expansion area the security of supply can be guaranteed both in the heating network and in the electricity grid.

Figure 53
Diagram of the planning sections for the development of urban areas.
© URBEM/TU Wien

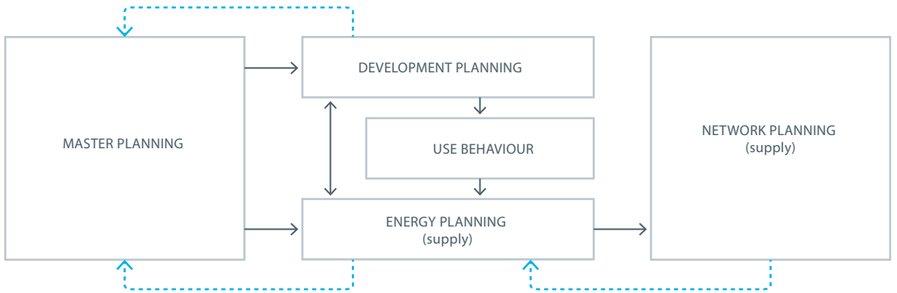


Figure 54
Master plan for the URBEM test planning area of Vienna's Westbahnhof.
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Figure 55
Information flow between the URBEM disciplines in the URBEM test planning area for examination of different supply variants. The numbers correspond to the respective dissertation topics – see Chapter 5 URBEM Contributors on page 94.
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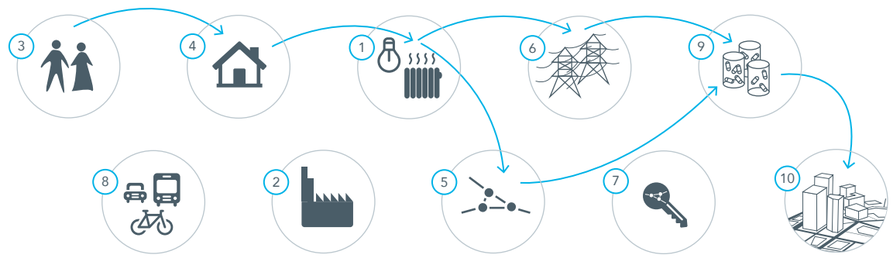

Figure 56 shows the effect on the electricity grid for pure electrical heat supply, combined heat supply with Viennese district heating and pure electrical heat supply in combination with photovoltaic systems and accumulators. All results are given at the block level. Thus any breach of data protection laws can be avoided.

The colour-coding of the infrastructure provides rapid information about the security of supply based on the selected supply variant. Various variants can be compared in real time with the proven models.

Figure 56
Utilisation rate in the electricity grid for stations and lines at block level (top), utilisation rate in the electricity grid for stations and lines in combination with the heat supply for the district provided by district heating at block level (middle) and utilisation rate in the electricity grid for stations and lines in combination with PV systems and accumulators at block level (bottom).
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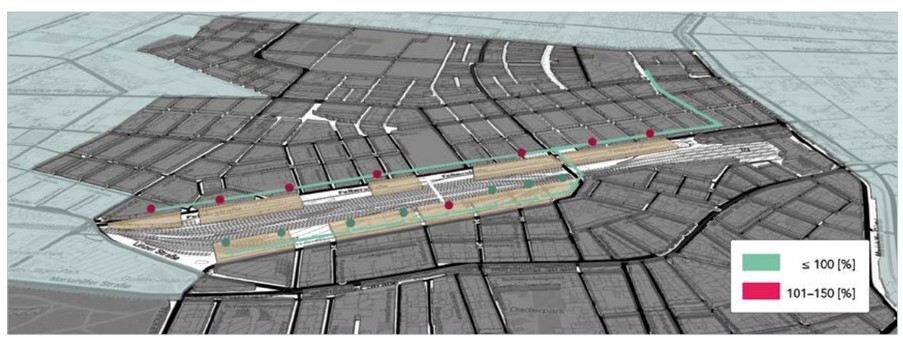

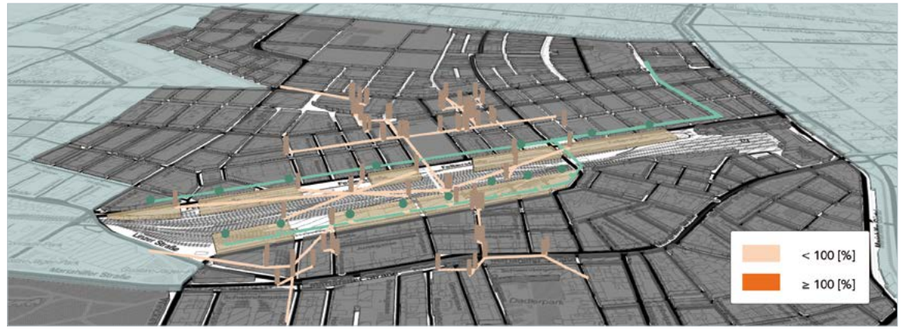

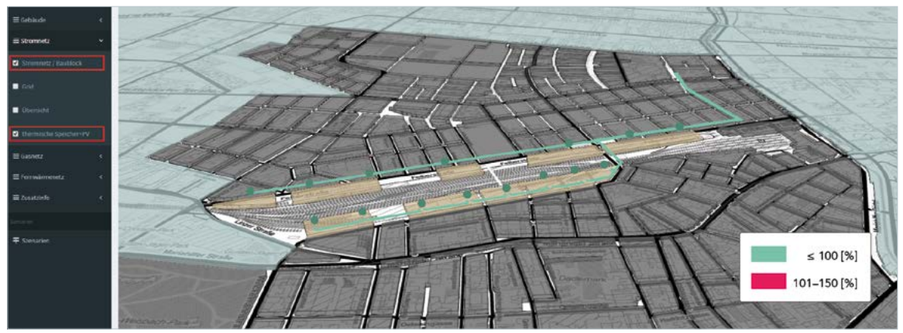

A process analogous to that used for the energy supply is used to represent the traffic circulation in the URBEM test planning area. Figure 57 shows the associated information flow for all participating URBEM experts.

In step one the modal split for the planning area is shown for the base year as well as for a forecast for 2045 in the environment (Figure 58). However, the modal split including the expected changes is not sufficient.

Figure 57
Information flow between the URBEM disciplines in the URBEM planning test run for investigation of the traffic circulation. The numbers correspond to the respective dissertation topics – see Chapter 5 URBEM Contributors on page 94.
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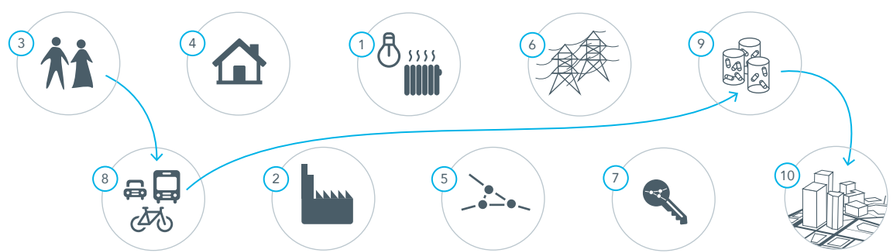
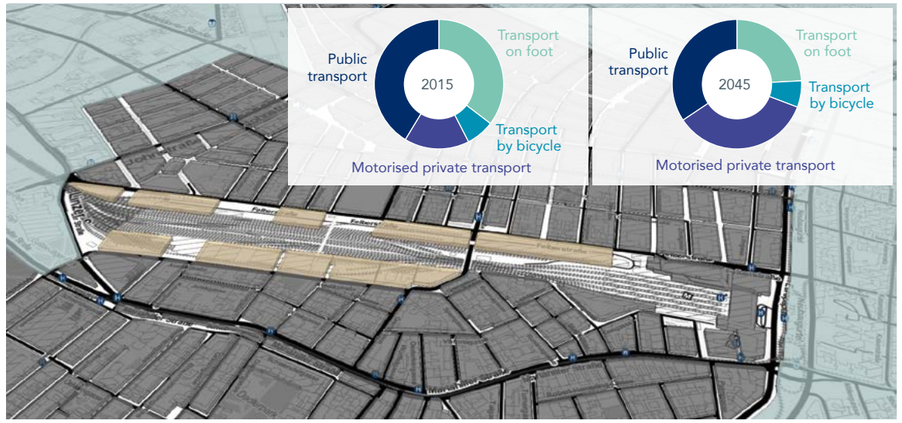


Figure 58
Share of travellers according to transport mode in the 15th district for 2015 and forecast for 2045.
© URBEM/TU Wien



To be able to make detailed statements regarding the traffic circulation, it is essential to know the traffic flows originating from a planning area. These can also be displayed in the URBEM environment (Figure 59).

Figure 59 clearly shows both the direction of the traffic flows and an indicator of traffic volume.

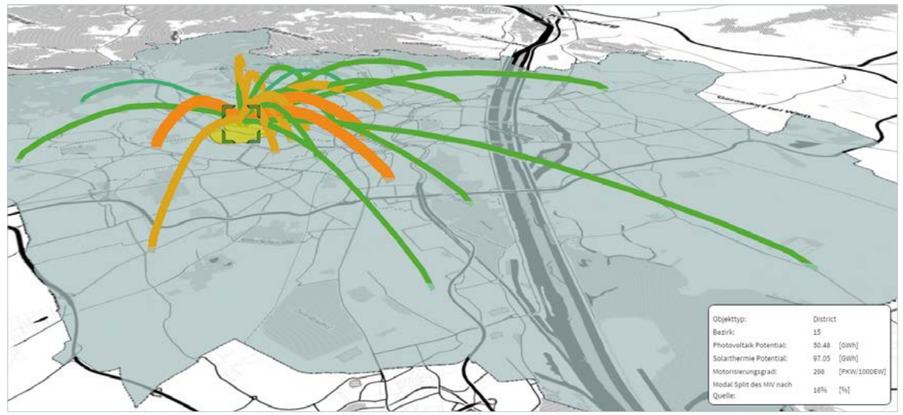


Figure 59
Display of traffic flows from the 15th district to other municipal districts of Vienna. The diameters and proportions of red indicate the traffic volume (greater diameter and proportion of red corresponds to higher traffic volume).
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The sample questions illustrate the high level of complexity that arises if the questions are answered on the basis of well-founded scientific methods. Hence both synchronised interaction of all models and a suitable form of representation are required.

The prototype of the URBEM visualisation is capable of displaying complex results in an easily understandable form for both individual and combined sub-models in real time. Together with the capability of answering complex and interdisciplinary questions, the URBEM visualisation makes the URBEM prototype a solid decision-supporting tool for all stakeholders.

4

how did **urbem** come about and what contributed to it?

4

Strategic cooperation between TU Wien and WSTW

The cooperation has the aim of actively shaping the necessary transformation process for the energy system and the area of mobility and furthering it through joint interdisciplinary projects. Essential to this is a sustainable partnership with a focussed strategic approach.

In 2012 TU Wien and Wiener Stadtwerke entered into a strategic cooperation to carry out joint research activities.

A holistic view of topics extending beyond individual projects and enabling a value chain to be created from the university to the company is made possible. Through a secure financing framework over a relatively long term, research topics can be treated exhaustively, which is particularly important in light of strategic and sustainability aspects. The main focus is on the exchange of know-how, the strengthening of interdisciplinary collaboration and the targeted training of young people.

The flagship initiative of this cooperation is the doctoral programme “Urban Energy and Mobility System” (URBEM-DK). TU Wien and Wiener Stadtwerke envision researching and developing a method for analysing probable variants in Austrian and global development scenarios for reaching a “sustainably serviced, affordable and liveable city”.

URBEM-DK was set up in accordance with the internal TU Wien doctoral studies programme, has a term of three years and was started in the 2013-2014 winter semester.

Topic definition and organisational structure

In summer 2012 the conceptualisation phase for URBEM-DK commenced. In this phase the primary fields of expertise needed for starting a simulation and analysis environment for the Urban Energy and Mobility System were identified in several workshops attended by experts from TU Wien and WSTW.

Building on the workshops, questions that were company-relevant according to Wiener Stadtwerke were identified. To establish the questions to be answered within the scope of the doctoral programme and to define the application areas to be treated by the different dissertations the following guidelines were jointly developed in the workshops:

- current stock: focus is on the current building stock structure in Vienna and the associated questions and issues
- framework conditions: consideration of the future dynamics of internal and external framework conditions (corporate strategy, political aims, doctoral education etc.)
- system view: central topics are changing large-scale systems and interconnections, no single aspects
- interaction/interdisciplinary character: important aspect is the interaction between various actors and the interdisciplinary approach in the doctoral programme

The ten dissertation topics were then jointly developed, formulated, coordinated and defined and the dissertation advisors were determined by TU Wien and the technical experts at WSTW and their subsidiaries. The advisory team for URBEM-DK comprised 16 professors and researchers from TU Wien as well as ten experts from WSTW; this basis was expanded over the course of the programme to include further expert advisors for technical aspects of the topics.

The scientific aspects of the project were overseen by a scientific director (professor at TU Wien). The cooperation and URBEM-DK were coordinated and carried out through the Energy and Environment Research Centre on the TU Wien side and via the Smart Cities & Regions specialist team at WSTW-Holding on the WSTW side. Wiener Wissenschafts-, Forschungs und Technologiefonds (WWTF[32]) made a decisive contribution in the research and innovation phase with its expertise in research and innovation.

[32] http://www.wwtf.at/

Recruiting

In the search for suitable doctoral students for the ten doctoral student positions,focus was on selecting the best people from the overall viewpoint of the doctoral programme. Apart from technical knowledge, cooperation skills of the doctoral students were rated highly in the selection process.

Hence a separate application and selection process was developed based on both the guidelines set forth by the TU Wien equal opportunities working group (AKG) and the application processes of Wiener Stadtwerke. Main focus was on the adequate formulation of the invitation to apply as well as on a list of criteria for the interview and the subsequent hearing.

The invitation to apply for the pre-doc positions was sent out in spring 2013 via defined scientific channels within Austria and in other (German-speaking) countries. The selection of applicants to be invited for interviews was assumed by the TU Wien faculty; the interviews were conducted by the major advisors and the co-advisors. The two or three most suitable applicants for each dissertation position were invited to a hearing in which it was ensured that all applicants were subject to the same selection process.

Lecture series

As an interdisciplinary doctoral programme, URBEM-DK offered the doctoral students a unique training environment. The integration of a large company encouraged entrepreneurial thinking.

Embedded in a highly interactive development process, the learning of competencies for successful teamwork (communication, planning, conflict management) was carried out in the course of "learning by doing". The possibility of broadening one's horizons was much higher for the individual doctoral students than would have been the case if they had been supervised separately. Particularly in the field of energy systems, the interdisciplinary approach and the ability to understand others are very useful for the future directors of R&D departments.

The curriculum of the doctoral programme comprises, among other things, two lecture series which provide both the doctoral students and their advisors with an overview of all relevant disciplines. The series took place at the start of URBEM-DK (Nov. 2013 – Jan. 2014) at TU Wien:

- Lecture series 1 ("Urban Energy and Mobility System – Scientific methods and interdisciplinary aspects") shed light on the topics handled in URBEM-DK (dissertations) from a general perspective (main topics, interdisciplinary character, understanding, definitions) as well as relevant methods. The faculty of the doctoral programme gave the lectures.
- Lecture series 2 ("Urban Energy and Mobility System – Interdisciplinary views of WSTW and City of Vienna") dealt with the actual state (technology and operation or current methods), the strategic outlook and coming challenges as well as framework conditions from the point of view of the city. Lecturers came from the companies in Wiener Stadtwerke, the municipal departments of the City of Vienna and amongst builders.

Teambuilding

At the start of the doctoral programme it was important to bring together all participants to formulate the expectations of how the cooperation should be shaped and how the defined dissertation topics could be concretely realised.

Prior to the official part of the kick-off event a teambuilding session took place for all advisors and doctoral students to get to know each other, document common points of view and concretise the next steps.

One project week in October 2013 and another one in February 2014 gave the doctoral students the opportunity to form a common understanding of the tasks, establish a common language and work out common solutions or clarify the necessary and relevant interfaces.

In autumn 2015 the students came together for three months of intense work with the aim of optimising the interfaces and the data exchange.

Teambuilding
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Events

In addition to the teambuilding sessions, organisation-internal meetings were held regularly, get-togethers involving all participants twice a year and a two-day workshop at half time.

Through these interdisciplinary approaches and activities it was ensured that the scientific programme and achieving of milestones was possible within the given time and that the initially defined guidelines were followed as well as that the simulation and analysis environment for the urban energy and mobility system took into account all aspects and was pinpointed in its implementation.

Regular meetings within the scope of URBEM-DK:

- Regular internal TUW meetings for faculty and doctoral students, once a month
- Regular internal WSTW meetings for advisors, every two months
- WSTW-TUW get-togethers involving all participants, once every semester
- Supervision of doctoral students by faculty, up to once a week if so required
- Advising of doctoral students by WSTW contacts, up to once a month if so required
- Project management TUW and WSTW, up to once a month if so required

In addition three large events were held within the scope of URBEM-DK to ensure scientific exchange between additional TUW research groups and WSTW departments:

- 17 October 2013: kick-off
- 20–21 April 2015: mid-term
- 29 September 2016: concluding event

Evaluation

The doctoral programme URBEM is a novelty in this form for both institutions involved.

Hence within the framework of the strategic cooperation between TU Wien and WSTW it was decided to evaluate the initiative internally with input from the Neuwaldegg consulting group.

Emphasis was placed on the following aspects:

- organisational setup (main focus on structures and processes),
- interdisciplinary cooperation and
- cooperation between science and business (main focus on added value and challenges).

5

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outlook and contributors

5

urbem outlook

The prototype of an interactive environment is capable of visualising diverse scenarios based on scientifically validated methods and supplying results to stakeholders.

URBEM has carved out new paths. URBEM supports ways of finding and understanding a sustainably serviced, affordable and liveable city.

Besides the newly developed methods, an understanding of the complex interactions in the city as a whole is especially important and can only be gained through the interaction of diverse scientific disciplines.

Diverse national and international research groups or research collaborations are currently addressing the complex system of the city[33]. The overall objectives of all these research activities show strong similarities, but the routes taken could hardly be more different. However, almost all initiatives have one thing in common: an interdisciplinary, holistic approach.

Based on the results and findings gained in URBEM the following further steps can be derived:

- Exchange with other research initiatives: exchange of experiences with the research community can allow findings, methods and application of these findings and methods to be compared and understood.
- Systematisation of interactive overall environment: to continue to improve the interactive overall environment its structure must be further systematised. Special attention should be paid not only to data protection and programming aspects, but also to the required flexibility for inclusion of future scientific developments.
- Transfer to real operations: the possible benefits of the methods appear to be high and hence implementation in real operations will be checked at the time of final report preparation. It will be particularly interesting to be able to identify the potential synergies between urban infrastructures by identifying complex interactions in the overall city system.

[33] CI-NERGY (www.cinergy.eu); City-SIM (www.citysim.epfl.ch)

urbem contributors

DOCTORAL STUDENTS AND TOPICS

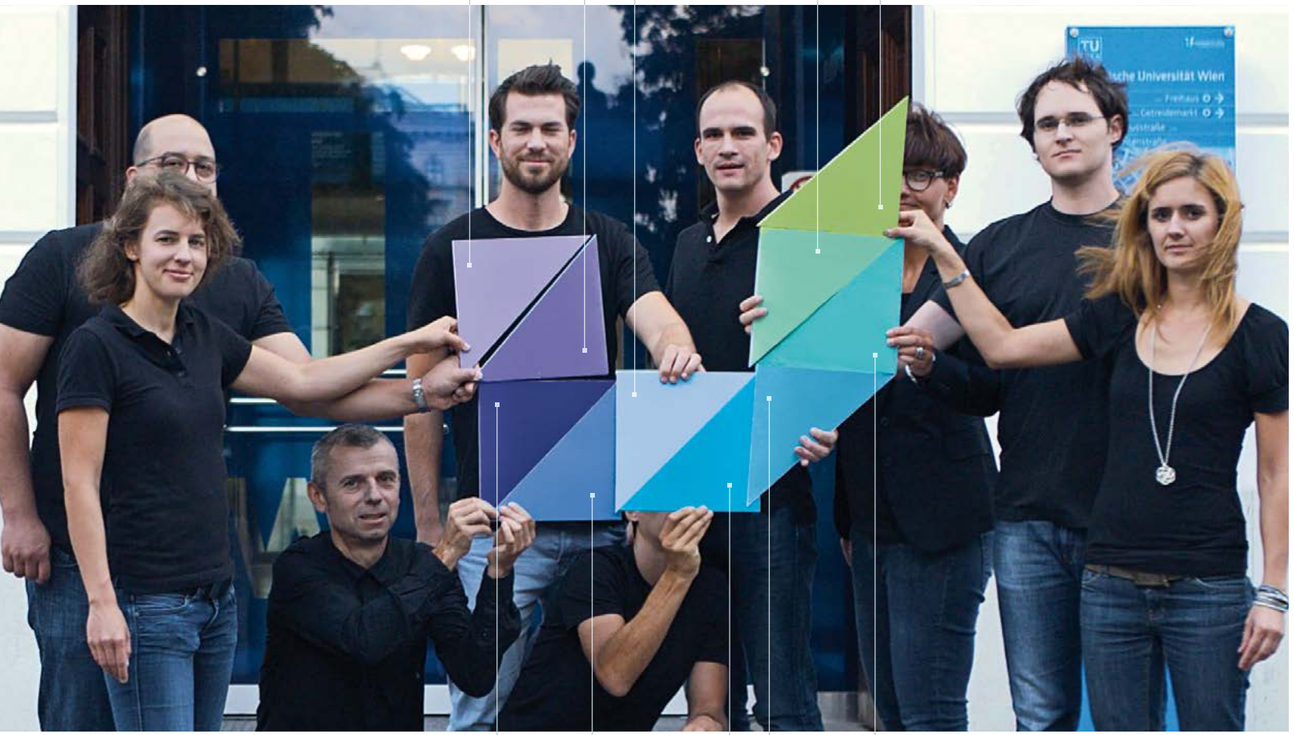
Julia Forster
◢ **10** – Visualisation

Johannes Schleicher
◤ **9** – Distributed computing

Dominik Bothe
◤ **5** – Heating networks

Nikolaus Rab
◢ **2** – Economics 2

Sara Fritz
◤ **1** – Economics 1



Christina Winkler/
Paul Pfaffenbichler*
◢ **8** – Mobility

Peter Eder-Neuhauser
◤ **7** – ICT networks

Thomas Kaufmann
◢ **6** – Electrical grids

Manuel Ziegler
◢ **4** – Buildings

Nadine Haufe
◤ **3** – Sociology

*Due to the departure of Christina Winkler Paul Pfaffenbichler continued working on the topic of mobility and prepared a research report on it.

	NAME (in alphabetical order)	DISSERTATION TOPIC	ORGANISATION
MANAGEMENT OF DOCTORAL PROGRAMME	Prof. Thomas Bednar		Scientific management: TU Wien
	Dr. Ilse Stockinger		Management: Wiener Stadtwerke Holding
	Dr. Gudrun Weinwurm		Organisational management: TU Wien
FACULTY TU WIEN	Prof. Thomas Bednar	Buildings	Institute of Building Construction and Technology
	Prof. Jens Dangschat	Sociology	Department of Spatial Planning
	Prof. Schahram Dustdar	Distributed computing	Institute of Information Systems
	Prof. Günter Emberger	Mobility	Institute of Transportation
	Prof. Wolfgang Gawlik	Electrical grids	Institute of Energy Systems and Electrical Drives
	Prof. Michael Getzner	Visualisation	Department of Spatial Planning
	Prof. Reinhard Haas	Economics 1	Institute of Energy Systems and Electrical Drives
	Dr. Lukas Kranzl	Economics 1	Institute of Energy Systems and Electrical Drives
	Prof. Karl Ponweiser	Heating networks	Institute for Energy Systems and Thermodynamics
	Prof. Thorsten Reinländer	Economics 2	Institute of Statistics & Mathematical Models in Economics
	Prof. Josef Michael Schopf	Mobility	Institute of Transportation
	Prof. Jesper Larsson Träff	Buildings	Institute of Information Systems
	Dr. Hong-Linh Truong	Distributed computing	Institute of Information Systems
	Prof. Andreas Voigt	Visualisation	Department of Spatial Planning
	Prof. Tanja Zseby	ICT networks	Institute of Telecommunications
WSTW CONTACTS	Daniel Dötzl, MSc	Mobility	Wiener Linien
	DI Katharina Fabi	Economics 2	Wien Energie
	DI Georg Geißegger	Buildings	Wien Energie
	DI Martin Höller	Heating networks	Wien Energie
	Dr. Rusbeh Rezania	Economics 1	Wien Energie
	Mag. Christian Schlemmer	Distributed computing	Wien IT
	Dr. Thomas Schuster	Electrical grids	Wiener Netze
	Dr. Ilse Stockinger	Sociology, visualisation	Wiener Stadtwerke Holding
	DI Wolfgang Wais	ICT networks	Wiener Netze
COORDINATION	Kathrin Brunner, MA		Wiener Stadtwerke Holding
	Solomon Gärtner		TU Wien – Energy and Environment Research Centre
	Mathias Rathammer		TU Wien – Energy and Environment Research Centre
	Dr. Ilse Stockinger		Wiener Stadtwerke Holding
	Mag. Sebastian Wehrle		Wiener Stadtwerke Holding
	Dr. Gudrun Weinwurm		TU Wien – Energy and Environment Research Centre

URBEM participants (doctoral students and advisors) at the concluding ceremony on 29.09.2016 together with Vice-rector for Research & Innovation Professor Fröhlich and Board Directors of WSTW Holding Dr. Krajcsir and Mag. Grüneis.

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Publications and prizes

One of the main Sustainability Award prizes – awarded by the Ministry of Science, Research and Business together with the Ministry of Agriculture and Forestry, Environment and Water Management – went to the interdisciplinary doctoral programme "URBEM" (Urban Energy and Mobility System) in May 2014[34].

S. Fritz, K. De Bruyn, L. Kranzl; Welche Auswirkung hat eine gebäudeübergreifende Betrachtung von Solarthermie auf deren Wirtschaftlichkeit?; Symposium Energieinnovation; Graz: 2014

N. Haufe; Smart City – Zukunftsstrategie für Stadt und Mensch?; Technologiegespräche, European Forum Alpbach: 2014

A. Murguzur, J. Schleicher, H. Truong, S. Trujillo, S. Dustdar; Drain: An Engine for Quality-of-Result Driven Process-Based Data Analytics; 12th International Conference, BPM; Haifa 2014

J. Forster, T. Kaufmann, N. Rab, C. Winkler; URSETA: An interdisciplinary decision support tool for sustainable energy and mobility strategies; WIT, Sustainable City; Siena: 2014

JN. Haufe; Eine sozial-räumliche Typologie zur Erklärung umweltgerechten Verhaltens – am Bsp. der Mobilität und des Energiekonsums; Kongress der Deutschen Gesellschaft für Soziologie; Trier: 2014

N. Haufe; Sozial-räumliche Erklärung von Mobilitätsverhalten und Energiekonsum – ein sozialwissenschaftlicher Beitrag zur interdisziplinären Mobilitäts- und Nachhaltigkeitsforschung; Nachwuchsnetzwerk Mobilität- und Verkehrsforschung PEGASUS; Karlsruhe: 2014

S. Fritz; Evaluating investments for existing District Heating networks depending on the development of buildings' heating demand applying Robust Optimization; IAEE European Energy Conference; Rom: 2014

N. Rab; Ausbau der Strom- und Wärmeerzeugungskapazitäten unter der Berücksichtigung risikoadjustierter Kosten; Präsentation, Internationale Energiewirtschaftstagung; Wien: 2015

T. Kaufmann, D. Bothe, W. Gawlik, K. Ponweiser; Optimierung der Lastflüsse in urbanen Hybridnetzen; 9. Internationale Energiewirtschaftstagung; Wien: 2015

N. Haufe; Sozial-räumliche Erklärung des Mobilitätsverhaltens und des Energiekonsums am Beispiel der Stadt Wien – ein sozialwissenschaftlicher Beitrag zur interdisziplinären Mobilitäts- und Nachhaltigkeitsforschung; Präsentation, Jahrestagung AK Verkehr der Deutschen Gesellschaft für Geographie, Nachwuchsforum; Erfurt: 2015

M. Vögler, J. Schleicher, C. Inzinger, S. Nastic, S. Sanjin, S. Dustdar; LEONORE -- Large-Scale Provisioning of Resource-Constrained IoT Deployments; System of Systems Engineering; San Antonio: 2015

C. Winkler, N. Haufe, J. Forster; Transport and Land Use Simulation Environment For Sustainable Planning Strategies In Vienna; World Conference of Transport Research SIG G3 Conference; Valletta: 2015

J. Schleicher, M. Vögler, C. Inzinger, S. Dustdar; Smart Fabric – An Infrastructure-Agnostic

[33] http://www.umweltbildung.at/fileadmin/umweltbildung/dokumente/Sustainability_Award/Broschuere_Sustainability_Award_2014_final.pdf

Artifact Topology Deployment Framework; IEEE 4th International Conference on Mobile Services; New York: 2015

N. Rab; Synthetic wind speed time series with Markov and ARMA models: comparison for different use cases; 12th international conference on the European Energy Market; Lisbon: 2015

S. Fritz; How public interventions in buildings energy efficiency affect the economic feasibility of a district heating network – a case study for Vienna; International Association for Energy Economics; Antalya: 2015

M. Ziegler, T. Bednar; Validated Load Profiles In Terms Of Density Functions For Residential And Non-Residential Buildings In Order To Enhance The Simulation Capability In A Comprehensive Urban Simulation Environment; 6th International Building Physics Conference; Turin: 2015

J. Schleicher, M. Vögler, C. Inzinger, W. Hummer, S. Dustdar; Nomads – Enabling Distributed Analytical Service Environments for the Smart City domain; IEEE International Conference on Web Services; New York: 2015

J. Forster, S. Fritz, N. Rab; Solar heat strategies for Vienna: identifying regions with highly reliable and affordable potential; Association of European Schools of Planning Annual Congress; Prague: 2015

D. Bothe, K. Ponweiser; Thermo-hydraulic simulation of district heating networks; International Conference on Smart Energy Systems and 4th Generation District Heating; Copenhagen: 2015

M. Ziegler, T. Bednar; A new approach to simulate buildings and their crucial characteristics in a comprehensive urban simulation environment; Sustainable City, 10th International Conference on Urban Regeneration and Sustainability; Medelin: 2015

J. Forster, S. Fritz, N. Rab; Spatial simulation environment for decision support; Sustainable City, 10th International Conference on Urban Regeneration and Sustainability; Medelin: 2015

S. Fritz, J. Forster, N. Rab; Buildings' Energy Demand modelling for sustainable decision support; Sustainable City, 10th International Conference on Urban Regeneration and Sustainability; Medelin: 2015

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N. Haufe; Smart City – Zukunftsstrategie für Stadtplanung und Soziologie?; Österreichischer Soziologie Kongress; Innsbruck: 2015

N. Haufe; Mit zielgruppenorientierten Ansätzen die Zukunft der Mobilität nachhaltig gestalten? Ein sozialwissenschaftlicher Beitrag zur interdisziplinären Mobilitäts- und Nachhaltigkeitsforschung; 6. Jahrestagung Pegasus Nachwuchsnetzwerk für Mobilitäts- und Verkehrsforschung; Wuppertal: 2015

J. Schleicher, M. Vögler, C. Inzinger, S. Dustdar; Towards the Internet of Cities: A Research Roadmap for Next-Generation Smart Cities; UCUI, Understanding the City with Urban Informatics (Workshop in conjunction with CIKM); Melbourne: 2015

T. Kaufmann, D. Bothe, W. Gawlik, K. Ponweiser; Optimization of load flows in urban hybrid networks; Smart and Sustainable Planning for Cities and Regions; Bozen: 2015

M. Ziegler, T. Bednar; Validated density function related on certain building use cases for non-residential buildings to run a comprehensive urban simulation environment; 14th International Conference of the International Building Performance Simulation Association (IBPSA); Hyderabad: 2015

P. Eder-Neuhauser, T. Zseby, J. Fabini; Resilience and Security: A Qualitative Survey of Urban Smart Grid Architectures; IEEE Access, SPECIAL SECTION ON SMART GRIDS: A HUB OF INTERDISCIPLINARY RESEARCH; Wien: 2016

N. Haufe; Energiesparen sinnvoll forcieren beim Konsumenten – Energieverbrauch von Wiener Haushalten verstehen und verändern; 14. Symposium Energieinnovation; Graz: 2016

P. Pfaffenbichler; Using System Dynamics to cope with demographic issues in spatial and transport planning; EMCSR, European Meetings on Cybernetics and Systems Research; Wien: 2016

N. Haufe, M. Ziegler, T. Bednar; Modelling Load Profiles for the Residential Consumption of Electricity based on a Milieu-oriented Approach; Sustainable Built Environment (SBE) regional conference; Zurich: 2016

N. Haufe, J. Dangschat; Energiekonsum – sozial differenziert betrachtet: Eine Reflexion lebensstil- und milieuorientierter Ansätze zur Beschreibung und Erklärung unterschiedlicher Energieverbrauchsmuster privater Haushalte; K. Großmann, A. Schaffrin & C. Smigiel: Energie und soziale Ungleichheit: Zur gesellschaftlichen Dimension der Energiewende in Deutschland und Europa. Wiesbaden: VS Verlag für Sozialwissenschaften / Springer Fachmedien: 633-660; Wien: 2017

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J. Schleicher, M. Vögler, C. Inzinger, S. Fritz, M. Ziegler, T. Kaufmann, D. Bothe, J. Forster, S. Dustdar; A Holistic, Interdisciplinary Decision Support System for Sustainable Smart City Design; International Conference on Smart Cities (SMART-CT 2016); Malaga: 2016

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Content
Univ.Prof.Dr.techn. Thomas Bednar

Contributors (in alphabetical order)
Thomas Bednar, Dominik Bothe, Julia Forster, Sara Fritz, Nadine Haufe, Thomas Kaufmann, Peter Eder-Neuhauser, Paul Pfaffenbichler, Nikolaus Rab, Johannes Schleicher, Gudrun Weinwurm, Christina Winkler, Manuel Ziegler

Graphic Design
Alexandra Reidinger, www.elysa.at

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