Climate Change Actions in the Urban Context: A Tool for Decision Makers

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Abstract

In the attempt to address climate change and to foster sustainable development local authorities play a crucial role. They are trying to establish and bundle political actions –for example in climate action plans - to reduce their local greenhouse gas emissions (GHG). However, the interactions and influences of such actions on the complex systems, like cities, are rarely visible and have been hardly investigated as of today. This evokes the difficulty for local decision makers to define and implement appropriate actions.
In this paper, we present a novel system dynamics application dedicated to simulate the impact of distinct mitigation actions. This will support the decision making process for local authorities. The application models the following city sectors:

- The residential sector including space energy demand on heating, electricity, and domestic hot water
- The tertiary sector including energy demand on heating, air conditioning and electricity
- The transport sector including energy demand on public and private transport.

Furthermore, mitigation actions influencing these sectors are integrated in the model and can be chosen individually by the model user. The application enables local authorities to gain valuable insights into the long-term effects of local climate action plans affecting the city system. Additionally, it might help closing the gap between academics and decision makers. For evaluation purposes the urban model was developed based on the city agglomeration "Région Mulhousienne" in France.

Keywords:
Climate change, mitigation, urban context, residential sector, tertiary sector, application, PCET

1 INTRODUCTION AND OBJECTIVES

Nowadays, climate change is one of the most controversy discussed topics. Slowly we see the effects caused by anthropogenic energy demand and the resulting emissions of climate effecting gases. However, the following questions still need to be addressed:

a) How to stop climate change?
b) And who should act to stop climate?

Different councils tried to answer these questions. In many countries climate change actions are defined on different political scales in the aim to stop the increasing temperature. For example the European Union defined in the 2020 targets to reduce greenhouse gas (GHG) emission by 20% and to increase energy efficiency by 20% as well as energy from renewables by 20% by the year 2020. Derived from these targets the French government defined national climate change targets in which a GHG reduction of 14% shall be achieved by 2020 (European Commission 2012). To accomplish this target, a national expert commission was formed in 2007: the so called *Grenelle Environnement*[1] *(Grenelle)*.

The *Grenelle* defines the key issues of governmental policies on ecological and sustainable development for the upcoming years. In their regulations Grenelle1 and Grenelle2 the committee identified and defined the targets for the different GHG emitting sectors. One main actor identified by the *Grenelle* are the local authorities of cities and agglomerations. The local authorities are called to define mitigation actions for the reduction of GHG emissions. To enable the local authorities to concentrate these political mitigation actions the local climate plan "*Plan Climat Energie Territorial*" (PCET) was introduced in 2004 (and updated in 2006). The PCETs became mandatory for cities and communities associations exceeding a size of more than 50 000 inhabitants[2] (ADEME 2010a).

As a result of the young genesis of the PCETs the measures, interactions and influences on the city system are rarely visible and have hardly been investigated as of today.

To gain first insights into the long-term effects of local climate action plans on the city system the research project "*Approche systémique pour les Plans Climat Energie Territorial: mise en perspective 2050*" (ASPECT 2050) was initiated. The objective of the research project is to draw the attention of policy makers to the development of urban systems. This is done while taking into consideration the influences of the defined PCET-actions. As part of the research city model was developed to simulate the interactions between city sectors and mitigation measures, which will be presented in this paper. For evaluation purposes the urban model was developed based on the city agglomeration "Région Mulhousienne" in France.

In the reminder of this paper we will first lay out the related work in the field of dynamic city simulation. In a next step the developed simulation model will be introduced. The main focus will lay on the module developed to model on energy demand and GHG emission utilizing the method System Dynamics. Afterwards the implementation of the model will be outlined. Finally the developed user interface which allows the user to analyze interactively the effects of different mitigation measures will be presented.

1.1 Review of Related Work on City Simulation with the Method System Dynamics

The existing literature emphasizes diverse possible and important sectors from strategic point of view within cities: energy, water, building, transportation, population, economy and business, waste, and land use…

Comparing System Dynamics with the goals of strategic management, one can easily find that System Dynamics supports the strategic management and planning in many cases (Latuszynska

[1] http://www.legrenelle-environnement.fr/
[2] Equal climate plans are obligatory for Regions and "Départements" as well.

2005). This is achieved through its methodological focus on policies, strategies, management rules, cause–effects relationships and dynamics of behavior of investigated systems. Additional the prospective simulation can provide as well added value to current and upcoming questions for urban development.

Still the introduction of System Dynamics in the urban context by Forrester (1969) had to face severe criticism (Alfeld 1995). As a consequence, this approach had not been used as an instrument for city planning and policy making for more than two decades. Alfeld (1976) summarized the experience made with the further development of "Urban Dynamics". In 1995 he gave an outlook on future prospects and challenges for the use of System Dynamics in a city context. In the same year, Radzicki (1995) presented an approach to apply System Dynamics to the study of sustainability in cities taking into account the sectors: demography, business, housing, pollution and government . The issue of sustainability and the complexity of the areas comprised in its definition (WCED 1987) turned out to be the main driver for further applications in System Dynamics for urban context.
Yevdokimov (2002) studied structural paths towards a sustainable transportation system in a city. The transport sector has further been the main topic of study in several publications (Raux 2003; Chen, Ho et al. 2006; Wang, Lu et al. 2008; Armah, Yawson et al. 2010; Lei, Zhang et al. 2012).
Sanders and Sanders (2004) took up the criticism on Forrester's aggregated representation of a city by introducing a spatial model for cities. Uchino et al. (2005) contributed to this approach with the addition of a concept for "attractiveness" derived from social sciences. Comprehensive models which take into account several sectors of the city can be found in Duran-Encalada and Paucar-Caceres (2009), Fong et al. (2009), Liu (2009), Shcherbakova (2010), Guan et al. (2011) and Hennessy et al. (2011).
Other studies focused on the building stock and the related energy demand for heating (Groesser and Ulli-Beer 2007; Filchakova, Wilke et al. 2009; Müller and Ulli-Beer 2010).

The multitude of publications in recent years which apply System Dynamics to the urban context indicate that meanwhile this methodology has proved to be an adequate basis for studying the complex relationships between the sectors in space and in time.

Extending the main aspects of the existing city models on emission mitigation, the System Dynamics based application presented in this paper adds the aspect of buildings and heating technologies as fundamental drivers of energy demand in cities. Energy demand is met by energy consumption, which in turn causes GHG emissions. Hence, urban policymaking should - among other measures - aim at influencing energy demand from buildings in the context of long-term emission mitigation without ignoring effects on other parts of the city. The multi-sectorial approach gives a comprehensive view on the city and the driving dynamics, which could not be gained by using isolated and sector specific models.

2 MODEL DESCRIPTION

2.1 Modelling Approach

In an initial phase the project analyzed the interactions of transport, land-use and the building stock in the urban fabric, as well as the policies taken into account by different exemplary local authorities. This led to the creation of an urban model which will be presented in this paper. The urban model enables to simulate interactions of different PCET measures with the urban system while displaying the energy demand and GHG emissions on the basis of a System Dynamics model.
The urban model was integrated into an interactive user-interface. The purpose of the resulting prototypical application is not only to carry out analyses on the development of energy demand

and GHG emissions, but also to allow the user to participate and investigate his own mitigation measures by providing a direct user-model interaction. This follows the suggestions of Alfeld (1995):

> *"If experience is any guide, then two central rules ought to guide any future application of urban dynamics:*
>
> *- emphasize answers, not models, and*
> *- emphasize interface, not data (Alfeld 1995)."*

Referring to the findings in the literature, different specific models are combined in the presented model. The model comprises three interrelated parts: (1) a land-use module, (2) a transport module and (3) a module for energy consumption and GHG emissions (view Figure 1). Only the last module has been realized with the method System Dynamics.

(1) The land-use module is modeling the household assignment. The households and their preferences for a certain city zone are calculated and distributed to the city zones, taking into account monetary considerations, accessibility, mobility aspects and attractiveness (for more details view: Laterrasse et al. 2012).

(2) The transport module (further referred to as GDMC) follows the classical transport "Trip-Interchange-Model". This model consists of four sub-models Trip generation (trips generated and attracted by each city zone), distribution (allocation of trips), modal choice (allocation in the matrix to different modes of transport) and assignment (public or private transport) (Ortúzar and Willumsen 2006). This calculation is done via MS Excel® and supported by VISUM®[3], while the data is based on the French mobility survey data “enquête ménages déplacements” (EMD).
The described modules land-use (1) and transport (2) are integrated due to the Land Use Transport Interrelation (LUTI) approach and the theory of urban economy (Mieszkowski 1993; Wegener 2004).

The third module (3) simulates energy demand and GHG emissions from transport, residential and tertiary sector by using the method System Dynamics. The module (3) is developed with the method System Dynamics and will be elaborated in detail in chapter 2.2.

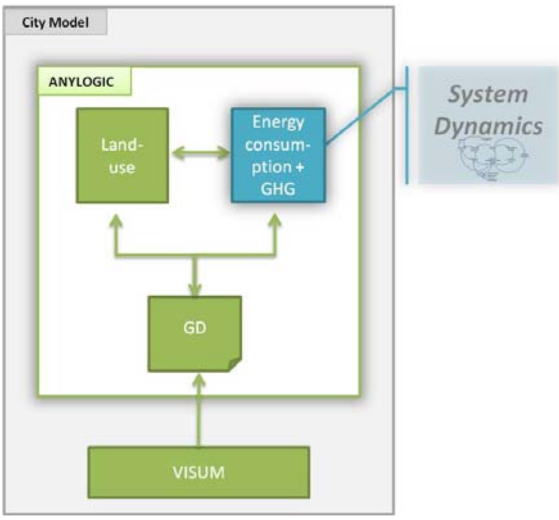


Figure 1: Model structure, highlighting the module (3) realized with the method System Dynamics.

[3] VISUM is a software system from PTV AG for transportation planning, travel demand modeling and network data management (www.ptv.de).

The above presented three modules interact with each other on different variables and parameters. For example the distribution of population and households in the different spatial entities are given from (1) the land-use module to (3) the energy consumption and GHG emissions module. In return, the energy bill per household calculated in the (3) energy consumption and GHG emissions module serves as an input to the (1) land-use module. Also the demand for newly constructed square meters is triggered in an interchange between the (1) land-use module (demand due to population) and (3) the energy consumption and GHG emissions (answering the demand on housing in square meters).

Currently the System Dynamics model is being validated via direct structure testing and (structure-oriented and pattern oriented) behavior testing (Barlas 1989) and different scenarios will be simulated and analyzed.

2.2 Modelled Sectors with the method System Dynamics

Modeling the city system the components regarded as important are within the sectors residential, tertiary and transport (see Chapter 2.3). The modelled sectors are displayed in Figure 2.

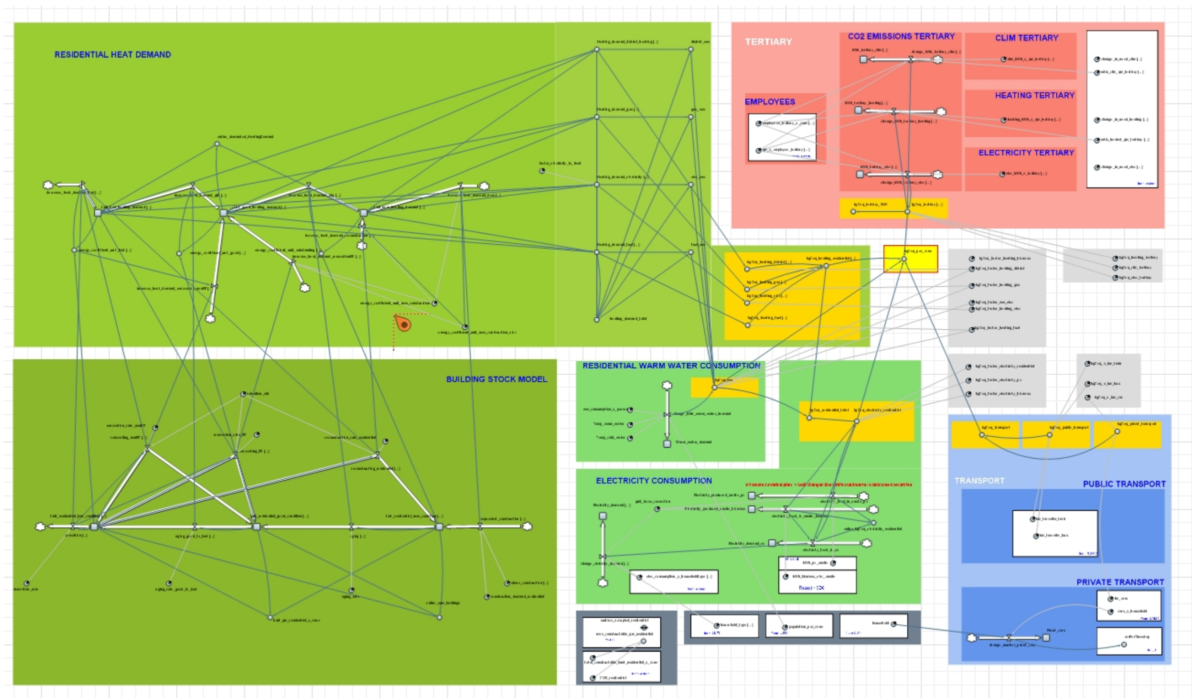


Figure 2: System Dynamics model and the interfaces to the other model compartments. Green areas represent the residential sector, red the tertiary sector and blue areas transport.

In Figure 2 green boxes highlight the residential sector, red boxes the tertiary sector and blue boxes transport. The majority of parameters and variables are embedded in the residential sector. The residential sector is accounted among the principle sectors for energy consumption and can be easily influenced by local decision makers. Additionally, parameters are chosen due to data constrains or in case of transport deriving from the fact that the main calculations take place in the GDMC module. White boxes include parameters and variables changeable by scenarios and recipes. Furthermore the interfaces to the land-use module and the GDMC are presented as white boxes.

The GHG calculations are highlighted in yellow. As mentioned above the structure of this energy demand module is implemented for all 23 zones equally.
In the following the modeled sectors in the System Dynamics module will be presented in detail.

Table 1 : Overview of module properties module on energy demand and GHG emissions

Module properties	Module on energy demand and GHG emissions
Model type	Dynamic Simulation (System Dynamics)
Sectors	Residential Sector (energy demand calculation on electricity, heating, domestic hot water) Tertiary (energy demand calculation on electricity, heating, hot water, air-conditioning) Transport (integration of GHG emissions calculated in the transport module)
Timesteps/Time horizon	Annual /2010-2050
Geographic scale	Zones and IRIS Région Mulhousienne, France
Environmental policies	Residential building sector (renovation strategies) Energy demand and supply (technologies)

2.2.1 Transport Sector

Transport accounts with 33% to the national GHG emissions in France. This makes transport the principle GHG emitter in France (ADEME 2010b). In the presented model the transport related flows are modeled via the introduced GDMC. Thus only few elements are implemented in the System Dynamics part. Included in the GDMC are public transport and private transport. The GHG emissions on public and private transport are calculated in the System Dynamics module via the inputs from GDMC. The emission factors are derived from the Bilan Carbone® (ADEME 2010c).

2.2.2 Residential Sector

Residential building stock

Input from the land-use module is surface (m²) demanded from the different household types. Due to this the here presented module will not simulate separate dwellings but surfaces in square meters. This will proceed in the aging respectively renovation chain of the defined building stocks (see below). Data initialization of the aging chain will be done with the help of the calculated CEREN energy coefficient for the building typology presented below.
The building stock can be considered as one of the most inert components of the urban energy system. With a renewal rate around four to five decades the newly constructed and refurbished buildings determine our future energy consumption substantially (Steger 2002; Kost 2006). Therefore the buildings standard and refurbishment strategies play a crucial role in the PCET.

Due to the semi-aggregated perspective of the model only a small number of attributes of the building stock are defined.
The building typology is defined as follows:

- Building type: social housing, individual houses and apartment houses.
- Age classes: before 1945, 1945-1974[4], 1974 till now.

[4] In 1974, the first important energy regulation was implemented in France.

And crossed with the heating system typology defined as follows:

- Main floor heating fuel: oil, gas, electricity, solid biomass and district heating.
- Heating system: central or individual (CEREN 2010).

In the model the principle residences are taken into account only. No data on secondary or vacant buildings are included. The number of buildings was not considered as a main indicator of the energy demand, therefore buildings are represented by their attributes and square meters (m²). The state of buildings is represented in an aging chain considering the “quality” state of the buildings (Müller and Ulli-Beer, 2010, 16). The quality states are implemented by three stocks in the aging chain.

- Outstanding state: Buildings recently constructed all belong to the outstanding building standard.
- Good state: Buildings still in good condition but not meeting the most resent requirements anymore. First aging signs may occur.
- Bad state: Buildings reaching end of life. The construction elements are defective.

The resulting different quality states of the building stock can be assigned in the aging chain. The aging behavior influences the transition from one quality state to the other. These quality states reflect the specific energy consumption of the buildings and are initialised by the corresponding energy coefficient. The energy coefficients take into consideration the building typology as well as the heating system installed, resulting in 27 energy coefficients. To calculate these coefficients French national data from CEREN was used while adapted to the study region via climate correction.

Directly integrated in the System Dynamics module are measures to change the building´s energy performance and its overall condition. These measures are:

- non energy-efficient renovation (paint job renovation, which does not influence the energy performance);
- energy-efficient renovation (insulation and other measures increasing the energy performance);

These measures are hierarchically implemented. Demolition has the first priority followed by energy-efficient renovation. The remaining buildings will apply to none energy-efficient renovation. The measures alter buildings from the stock in a “bad” quality state through flows linked to the stocks “outstanding” and “good” quality state (view Figure 3). This is realized as a first-order material delay, where perfect mixing is considered and the outflow to be proportional to the stock of material in transit (Sterman 2000: 416).

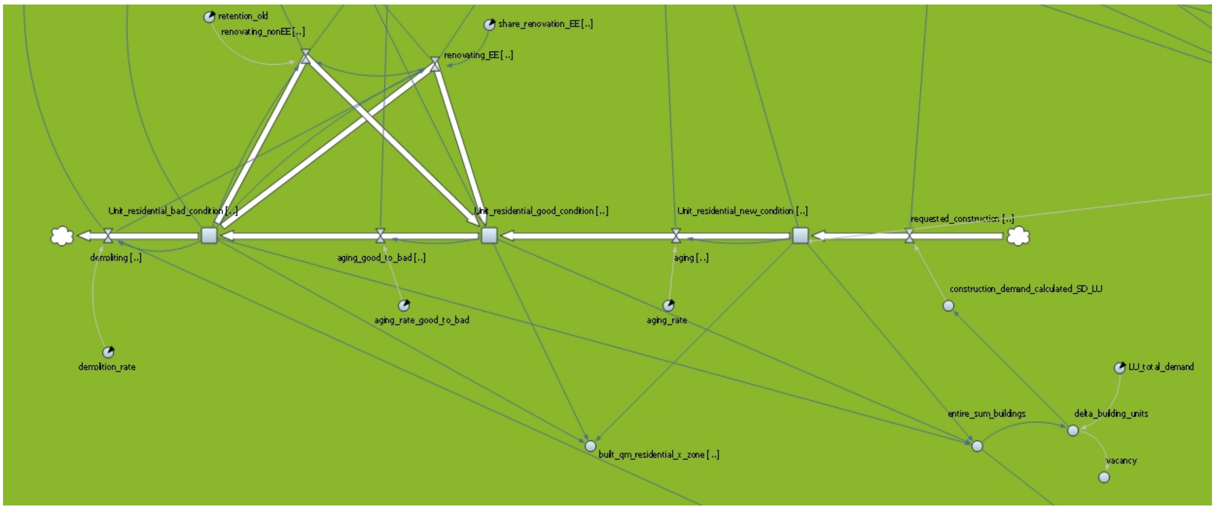


Figure 3 : Stock and flow diagram of the building stock. The arrays include typology information (Schmidt, S., Jäger, T., Karl, U., 2012).

Residential Energy Demand

Heating

In France, 64% to 70% of the energy demand is caused by heating in the principle residences (Direction Générale de l'Urbanisme 2005). One important characteristic of the French heating market is the common installation of electrical systems for heating, especially in new buildings. The different fuels taken into consideration and linked to the building stock are oil, gas, district heating, electricity and solid biomass.
The energy coefficients taken into consideration the building typology and the heating system installed. Energy coefficients are defined specifically relating heat demand to the heated square meters. Hence, the heat demand can be implemented as a co-flow structure of the aging chain (Sterman, 2000, 497pp.) for the heated floor space (see Figure 2). Additionally the energy performance of the building stock is displayed in kWh/m² (the above described energy coefficient). The energy performances for the stocks stay the same for all subscripts. Only the current constructed buildings applying the new building standards. The vales applied follow assumptions and actual values derived from the French building code.
Changes in the energy demand resulting from renovation actions and reconstruction are modeled. The influence of the Thermal Regulation in 2012 (RT2012) is taken into account for new construction and energy-efficient renovation; decreasing the energy consumption to a BBC (*Batiment Base Consomation*) Standard for new buildings of 65 kWh/m² and an improvement through renovation of 20-50%.
According to their aging dynamics, old heating systems are replaced by new heating systems. The choice of the fuel for the new heating system can be influenced by the explained PCET-policies.

Electricity

The model takes into account electricity demand per household size and produced electricity onsite. Electricity demand comprises non thermal uses. The model distinguishes four household categories, starting from one-person household to four and more persons.
Waste and photovoltaic (PV) are considered as renewable energy sources. PV installations are considered for each zone and the generated potential is calculated. The actual installed capacity is derived from the French planning document SCOT. Electricity generation from waste is modelled on the total agglomeration and distributed over all zones evenly. This reflects the specific conditions in Mulhouse. The assumption is made that electricity from PV is used directly in each zone, while

electricity produced by waste combustion is distributed to the total agglomeration. A parameter on prospective changes in electricity consumption can be modified.

Domestic Hot Water

Energy consumption due to domestic hot water demand accounts for around 20% in the principle residences (Direction Générale de l'Urbanisme 2005). The energy used to generate domestic hot water is obtained by using national statistics and installed technologies for floor heating. It is assumed that national statistical data will reflect the uses of gas and electrical systems. The national statistics indicate the use of electrical systems with 53% in individual residents and 38% in collective residents. For gas systems they indicate 29% in individual and 49% in collective residents (ADEME 2010c). For the other fuels used for domestic hot water heating it is assumed that they account equally to the remaining share for domestic hot water heating as they do to floor heating. Until now no alternative technologies are taken into account for warm water heating.

2.2.3 Tertiary Sector

Together with the residential sector, the tertiary sector is the second largest source for GHG emissions in France (ADEME 2010b). In the tertiary sector the model distinguishes between administration and offices, commerce, health, education, and others. On the energy side air-conditioning, electricity and heating are modeled. Precise data on the tertiary building stock was not available. Thus the model is based on the assumption that through the number of employees by branch and the square meters (m^2) for each employee by branch the energy demand can be calculated accurately. The assumption is derived from an approach of the French Ministry for Ecology, Sustainable Development, Transport and Housing (MEDDTL 2011). The calculation was made for each of the 23 zones. Data from the Bilan Carbone® was used for kWh gas for heating, air-conditioning and electricity.

2.3 The model implementation

The System Dynamics Model has been developed within the software AnyLogic® which is based on Java. This software has been chosen due to the spatial aspects in the project and the software's capability to combine agent based modeling with System Dynamics. Additionally the user interface design for the prototype could be realized in this software directly.

Final energy consumption and GHG emissions are defined as the main outputs to be evaluated. The GHG emissions are calculated in carbon equivalent (kg Ceq). The model simulates the city and GHG emission development in a horizon from the year 2010 to 2050. Looking at the life time of principle urban elements (e.g. buildings), this time horizon was defined, even though uncertainty increases with long time scales. The discrete time steps are set to years in all three joined modules.

The model boundaries are set to include the components producing the behavior of interest (Sanders and Sanders 2004). Exogenous parameters are those which are not influenced by other parameters of the model but need to be assigned to a value due to their strong influence on the system behavior. In the described model, these parameters are energy prices and the employment trend, for instance.
Endogenous variables describe the key elements of the urban system which are interacting. Since a urban system is a system of interacting sectors (Alfeld 1976), a multi-sectorial approach is considered to describe the urban system. Here the residential sector, the tertiary sector and the transport sector are regarded as the principle sectors emitting GHG in the urban context which can be influenced by local decision makers.

Regarding its spatial extent, the model integrates data about the city of Mulhouse and the agglomerated communities, which create the Région Mulhousienne. Since not all data was available for the Région Mulhousienne data from different other sources was gathered. Due to this the obtained results may not represent the region accurately.

A a city can be considered as a system consisting of different subsystems[5] (here sectors) (Hastings 2001), thus it is possible - from the modeling point of view - to analyze urban subsystems separately or analyze the system as a whole. The module developed with System Dynamics covers two different scales: the a) global scale and b) the detailed scale. The different scales comprise different characters and functions in an urban system (Sanders and Sanders 2004):

a) Macro scale - global scale including the interactions with the surrounding area
b) Meso scale – the different communities as endogenous driven systems in the urban agglomeration

The a) macro scale describes the Région Mulhousienne as a whole. It includes global components like main infrastructure, external influences and interactions with the surroundings (for example for external influences and interactions: energy mix, energy price etc.).
On b) the meso scale the agglomeration of Mulhouse is represented in 23 different zones. In this the commune Mulhouse is divided in 9 zones (righthand side Figure 4). This approach presents the urban system more accurately and enhances the understanding of the complexity of the urban system, as it describes the communities in the city as individual endogenous driven systems. In all 23 zones the same universal System Dynamics module is integrated, while each zone integrates different initial values.

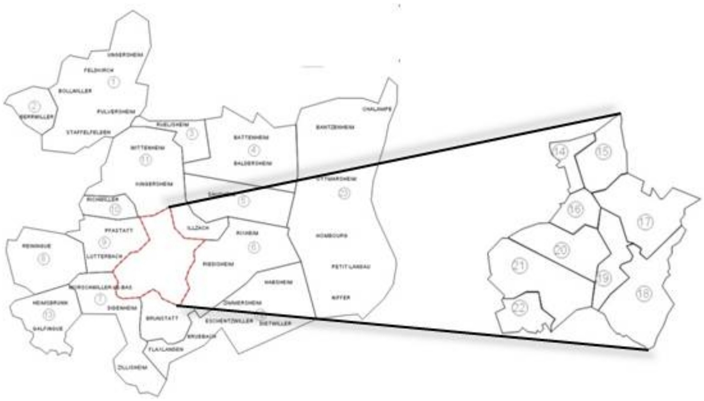


Figure 4: The defined zoning of the Région Mulhousienne for the simulation. On the right side the commune Mulhouse; on the left side the surrounding communes and the zones.

The prototype uses the several categories and sources of data:

- Exogenous Parameters – editable table which includes global and local scenarios, effecting all modules;
- Policies – editable table which includes the PCET-policies, effecting all modules;
- Input data – stored in a database (City DB);
- Output data – stored in a database and as graphical elements (diagrams etc.);
- Meta data – information about the data sources etc.;
- Interface to other modules: Land use module and transport module;

[5] Subsystems system elements which are treated as separate systems. The distinction between system and subsystem has a subjective character and is strongly depending on the defined boundaries of the considerate issue

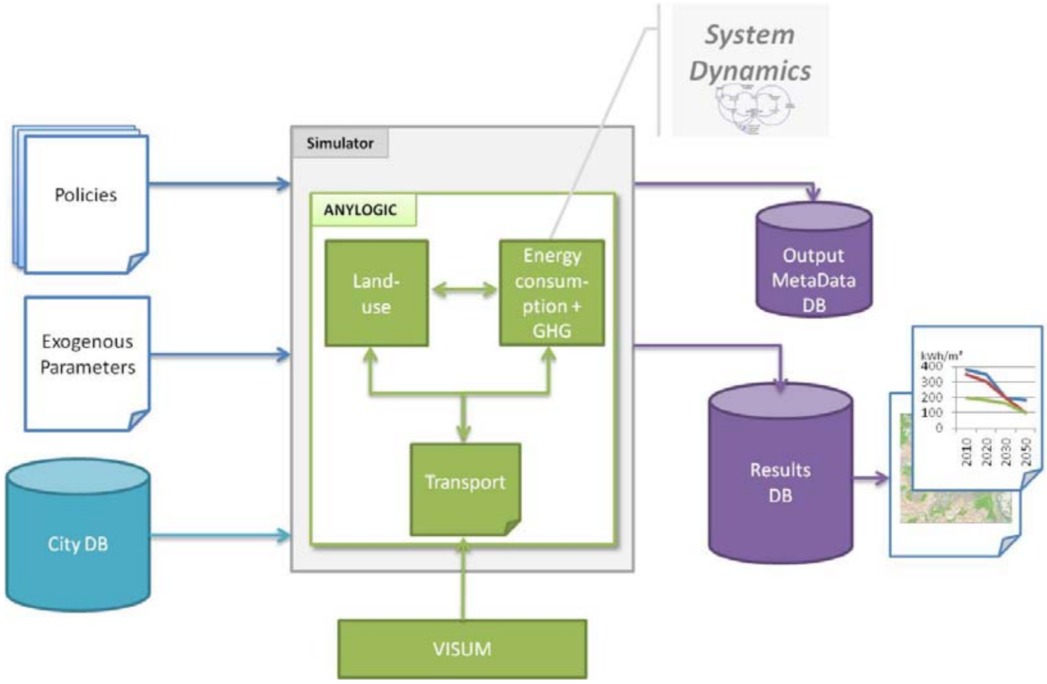


Figure 5: General prototype architecture and data flows.

Figure 5 shows the general model architecture and data in- and output. The input data used by the model includes the following sets of data: standard data for France, exogenous data, Mulhouse data (city level) and data on the neighborhood level. For input data storage, the relational database was created using the MS Access2007® as a database management system (DBMS). This DBMS has been chosen due to its rich graphical interfaces, which allows a quick database design, object creation and small to medium size data volumes handling. Even though the main purpose of the database is data storage, some calculations have been done within the database if treating a large amount of data had been necessary. The communication between AnyLogic® and the database is realized via Java code with embedded SQL statements. The structure of these two consultation components will be described in the following.

2.3.1 Exogenous Parameters

The exogenous parameters set the boundary conditions of the model itself. The exogenous parameters are combined in table files which are called "Meta-Scenarios". The Meta-Scenario parameters have an impact on the city as a whole. They invoke changes which cannot or can just sparely be influenced by accurate policy measures. The parameters introduced are on one hand influences on a global or national scale which cannot be influenced by the city and decision makers but will affect the city (fuel prices, fuel mix on electricity etc.). On the other hand they are parameters which influence due to local decisions the city system (population, employees …).
The Meta-Scenarios table file comprises three sheets, each describing a different meta-scenario. A set of representative parameters is listed and their corresponding values are filled in for forty years. For example the Meta-Scenario "Business as Usual" (BAU) suggests to set rather moderate values for the parameters as energy price and population growth etc., whereas the Scenario "Accelerated" would assume rather extreme conditions.

2.3.2 PCET-Policies

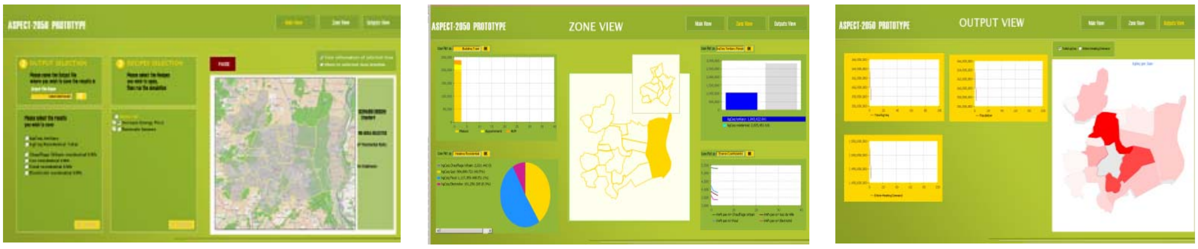
PCET-policies represent mitigation measures applicable to urban areas by the local authorities. The policy parameters are set using the employed MS Excel® file. With this "policy file", parameters can be set and changed for different spatial zones at a certain time step and certain duration. The PCET measures of interest can be chosen by the user directly and thus obtain further insights in the effects of the measures.

2.4 Prototype

To increase the understanding of cause and effect in the urban context and mitigation actions the prototype tries to fill the gap between theoretical knowledge, modelers and city planners. To accomplish this, a user-friendly and interactive interface has been created and can be turned into a flexible analyzing tool. The user is guided and introduced to the topic of climate change actions in the urban context itself but also motivated to take part in the decision-making process.

The prototype employs three main analysis view areas, each of them displaying results on different spatial scales and via different output designs (GIS, dynamic map, total agglomeration, zones etc.). Additionally two main consultation components are embedded, to enable user interactions within the model: The exogenous scenario parameters which define the boundary conditions and the recipes representing the influences of certain policies predefined by the user himself before model start. The recipes therefore represent the core of the prototype. By defining a certain measure the user can set parameters for different zones for certain time steps or time sequences, as described above.
The users' access to the model is provided by two editable Excel tables, which are read into the model at startup. In this way no programming knowledge is required by the user and the integrity of the model is preserved.

2.4.1 Model View Areas



a) b) c)

Figure 6: The different view areas of the prototype are displayed: a) the Main View Area, b) the Zonal Output Area and c) the City Output Area.

As previously described, the model employs three different view areas in order to make precise and effective analysis after but also during model run (see Figure 6). Their main functionalities will be described below.

Main View Area

After choosing the desired boundary conditions the user is led to the first Main View Area, containing an 'Output Info Panel', a 'Recipe Info Panel' and an interactive Map of Mulhouse (Figure 6a). In the 'Output Info Panel' the user can select the Outputs which shall be written to the external output database after model run. The exogenous parameters and their corresponding values (for example for the BAU Meta-Scenario) are already set, so the user can run the model without any individual contribution and observe the city GHG emission development. In the Recipe Info Panel the user selects the desired recipes to be applied during model run and –if desired - commits further changes. Previously selected values and zones can be changed by the user, in order to provide the maximum flexibility within the analyzing process. For example the renovation rate for zone X can be increased by ten percent, while in zone Y the same parameter will be decreased.

Influences of those changes can be observed in the different model windows and -if desired- stored in a separate access database.
The interactive map shows the zoning structure of the city Mulhouse on which the model data is based on. The map comprises an informative and a navigable functionality. Former enables the user to retrieve general information of particular zones by clicking on the corresponding zone shape in the map. Latter leads the user to the second main view area, called the zonal 'Output View'.

Zonal Output View Area

The second view area comprises a map and a set of plots, each of them displaying different output parameters for one selected zone (Figure 6b). The selection is done within this view area. Here the user can click on a certain zone on the city map and the according values in the plots will be updated automatically. A special functionality enables the user to save screenshots of the plots automatically in the model output folder. The headline of each view area provides a direct navigation to the other two view areas, so that the user can compare results and developments within a certain zone and for the entire city. For the latter case the third view area was developed.

City Output View Area

The third output view focuses on the direct cooperation of all zones (Figure 6c). This is obtained by a dynamic map and a set of predefined plots displaying aggregated values of all zones. Contrary to the other two maps included in the model, this map presents a weighted percentage of the value in each zone by applying a color range from white (low value) to red (high value).

Figure 7 summarizes the interaction between the described model and the user-interfaces.

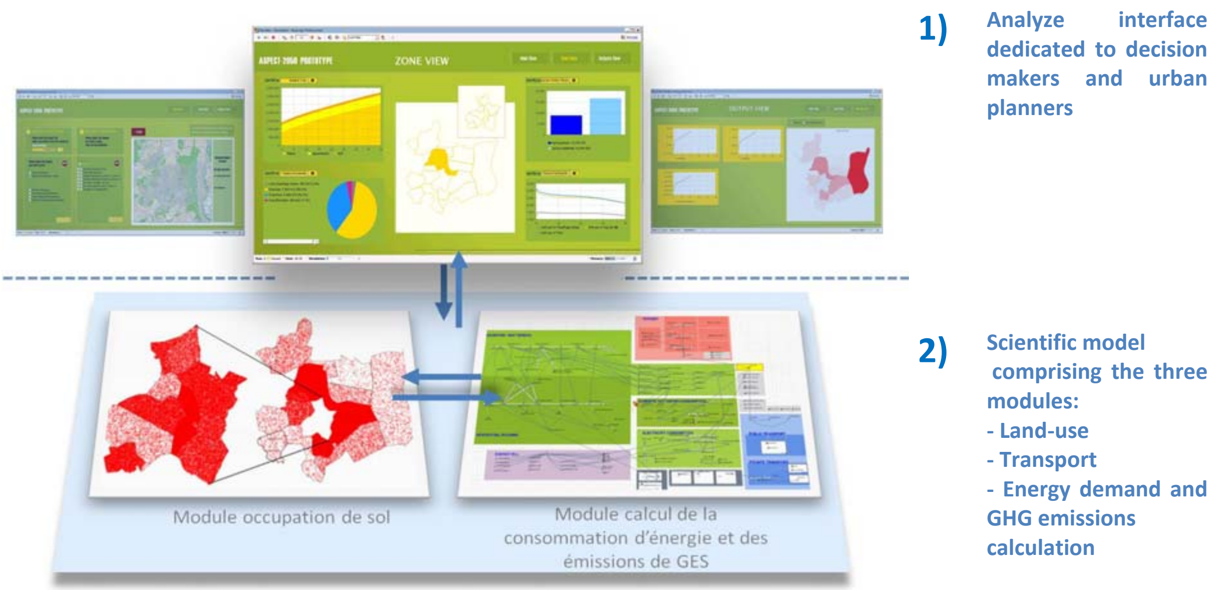


Figure 7: The model developed in the project ASPECT 2050 integrates two parts: 1) The user-interface for the decision makers, which permits data manipulation and simulation analysis. 2) It is feed by a scientific model comprising the three described modules.

3 Summary and Outlook

In this paper we presented an application of a city model to support the decision making process on climate change actions. The application includes of three different modules: land-use, transport and energy demand and GHG emissions. This paper focuses on the last module on energy demand and GHG emissions, which was modeled utilizing System Dynamics.

In the module on energy calculation the emphasis lays on the residential sector. The residential energy demand can be regarded as a principle source for local GHG emissions and thus encompass a high potential for emission reduction. Additionally the local authorities – addressed with the developed application- are the entity closest linked to the citizens and thus can best influence residential sector (Huber et al. 2010). Currently the residential sector comprises the modeling of the aging dynamic of the residential floor space and the related energy demand on heating, domestic hot water and electricity. The method System Dynamics permits the easy simulation of aging behavior and information delays. Through this the inertia of the building stock towards changes in the Thermal Regulations is presented in a comprehensive way. Furthermore the tertiary sector is modeled taking into account the energy uses air-conditioning, heating and electricity. The transport sector is modeled separately.
Additionally to the above described scientific model, the city application comprises a user-friendly and interactive interface. The user-interface allows manipulating different data entries (initial data, policies and exogenous scenario parameters like energy prices) and thus analyzing the long-term effects of different chosen policy measures to meet climate change targets.
The user – local decision makers and/or planners – gains valuable insights in the interaction of PCET actions and their long-term effects. He is as well being motivated to take part in setting the model boundaries to meet the desired targets on GHG emissions reduction.
The participatory approach of the model by integrating the user in the decision making process equips the user with transparent and comprehensive information. This can support filling the gap between academics and local decision makers.

The model was realized for a city or city agglomeration, while here the territory of the Region Mulhousienne was chosen as reference location. The prototype provides a “multi-spatial” approach in modeling each of the 23 defined zones separately. The political measures to be applied can be adjusted for each zone correspondingly. In this way specific characteristics of each zone are taken into consideration and provide a more detailed insight into the GHG development. This multi-spatial approach goes along with the European wide discussion on sustainable neighborhoods (EcoQuartier (France), BREAM Communities (UK) and DGNB NSQ (Germany)) as seedbed of sustainable city development.

First simulation experiments showed valuable insights in:

- The interaction of the urban system on implemented mitigation actions
- The effect of time delays on implemented mitigation actions on the targets
- The interrelation and interaction of the different mitigation actions applied

The next steps will be the integration of a dedicated agent based approach in combination with the existing System Dynamics method, to model the interaction between the city zones.
Another step will focus on the integrated variables and parameters in the further integration of parameters on energy efficiency and alternative energy sources to extent the model in the direction of energy transition in urban areas.

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