# Energy demand in city regions – methods to model dynamics of spatial energy consumption

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## Abstract

Most of the worldwide energy consumption takes place in urban agglomerations, where half of the world population lives. The energy demand in urban context is continuously rising, challenging the energy supply of existing cities in particular. The analysis of this situation requires detailed knowledge for different kinds of investment decisions. For this matter, information is particularly lacking concerning the spatial distribution of energy demand on local scale and the interaction with the urban development. The location of the energy demand energy in space reveals more and more energy efficiency potentials to get conscious about as well as their forces of change. The dynamics of such changes in local demand can be assessed, simulated and visualized. A good knowledge of the most relevant locations regarding energy efficiency offers strategic reaction in place and time. The paper argues that the dynamics of the building stock plays a crucial role for planning of energy efficiency in space and time. The methods of investigation and representation of these changes will offer a strategic instrument to assess the dynamics of changes in urban space and to track and detect potential locations adapted to the implantation of energy efficiency measures. As a basis, complex energy models and interventions with innovation developments will be shown. Several approaches come up against a lack of available data, non-spatial information sources, different aggregation levels, quality and consistence of data, among others. The presented approach shows methods to simulate the changing land use in the course of time, the dynamics of building stock and the variations of energy demand in space. A case-study will be presented to illustrate these methods, showing the evolution of the land use in the considered region as well as the located energy demands that result.

## Introduction: Energy and urban development

The authors concentrate on four main hypotheses:

1. Rather than at the level of individual buildings, **energy efficiency measures should be considered and implemented on larger scales**: settlements, cities and agglomerations represent a relevant structure of action and objects of long-term perspective in planning. The traditional urban form is and will be more and more influenced by the needs of new consistent energy clusters of localized supply. The existing structure also dictates new influences to the local energy needs.
2. Beside the sectoral energy efficiency, the **localization of energy demand** in the urban space and the related adequate energy supply clusters will constitute a key issue to describe adapted and optimized systems. An enormous amount of knowledge concerning the energy demand exists, but still its dynamics of change as well as localized information about change potentials and innovation are inconsistently described.
3. Even though most of the energy efficiency potentials lies in the **demand side management**, the localization of energy demand, its dynamics and its interaction with the existing structures offer unknown possibilities to establish **new supply systems** and raises **new potentials.**

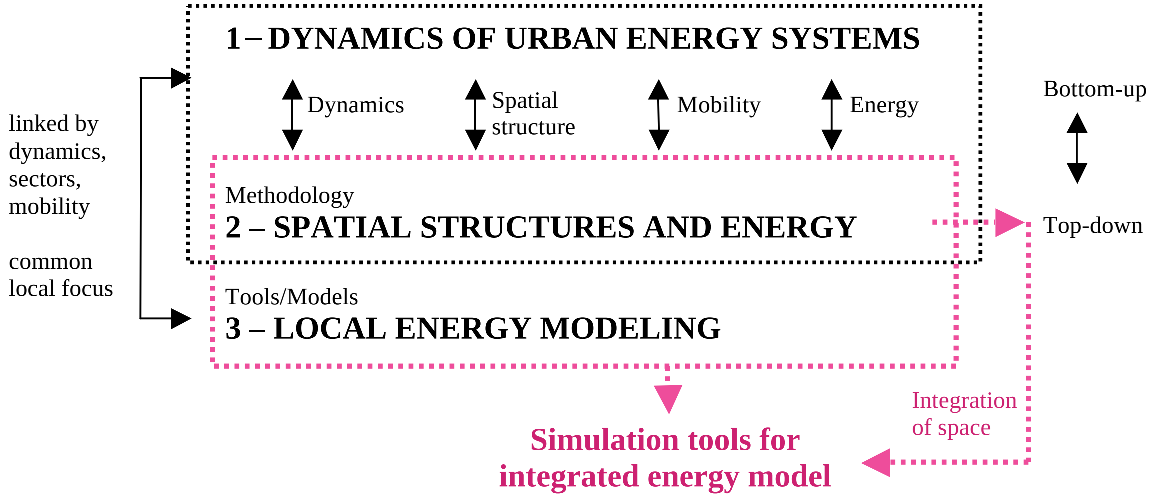


*Figure 1. Correlation of local energy models, spatial distribution and dynamics of change, representing interconnections and goals (EIFER 2008)*

4. The **time and spatial dynamics of the urban space** and more precisely the diffusion of innovations of decentralized technologies will become a key issue to understand and assess the distribution of energy efficiency measures within the urban space. Modern supply techniques and methods can be adapted to these needs, by understanding, analyzing and simulating these changes in order to optimize the exploitation of present and future energy efficiency potentials.

Investigating the future decisions regarding energy demand requires more knowledge about spatial, space-related and temporal dynamics in urban development (see Figure 1). The close interrelation between energy and space becomes obvious by looking at the historical development of cities, where 85% of the worldwide energy is consumed nowadays. A reciprocal influence between energy and urban dynamics has always taken place. Obviously, most of the energy efficiency potential and the relevant changes impacting the future energy demand are likely to take place in the existing urban fabric. Yet the localization of these incidences, their dynamics and interferences are only scarcely known.

Urban structure is historically based and developed following the availability of energy spatial development of production and transport environments. Thus the urban structure has always resulted from the urban functional processes. The availability of energy in urban space has not been a decisive prerequisite for the development of cities since at least the industrial age. Whereas the medieval city was erected as trade place at walking distances –human and animal transport energy- for the predominantly rural population, industrialization based on the use of carbon resources, steam machines and steel led the way towards technical progress, increased reach hence spatial extension. The mechanization of agriculture and higher yields induced a drift from the land and made it possible to feed the increasing population. Suburbia and city merged. In the 20$^{th}$ century petroleum, chemical and electrical industry became drivers of development in the modern world. As long as accessible, the localization of former urban activities became more and more irrelevant. On this basis, the limits of energy production, supply and transport were no longer absolute determinants for the urban structures.

Based on these considerations the following main topics of research have been figured out:

- Models to classify and analyze the present character and the structure of the urban fabric as well as its trends of development;
- Methodologies to investigate urban and regional areas, offering insights into relevant structures for the future energy demand and its localisation;
- Classification methodology of functional and spatial distribution for demand site potentials and future development;
- Empirical spatial approach to simulate urban growth scenarios applied to a case-study region.

## Energy efficiency on urban scale

Energy demand in urban agglomerations is still continuously rising. The main challenges to supply existing cities with energy and the complex demand modulation constitute key issues for an efficient energy use. In Germany as well as in other countries, major national support and development programs are currently addressing the energy demand of the existing building stock, leaving aside the specific reproduction rate of this structure. According to the German national energy efficiency action plan (EEAP) for instance, the main goals are: the reduction of energy use in buildings, the duplication of micro Combined Heat & Power (mCHP) for electricity production, the achievement of efficiency in economy and traffic, new establishment of standards and labels for equipment. Most of these actions take place on urban scale, which eventually requires the localization and the information of dynamics to establish long-term strategies. Meanwhile many data concerning the statistical distribution of economic sectoral energy needs are nowadays available but still there is lack of information concerning the localization and the presence in space as part of a communal strategy. These concepts also have to take into consideration the existing energy infrastructure and related concepts of a consistent supply side structure. Beside the current available technologies the quantified distribution in space represents a key issue of future research. The document on hand introduces methods describing these coherences based on the case-study of the Metropolitan region of Stuttgart.

The challenge regarding energy efficiency on urban scale and the competition concerning energy infrastructure requires furthermore detailed knowledge for different kinds of investment decisions for a consistent future urban structure based on scenarios for the urban development (Figure 11). The urban development is characterized by highly diversified reactions on different scales and complex interrelations: structural growth and shrinking, economical triggers and the influence on energy demand become more and more unevenly distributed within urban regions. A polarity between prosper and developing places on the one hand and streets/quarters/towns with negative development trends on the other hand can often be pointed out (Batty, 2005) (Fujita, Krugman, & Venables, 1999). These phenomena of settlement development have an enormous influence on the demand and the management of future efficiency.

Currently most of the efficiency potential has been ascertained in the building stock, its replacement and its refurbishment. A closer look at the building stock reveals that the dynamics of replacement are main figures to describe the penetration of different technological solutions and their specific potentials. Analyzing the scale of the different distributions in the urban fabric, it appears that that much more specific information about the location of the determinants and effects of the local potentials is needed as well as about the dynamics of appliance is still needed. Furthermore a consistent knowledge on the composition of the existing building stock as one of the main fields of interest is essential (Kohler & Hassler, 2002). With respect to the existing building stock, energy efficiency on urban scale results from an implementation in time of replacement rates for the existing structure of the building stock (Bradley, 2007), potentials of thermal refurbishments and the opportunities given by specific local interactions from different demands.

The investigation at hand gives an insight into the existing distribution of the stock and single urban functions in the urban convolute, the methods to invest and understand, and finally the simulation approaches to foresight complex developments in space.

As a case-study in the average European, representative urban situation, the Metropolitan Region of Stuttgart has been analyzed. Results are transferrable to comparable urban compositions.

To support the analysis of a long-term perspective of energy consumption in cities in relation to the urban development, knowledge addressing the urban development as well as the simulation of structures, demands and replacement is fundamental. Being aware and anticipating these developments is a key competence to establish further strategies to implement energy efficiency on urban scale. The spatial dimension of energy demand is still an underexposed field with no methodological references. The spatial view on the energy demand generated from the urban dynamics is a field of research that has a wide potential of definition and development. However the relation between city-planning actors and the strategies related to energy use and supply is neither clear nor methodologically defined as a research topic. (Rickwood, 2007; Wei & Kohler, 2008)

## Cycles of urban change

One of the working hypotheses of the present work is that for a consistent understanding of energy demand and positive development in cities, a better understanding about general clusters and dynamics of urban development, its actors motivations and planning procedures, is unavoidable. This way it is possible to foreseen and influence dominant processes for the implementation of any local energy efficiency strategies. This chapter introduces to structures, concerned disciplines and present knowledge about these dynamics.

The average European city development is directly affected by known trends and its energy demand: triggered by various influences regarding the spatial situation, the distribution of functions, the economical sectors on urban and neighbourhood scale, the city density, the extension of transport infrastructure are changing. Various investigations and prognosis concerning the refurbishment potential, the composition of the thermal behaviour of the building stock have been undertaken and appropriate recommendation on national scale have been formulated (Kleemann, 2000). However less is known about the precise distribution and the localization, as well as the interactions of processes and building provision (Bradley, 2007).

Future changes of the economical sectors in present urban environments occur with differing space- and time-cycles. Long-cycle development, which mainly takes place on local level, concern two entities: habitation (30-60 years) and infrastructures (50-100 years). Short-cycle development, which depends on global decisions and affects large areas of the city, is significant in the industrial sector and the tertiary activities (5-30 years). Various economical reasons like short payback periods create a different background for decisions towards the future. This cyclic classification for changes depends on the cultural background too: the presented classification applies to the European framework; in America for instance, the habitation sector chances faster, the shorter life-cycles of houses describe a more flexible society. The authors of this paper argue that the knowledge about these dynamics and the presented analysis methods constitute a key competence for future strategic investment in the city regions regarding energy efficiency.

The reasons explaining short cycles in the industrial sector -rather connected to global influences, strategies and decisions- and tertiary activities – rather linked to regional and local dynamics – with focus on trade and leisure, are exposed below:

- The trend of industrial relocation towards the periphery or outsourcing overseas causes high velocity of change for large areas. Trade and leisure substitute to industry as part of the transformation towards a service society. Spatial changes will be evoked further.
- Dynamism is caused by a strong need of space and energy: the sectors trade and leisure are characterized by an enormous and still increasing space demand. Industry is respon-

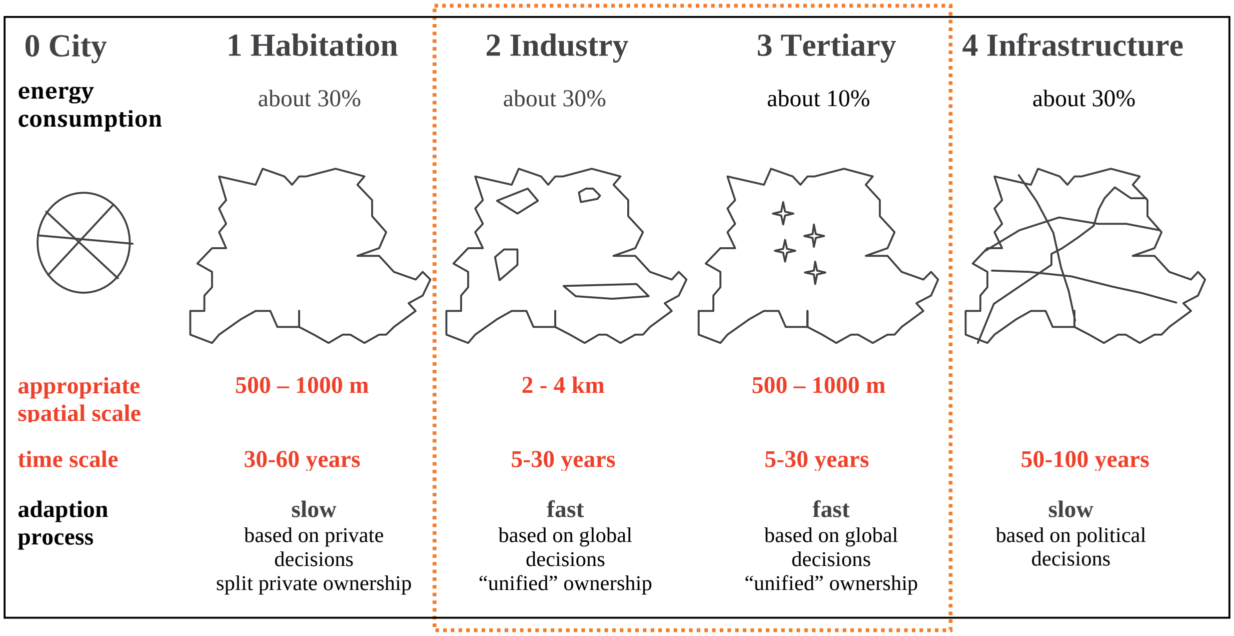


*Figure 2. Different time-cycles of development and multi-scaling approach per sector (EIFER 2008)*

sible for 30% of the overall energy demand and provokes important changes.

- The energy demand in the sectors trade and leisure is dominated by mobility: daily activities related to the accessibility has expanded, the interconnection between urban structure and mobility has changed a lot for tertiary activities.
- The sectors industry and tertiary (trade/leisure) offer employment, the capacity of other sectors to act depends on their economic capacity. The economical effect -available jobs- causes reactions for the entire urban structure.

These approaches and definitions of urban development are taken as a basis to present the relevance for the establishment of scenarios and the implementation of energy efficiency measures on urban scale, the dynamics of distribution and the interaction with the policies and strategies to implement energy efficiency.

## Methodologies

Based on data provided by the studies examining the dynamics of spatial distribution and the development of land use, a classification model of the existing building stock has been undertaken. In particular, the description of the demand side and especially the different economic sectors, including specific energy demands, has been carried out. In addition, the long-term dynamics of urban metamorphosis and the change of use for localized urban functions have been taken into consideration, focusing predominantly on the distribution of energy demand in the localized urban environment. These data derive from evidence-based investigations dedicated to the change of use in urban function of case studies, looking at different time-cuts and represented local functions. Finally, visualization methods and prospective simulation have been used to show a localized impression of future urban energy demand re-associated to the urban morphology. These representations of the dynamics of urban developments are the source code for the presented simulation approaches.

Most investigations are based on the analysis of the Metropolitan Region of Stuttgart, Germany. This case-study offers an insight into the availability of different data correlating energy and space, as well as the administrative and regulative policies. The applicability of localized data on buildings, economical phenomena, spatial distribution and land use development have been exemplary tested via the described models and the available data. Furthermore the energy demand of buildings will be evaluated in cross-reference with the processed statistical energy data; based on the energy typology of a spatial distribution, patterns and rules for the selected functions derived from the localization. The classification of companies and their input to energy demand relatively to the number of employees, surface or national and European sectoral scores (Statistisches Bundesamt Deutschland, 2003) mentioned above, was transferred to the case-study region. These data offer a data pool for the systematic simulation of the urban development for future energy demand (see below).

## Functional distribution of urban demand systems

The energy demand related to the building stock and the demand due to the processes applied in the different economical sectors can be distinguished. They are subject to dynamic changes impacting their intensity and their spatial distribution in a long-term perspective. In order to approach the complexity of urban spaces, the system needs to be subdivided and classified into branches sharing common characteristics from an energetic point of view. After the establishment of an appropriate typology, each subdivision, considered as an energy branch, is energetically characterized as follows:

1. Assessment of the total energy demand per reference unit (number of employees, unitary surface, etc.)

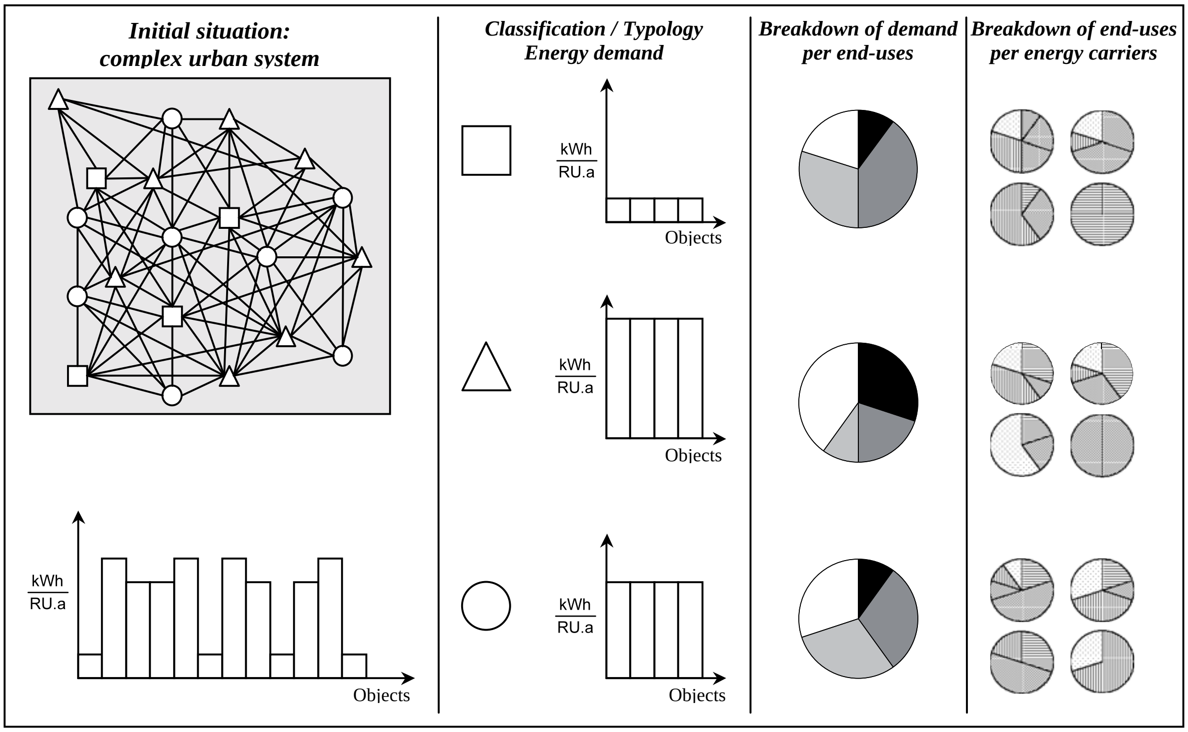


*Figure 3. Methodic approach tackling the complexity of urban systems to characterize them energetically (RU=reference unit)*

2. Breakdown of the final energy demand per end-uses (space heating, process heat, cold production, mechanical energy, etc.)
3. Breakdown of each end-use per final energy carrier (natural gas, electricity, heating fuel, etc.). The breakdown of the end-uses, not the total consumption, makes it possible to analyze and understand the consumption of consumptions hence to assess the efficiency potential in a more detailed way. In the practice, the breakdown per final carriers mostly regards the production of heat: space heating, warm water heating, process heating with different temperature ranges e.g. less than 100°C, 100-500°C, 500-1000°C, more than 1000°C.

The figure below represents a snapshot of the urban system at a given time-point and recapitulates the different steps of the approach to assess the characteristics of the energy demand of the urban system at this time-point. In this figure, the different forms (triangle, square, circle) represent interacting components of the urban system sharing common energetic properties e.g. residential buildings, industrial production sites, etc. Such a snapshot changes in the course of time. At another time-point, existing components are will change or disappear and new components will come up. The energy consumption is also likely to vary, the breakdowns per end-uses and energy carriers as well.

### ENERGY TYPOLOGY

Urban spaces can be considered under various points of views and considerations: social problematic, economic attractiveness, employment, technological innovation, geography, environmental impacts, energy consumptions, etc. Focusing on the final energy consumption, four main consuming sectors come up and make it possible to carry out a first energy division of the urban system: residential sector, tertiary activities, industry and mobility/transports.

Most of the final energy consumption in residential sector is due to space heating hence directly related to the building characteristics: mostly type, age, refurbishment level. In Germany, the consumption due to home appliances represents 20% to 25% of the final energy consumption (Schoer, Buyny, Flachmann, & Mayer, 2006). The rest is due space heating and is tightly linked to the climatic conditions. Yet very variable from one activity to another, the weight of processes as opposed to the building characteristics increases in the tertiary sector. In the industry, the processes achieving a given type of production represent most of the energy consumption. For these two sectors, a classification of the activities is consequently close to a classification of energy end-uses. Economic classifications like the “Klassifikation der Wirtschaftszweige” (Statistisches Bundesamt Deutschland, 2003) in Germany are consequently of great interest to establish an energy typology of industrial and tertiary sectors. (Greulich, 2004).

Such economic and statistical classifications are commonly elaborated on worldwide scale so that their harmonisation can be made possible. Reference classifications defined by the United Nations such as the ISIC classification are adapted to suit community or national levels, in particular the NACE codes in Europe and the “Klassifikation der Wirtschaftszweige” in Germany. Correspondence tables are constituted to relate and transpose classifications from one entity to another.

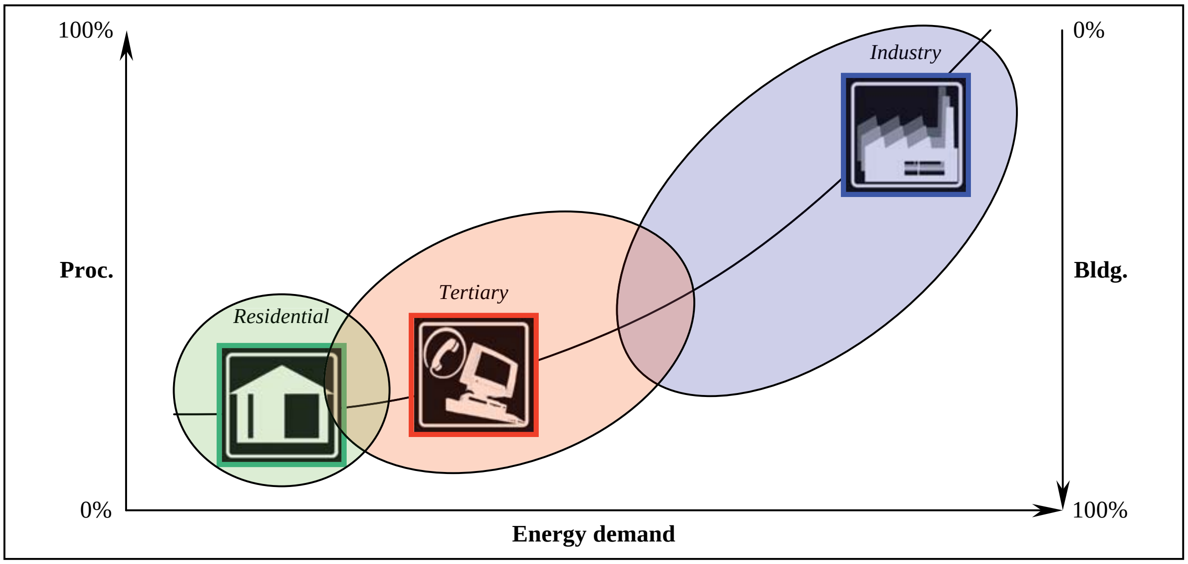


*Figure 4. Schematic representation showing the relative weight of building characteristics and processes in the final energy demand for residential sector, tertiary activities and industry.*

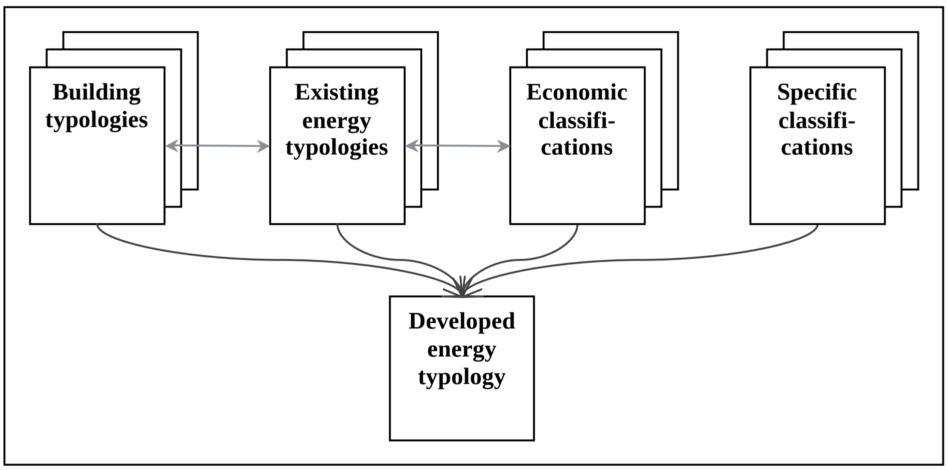


*Figure 5. Constitution of energy typology from already existing energy typologies, economic classifications, building typologies and specific classifications.*

The suggested energy model developed to describe urban systems is based on pre-existing energy typologies developed in different contexts, in particular the development of thermal standards specified by the Energy Performance of Buildings Directive (EPBD) and its application into the German legal frame as *Energie-Einsparverordnung* or EnEV 2007 which, in particular, organizes the establishment of energy performance certificates in residential and non-residential buildings (Rohde, 2008). Such references enable to validate the subdivision of the developed classification and provide reference values regarding the final energy demand of the considered sectors and energy groups., (Schlomann et al., 2004), (ARGE Benchmark, 2007)

As stated above, such typologies are usually linked with classifications of economic activities and building typologies (Besch et al., 2000), (Institut Wohnen und Umwelt, 2003). In addition, the developed typology also includes specific classifications to subdivide given activity branches e.g. lodging business or retail trade.

### ENERGY DEMAND OF CONSIDERED ENERGY BRANCHES

After subdividing the urban system into energy sectors and branches, specific consumptions are assigned to these branches to assess their energy demand. A first issue lies in the definition of reference units which need to be chosen in a way that energetically makes sense. The surface of residential dwellings for instance is appropriate as most of the energy consumption in this sector is due to space heating. Even though it is also commonly used to estimate the warm water heating demand, the surface is not as relevant as the number of inhabitants for this energy end-use because most of the warm water heating is related to the number of showers taken. In the industry sector, the surface of the buildings on the production site does not make sense as the energy consumption is related to the production, not the building fabric.

The data related to the chosen unit also need to be available on the considered geographical scale. Typically, many sources backing up the implantation of energy certificates consider the building scale and consequently suggest the unitary net floor area as reference unit. Except for a very few tertiary activities and for the residential sector where the heated surface, if not available from statistical sources, can at least be estimated with relatively acceptable accuracy, such data are hardly available at the level of the city or even on regional scale.

Moreover, the chosen reference units should be the same for the largest possible amount of activity branches to enable the comparison of branches. Whereas the number of employees seems like a reasonable alternative for most tertiary activities, it is not the most appropriate choice for industry where two types of energy consumptions can be distinguished: the consumption related to the industrial production process (mechanical energy, process heat, cold production, etc.) and the consumption for personal accommodation (space heating, etc.). While the energy consumption for personal accommodation may be correlated with the number of employees, the consumption due to the industrial process is directly related to the production. In this case, the gross value added was suggested as reference unit but this choice needs to be validated. Some research work is currently being carried out to examine the potential connection between these energetic investigations and economic considerations, methods and/or tools.

#### BREAKDOWN OF THE ENERGY DEMAND PER END-USES

The energy demand is then broken down into the specific energy end-uses. Additionally to the characterisation of the energy branches, the considered uses should enable the comparison of branches and more importantly the confrontation between data sources. Depending on the objectives and the applied methods, the considered uses often vary from one study to another.

The least common denominator leads up to distinguish the electricity and heat consumptions only. Beyond the lack of details by considering these only two end-uses, this distinction often reveals surveys whose data are based on the collection of energy bills i.e. actual energy consumptions whereas other sources assess the energy needs. In addition, electricity is no energy use as such. A part of the electricity consumption is dedicated to the production of heat and cannot be extracted from the overall electric consumption.

#### BREAKDOWN OF THE ENERGY DEMAND PER ENERGY CARRIERS

As a last step, a breakdown per energy carrier of each end-use in each energy branch should be carried out. Whereas a number of end-uses are mostly or entirely provided by electricity (lighting, information and communication technologies, air conditioning, cold production, ventilation, mechanical energy…), heat can be provided by a variety of energy technologies. For each energy branch, statistics can be found on this subject. National sources can usually be transposed to more local scales. In some cases when the considered branch concerns only a limited number of buildings in the urban space (swimming pools, ice rinks…) the information related to the energy systems can be directly gathered through local interlocutors.

While the energy demand and the breakdown per end-uses are homogenous for all elements of a considered category in the energy typology, the breakdown per energy carrier is very variable for some uses – mainly the production of heat. In the residential sector for instance, while most of the buildings show a similar repartition between space heating, warm water heating and other end-uses, some buildings are supplied for space heating with natural gas, others are connected to a district heating network, use heating fuel systems, electric heaters or renewable resources.

The spatial distribution of aggregated, statistical data is very difficult on this topic. In most cases, information is lacking to assess the heating systems on local scale. A study of local energy infrastructures (natural gas grids, district heating networks) can be carried out but such analyses are time-consuming, particularly when a whole region has to be covered with a fine resolution. In addition, this method only leads up to the exclusion of a limited range of technologies without determining the exact technology which is indeed implanted at the considered landmark of the urban space. For example, the lack of natural gas grid or a water protection area in a district leads up to the exclusion of gas boilers or geothermal drillings for the considered buildings, but other options are possible and the problem remains unsolved: heating fuel, electric heaters, biomass systems, etc. Moreover, the success of such investigations is limited by the confidentiality of data related to energy distribution networks.

One of the alternatives consists in distributing average characteristics from the most possible local level to all elements of the examined energy branch. For instance, average characteristics gathered at the commune level for a given category of the energy typology will be distributed to all buildings of the commune (Figure 6). In this figure, aggregated data indicate that system A provides 25% of the buildings, system B 25% and system C 50%. As the exact spatial distribution cannot be known, the model considers that each building has 25% chances to be provided by system A, 25% chances by system B and 50% by system C.

## Spatial distribution of energy demand

Based on the data of sectoral uses in urban space, combined with the specific energy use and sectoral classification, the energy demand in public space is represented. Through geo-simulation methods [Benenson, 2004 #12] of urban development allow some forecast scenarios of the urban space and the related energy clusters. It is assumed that -beside the potential of the sector specific potentials of energy efficiency- the basis knowledge for understanding future energy demand concerning location and distribution needs can be understood by localized data, leading to consistent energy efficient approaches based on adapted local supply structures.

The present investigation aims to simulate demand-side future energy scenarios on the urban scale and in relation to existing urban development scenarios. By this it offers information and scenarios as basic information for a long-term planning perspective but at the same time consistent data for future layout.

On the one hand, information about energy production is already available partially by the energy companies, and can be located by using addresses and postal codes. On the other hand, consumption of heat and power is poorly seen as a problem of spatial distribution, and mostly treated in an aggregative way. A better knowledge about this distribution helps to develop long-term optimized energy supply landscapes, managing reduced losses and a better exploitation of local renewable energy resources.

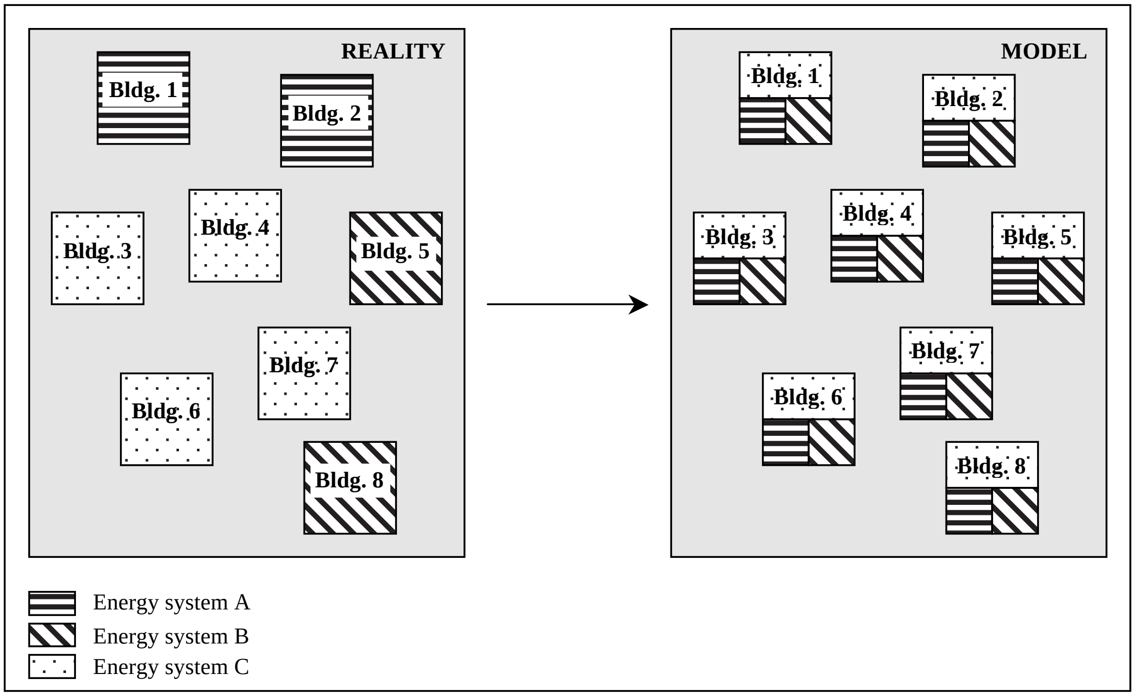


*Figure 6. Redistribution of individual characteristics as average characteristics regarding the breakdown of energy demand per energy carrier*

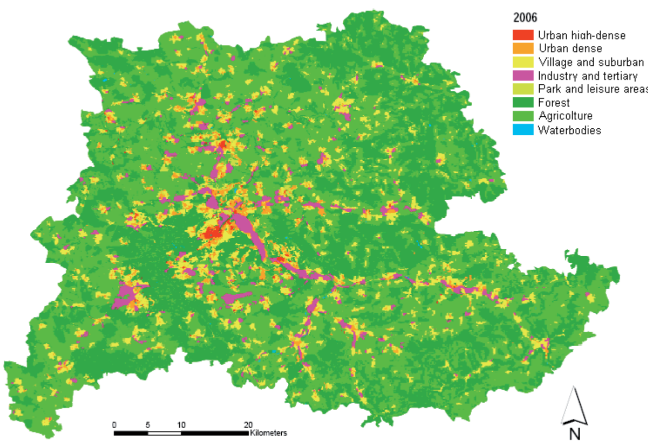


*Figure 7. Stuttgart metropolitan region: land-cover map of 2006 as example for the constructed dataset 1977-2006*

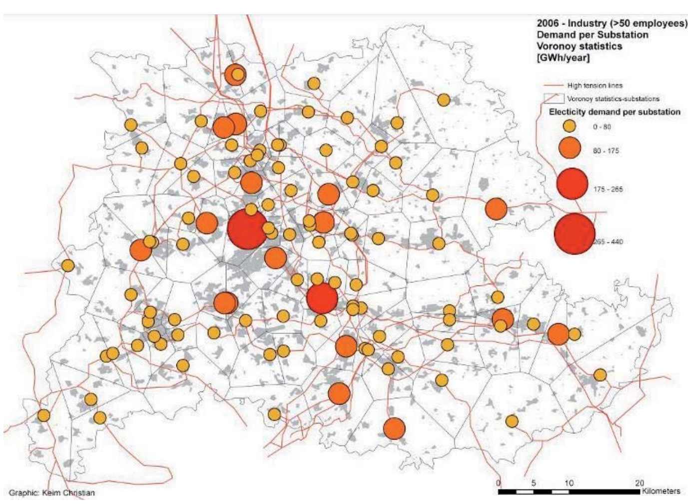


*Figure 8 : Example for energy demand: Energy demand per substation, generated by the industrial sector (industries with more than 50 employees), defined trough Voronoi analysis Method.*

One of the major problems before being able to allocate energy demand on a fine scale deals with the classification of spatial land use classes (LUC). This classification is carried out by using aerial data, and refers to spatial structures. This means no references are made to the energy production or consumption associated to the land use class. To obtain this information it is necessary to deal with statistical data referring to the different land uses and to this situation it has to be pointed out that statistical sources mostly are not spatially related and are not at a sufficient resolution, as generalized on the scale of administrative boundaries.

At the same time it is necessary to discriminate between the approach described above, a statistical approach, that could help to create models and generalize distributions, and a deterministic approach, dealing with specific real data but incapable of generalizing the results to a different case-study. The data from the underlying case-study offers advancements to more generalized models applicable to other case studies with specific local use clusters. Looking at the energy consumption of residential sector, multidimensional layers (socio-economically / urban structure / historical data) are necessary to increase accuracy and reduce uncertainty in the model. The same is valid for consumption areas due to tertiary functions as well as production regions for industry. As already seen, all three sectors have to be treated differently, which represents the problems for the sensitivity analysis of the models, as each one has its own calculation method.

Regarding the residential sector, major improvements can be achieved with more accurate data and including socio-economical landscapes in the model. Likewise, a model for commercial sector could be improved with further work. The industrial sector model is still too deterministic, related to data-mining and not sufficiently reliable to be extrapolated to other case studies. National averages or expert values can be used for small industries but for large industries, accuracy depends on the data availability (and their accuracy).

For the case of the residential sector, the data needed to define the energy relevant parameters were reliable as far as the extent of the temporal data could provide. For urban areas concerning earlier developments, the age and the building type are assessed from higher national averages to describe the housing sector and its related energy demand (Schlomann et al., 2004), (Institut Wohnen und Umwelt, 2003). Distributions of building typologies and age classes were then disaggregated to the urban LUC. This methodology has been coupled to a Cellular Automata modeling approach [Batty, 2005 #10], based on a 100x100m raster resolution of the case study region and 8 main LUC (5 Urban and 3 non-urban), for long-term forecast.

Based on this sectoral distribution of energy demand and the specific land use data, first simulation results on the urban and regional scale show the specific distribution of energy demand in space (Figure 9, Figure 10). Depending on the scale of aggregation it offers reliable data for hot spots in energy demand in future urban development and sectors (Figure 11). The forecast scenario shows its value not only to understand the spatial distribution but also direction lines of consistent supply solutions and developments. The comparison of different time lines can give an insight into main strategic action fields in long-term perspective (Figure 11). Figure 10 shows the spatial distribution of the major industries in the region and how they are not spatially correlated with other spatial entities. The largest differences can be found in the surroundings of dense urban areas as well as in rural or suburban zones.

## Conclusion

Particularly at the level of the agglomeration and on smaller scale, energy-related statistics are hardly available. Based on a typology comprehending the complexity of the urban space, the establishment and the analysis of energy efficiency potentials at this geographical level consequently requires the reassessment of energy characteristics as a first step. To this end, first investigations connecting energy research and the economical sphere, in particular, show full relevancy.

In addition, the spatial dimension of energy is still little examined and too few relevant data making the investigation in the field of energy efficiency possible are localized in the urban space. Yet the spatial characterization of energy demand generated from the time and spatial urban dynamics constitutes a field of research with a wide potential of development and definition. Not even the relation between city actors and energy is clearly established and methodologically defined within the research community.

The presented methods connect various fields of knowledge, especially urban development, geographical approaches, energy demand assessment through the analysis of the building stock and the examination of economic activities, energy supply technologies, diffusion of innovations in urban space, data mining and statistical analysis.

The kind of model used here intends to focus on the context of strategic planning and the related decision-making, to show trends and stochastic processes. It does not pretend to constitute an accounting model distributed spatially.

The authors argue that a broad field of research exists to assess the energy demand on local scale, assess and understand its localization in the urban fabric, establish its spatial distribution in the course of time and simulate these phenomena to establish tendencies. In addition, as disaggregated data allow better knowledge of energy systems through visual analysis and spatial tools, this information is easier to implement in decision-making processes.

## References

ARGE Benchmark. (2007). *Benchmarks für die Energieeffizienz von Nichtwohngebäuden – Referenzwerte für Energieausweise* (Zwischenbericht): Ingenieurbüro Klöffel GmbH, ennovatis GmbH, Lenz Weber Ingenieure, Ingo Therburg – im Auftrag der Bundesrepublik Deutschland, vertreten durch das Bundesamt für Bauwesen und Raumordnung.

Batty, M. (2005). *Cities and complexity : understanding cities with cellular automata, agent-based models, and fractals*. Cambridge, Mass.: MIT Press.

Besch, H., Neuffer, H., Witterhold, F. G., Schönberg, I., Jochem, E., Radgen, P., et al. (2000). "Strategien und Technologien einer pluralistischen Fern-und Nahwärmeversorgung in einem liberalisierten Energiemarkt unter

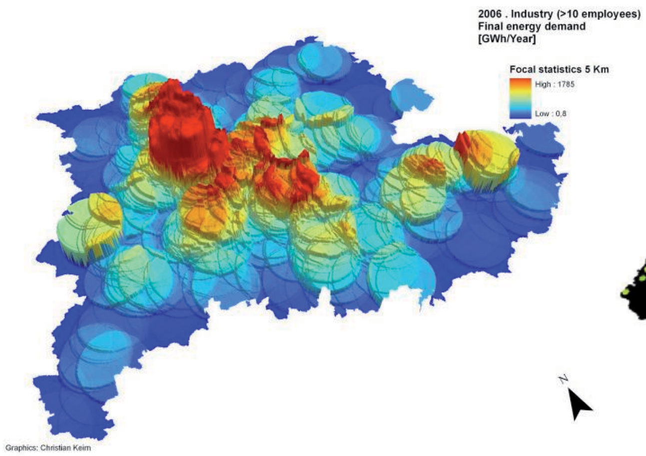


*Figure 9. Localization of the final energy demand of the industrial sector (Focal statistics of 5 Km - The elevation of the model is proportional to the corresponding energy demand).*

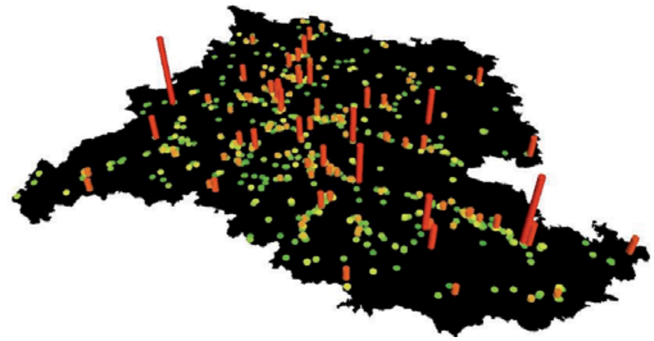

*Figure 10. Metropolitan region Stuttgart. Estimated final heat demand for the industrial sector based on 2006 data.*

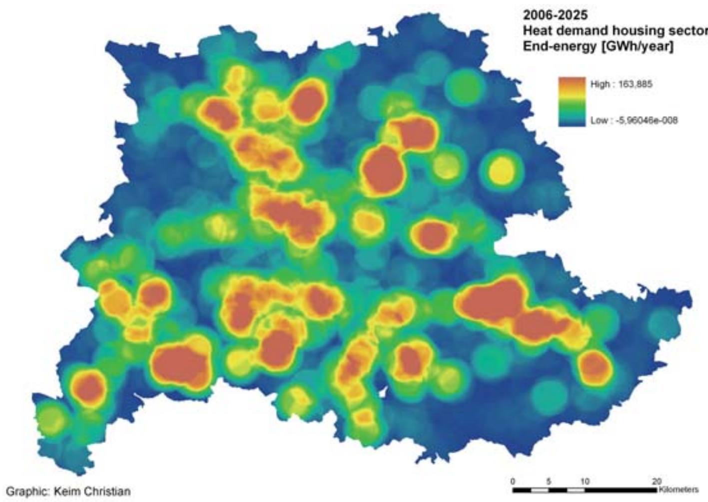


*Figure 11. Visualization of the spatial change of final heat demand according to the forecast scenario for the residential sector between 2006 and 2025.*


besonderer Berücksichtigung der Kraft-Wärme-Kopplung und erneuerbarer Energien".

Bradley, P. E. (2007). Methodology for the survival analysis of urban building stocks. *Building Research & Information*, 35(5), 529-542.

Fujita, M., Krugman, P. R., & Venables, A. (1999). *The Spatial Economy: Cities, Regions, and International Trade*: MIT Press.

Greulich, D. V. M. (2004). Revision von Wirtschafts-klassifikationen bis 2007 – ein Zwischenbericht. *Wirtschaft und Statistik*.

Institut Wohnen und Umwelt. (2003). *Deutsche Gebäudetypologie – Systematik und Datensätze*. Darmstadt: Institut Wohnen und Umwelt GmbH,.

Kleemann, M. (2000). *Die Entwicklung des Wärmemarktes für den Gebäudesektor bis 2050*: Forschungszentrum Jülich, Zentralbibliothek.

Kohler, N., & Hassler, U. (2002). The buildings stock as a research project (Vol. 30, pp.226-236).

Rickwood, P. (2007). Urban Structure and Energy – A Review. *Urban Policy and Research*, 99999(1), 1-1.

Rohde, C. (2008). *Die Energieeinsparverordnung 2007*: Diplomica Verlag GmbH.

Schlomann, B., Gruber, E., Eichhammer, W., Kling, N., Diekmann, J., Ziesing, H. J., et al. (2004). *Energieverbrauch der privaten Haushalte und des Sektors Gewerbe, Handel, Dienstleistungen (GHD). Abschlussbericht an das Bundesministerium für Wirtschaft und Arbeit*: ISI, DIW, GfK, IE, TUM.

Schoer, K., Buyny, S., Flachmann, D. G. C., & Mayer, D. V. H. (2006). Die Nutzung von Umweltressourcen durch die Konsumaktivitäten der privaten Haushalte.

Statistisches Bundesamt Deutschland. (2003). Klassifikation der Wirtschaftszweige mit Erläuterungen: Wiesbaden.

Wei, Y., & Kohler, N. (2008). Simulation of the evolution of the Chinese building and infrastructure stock. *Building Research & Information*, 36 (1), 1-19.