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Title:

Urban balance analysis tool

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1. Introduction

In order to supply population and industry with electricity and heat, cities have energy available in different amounts, forms and under different conditions. For example, the chemical energy contained in coal through certain processes can be transformed in heat and in electrical energy. Wind energy can be transformed in electrical energy as well. It depends on the city policies, requirements, budget, planning, availability of resources and other factors which type of energy will be used to be transformed into electricity and heat. Another aspect to keep on mind is that energy markets can be volatile and that future energy availability is difficult to predict. This development will likely have an impact on the energy supply and consumption patterns.

Climate mitigation policies in municipalities have not only global impacts on climate change but there are local impacts on the municipalities as well. For instance, energy policies may add or reduce fine particle emissions and thus influencing effects on human health such as cardiopulmonary diseases. Activities in a city will also affect health outside cities, e.g. the use of more electricity might lead to increases in emissions from coal fired power plants elsewhere.

Thus, an analysis of energy related issues requires a comprehensive presentation of the energy flows not only within the specific spatial domain but the interactions with other regions should be taken into account as well. An instrument commonly used to depict these interactions is the energy balance. The energy balance describes the flow and transformation of energy carriers within a certain spatial location. They are widely used on country as well as on city level to characterise the energy system of this unit.

In this document we describe the urban analysis tool developed within the framework of the Project URGENCHE. The main goal of this methodology is to provide a simple online impact model for climate policy support including energy use and the related emissions generated directly and indirectly during the up- and downstream processes. The model was designed to be both a modelling and dissemination tool, and able to be updated and run by municipality authorities or even by interested citizens. In the following sections we describe the main components of the online model and first results of its implementation.

2. Methodology

The online model is built primary on energy balance data for each city, an energy model solving a set of linear equations, and data on up- and downstream emission and on future energy scenarios. Each component is briefly described in the following sections.

2.1. Energy balance data

Available data was collected for three European cities and one Chinese city. For the cities of Stuttgart and Basel the energy balances were available to some extend and only minor additional calculations were needed (Department of Environment and Energy, 2004; SEE Project, 2010). As the energy balances for Kuopio and Suzhou for the year 2010 were not available, they were generated within the project. Figure 1 shows the Sankey diagrams for the city of Suzhou. The corresponding diagrams for th cities of Stuttgart and Kuopio are included in the Annex.

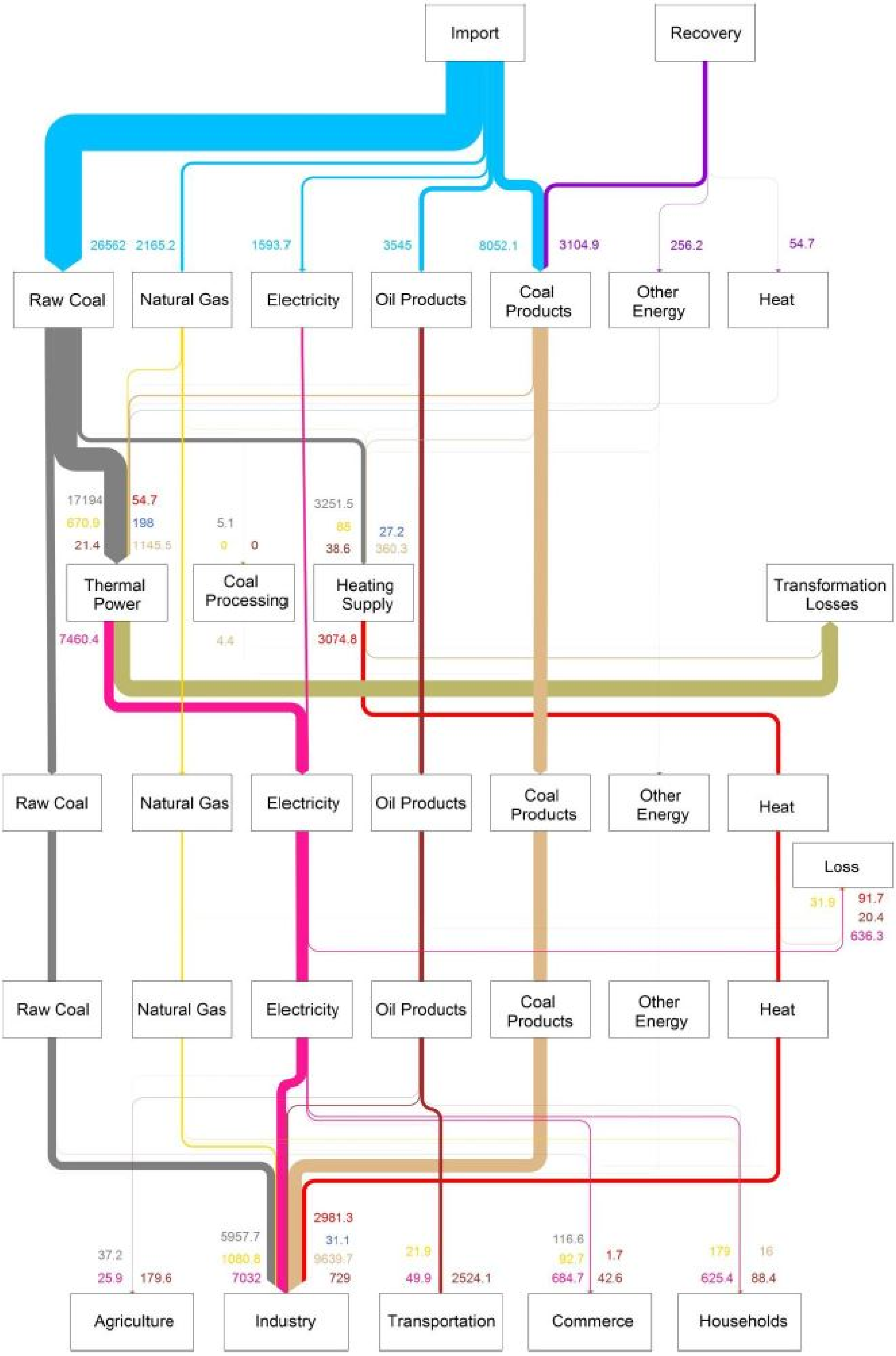


Figure 1. Energy Balance Suzhou for the year 2010

2.2. Energy model

One of the main goals in this project is to be able to model energy scenarios and their associated effect on emissions and human health. Although an energy balance provide valuable insight into the local energy flows, its static nature does not allow for analysing the impact of changes in energy consumption, energy carrier shares or conversion efficiency of a certain power plant. In order to gain insight into the effects of changes in the energy system, such as increasing use of biofuels, increasing use of biomass in domestic heating, fuel shifts, etc., the energy balance data was transformed into a system of linear equations that depict the energy flows and transformation processes within a city. The mathematical formulation used to derive the equations system follows the theory of linear systems: A linear equation in variables $x_1, x_2,\ldots,x_n$ is an equation of the form

$$a_1x_1 + a_2x_2 +\ldots+ a_nx_n = b,$$

where $a_1, a_2,\ldots,a_n$ and b are constant real or complex numbers. The constant a_i is called the coefficient of x_i and b is called the constant term of the equation. A system of linear equations (or linear system) is a finite collection of linear equations in same variables. For instance, a linear system of m equations in n variables $x_1, x_2,\ldots,x_n$ can be written as:

$$a_{11}x_1 + a_{12}x_2 +\ldots+ a_{1n}x_n = b_1$$

$$a_{21}x_1 + a_{22}x_2 +\ldots+ a_{2n}x_n = b_2$$

$$\ldots$$

$$a_{m1}x_1 + a_{m2}x_2 +\ldots+ a_{mn}x_n = b_m$$

A solution of a linear system is an ordered set $(S_1, S_2,\ldots,S_n)$ of numbers that makes each equation a true statement when the values $S_1, S_2,\ldots,S_n$ are substituted for $x_1, x_2,\ldots,x_n$, respectively. The set of all solutions of a linear system is called the solution set of the system.

For this model, the set of linear equations is constructed based on discretization of each energy process found in the energy balance as it is depicted in Figure 2.

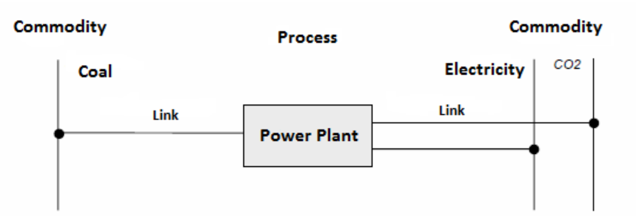


Figure 2. A simple energy process (Schlenzig, 1998)

In this figure, the input into the system of a certain commodity (coal) is linked to its transformation into electricity by a power plant and it is linked to its use as electricity as well. The following equation describes this process:

$$C_1x_1 + E_1 = 0$$

Where:

x_1 = Coal quantity

C_1 = Conversion efficiency in power plant 1

E_1 = Electricity required

In this simple example, it is clear that when the electricity required increase, the coal supply increases as well. Furthermore, if the conversion efficiency in the power plant where to be increased, the coal supply would decrease accordingly. Using a similar approach, one linear equation is built for each process depicted in the energy balance, resulting in a set of linear equations. The system is then solved numerically using matrices.

The model was implemented in an open web workspace Opasnet with R software. The structure of the balance table was taken from the OECD energy balance sheets, with city-specific modifications when needed. It is important to note that the user can easily define a multiple sets of variables that are solved one at a time. This is useful when comparing e.g. different decision options, time points, seasons, etc.

2.3. Up and downstream emissions

Up and downstream emission take into account that significant emission sources linked to energy use activities are often located outside of the spatial domain where those activities are taken place. The Life Cycle Analysis (LCA) investigates the environmental impacts through the analysis of the full life-cycle of a product or a system. LCA can improve the efficacy of environmental regulations, as it can pin-point with a great certainty the source of environmental pollution or resource use of upstream and downstream processes (Weisser, 2007). It is also important to note that LCA studies are subject to several variations that could yield in different results even when the same system or product is analysed. Such changes in life cycle emissions should have to be taken into account, and thus the urban balance is extended by a satellite balance that takes account of important life cycle emissions, These are especially emissions from supplying secondary energy carriers, e.g. from electricity production, refineries, and biomass production.

The basic idea of the LCA is that all the environmental burdens connected with a product or services have to assessed, back to the raw materials (upstream), and down to the waste removal (downstream). A very special characteristic is that it avoids positive ratings for measurements, which only consists in the shifting of burdens (Klöpfer, 1997). For this project, LCA data from the Ecoinvent database was available.

2.4. Future energy scenarios

Energy markets can be volatile and future energy availability is difficult to predict. This development will likely have an impact on the energy supply and consumption patterns. In order to have a common analytical framework for analysing future energy scenarios, an energy system model was for the European Cities. For the Chinese cities, general country projections drawn from the International Energy Agency were used. A brief description of the Energy model is provided in the next section.

The Pan-European TIMES energy system model (short TIMES PanEU) based on the model generator TIMES. It is a model of 30 regions which contains all countries of EU-27 as well as Switzerland, Norway and Iceland. The model covers on a country level all sectors connected to the energy supply and demand, for example the supply of resources, the public and industrial generation of electricity and heat and the industrial, commercial, household and transport sectors. The model contains three different voltage levels of electricity and two independent heat grids. Both greenhouse gas emissions (CO_2, CH_4, N_2O) and local air pollutant emissions (CO,

NO_X, SO_2, NMVOC, PM_{10}, $PM_{2.5}$) are covered. The transport sector integrates the areas of road transport, rail transportation, navigation and aviation in the model. The road transportation encloses five demand categories for passenger transportation and one for freight service. The rail transportation includes the three categories rail passenger transportation (short and long distance) and also rail freight transportation. The household sector contains eleven demand categories (space heating, air conditioning, hot water, cooking, lighting, refrigeration, washing machines, laundry dryer, dishwasher, other electrics, other energy use) whereof the first three are specified according to building types (single family houses in urban and rural areas and multi-family houses, each with stock and new buildings). The commercial sector is represented by a similar reference energy system (RES).The industrial sector is divided into energy intensive and non-intensive branches. While the intensive ones are modelled by a process orientated approach, the other industries have a similar structure of energy services. The industrial sector is subdivided into several branches. For extensive information about the TIMES PanEU Model, the reader is referred to Blesl (2008) and Blesl et al. (2008).

Figure 3 and Figure 4 show the final energy consumption by energy carrier for Germany and Switzerland. Similar results are available for Finland, Greece and The Netherlands.

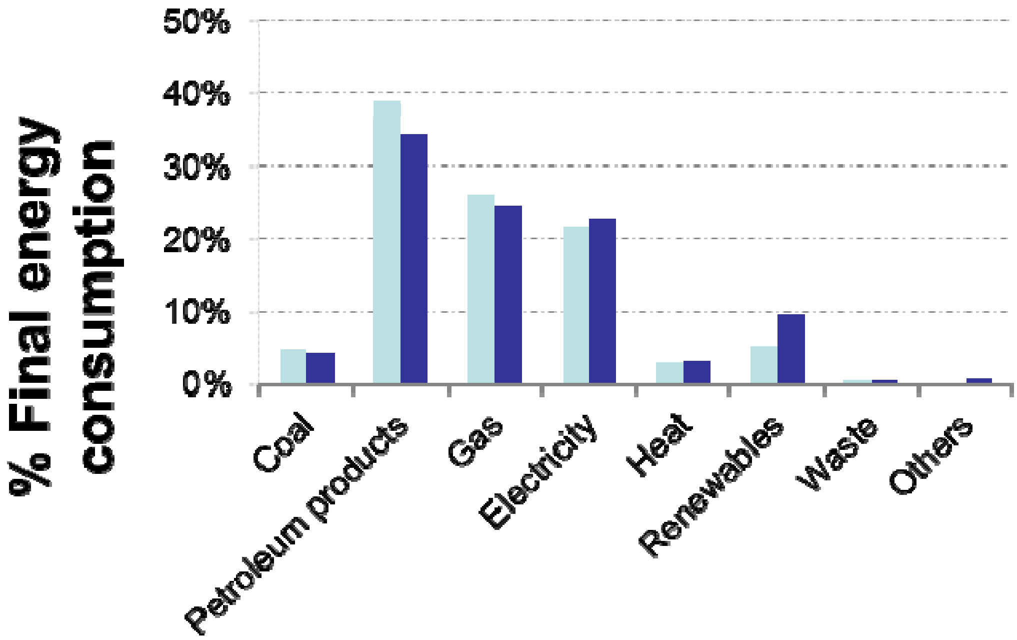


Figure 3. Final energy consumption by energy carrier for Germany in the year 2025

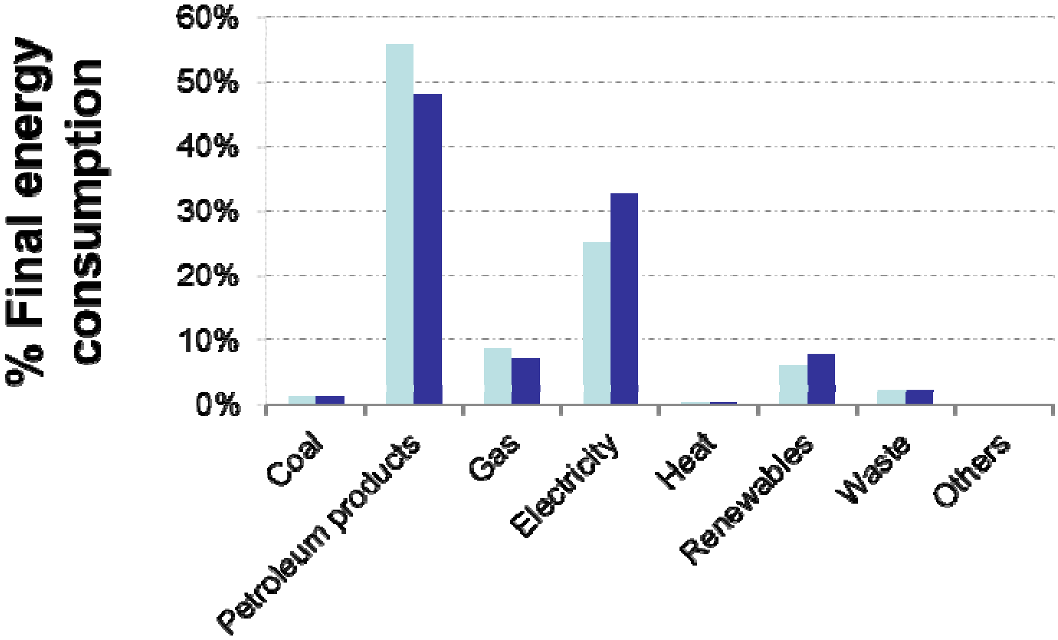
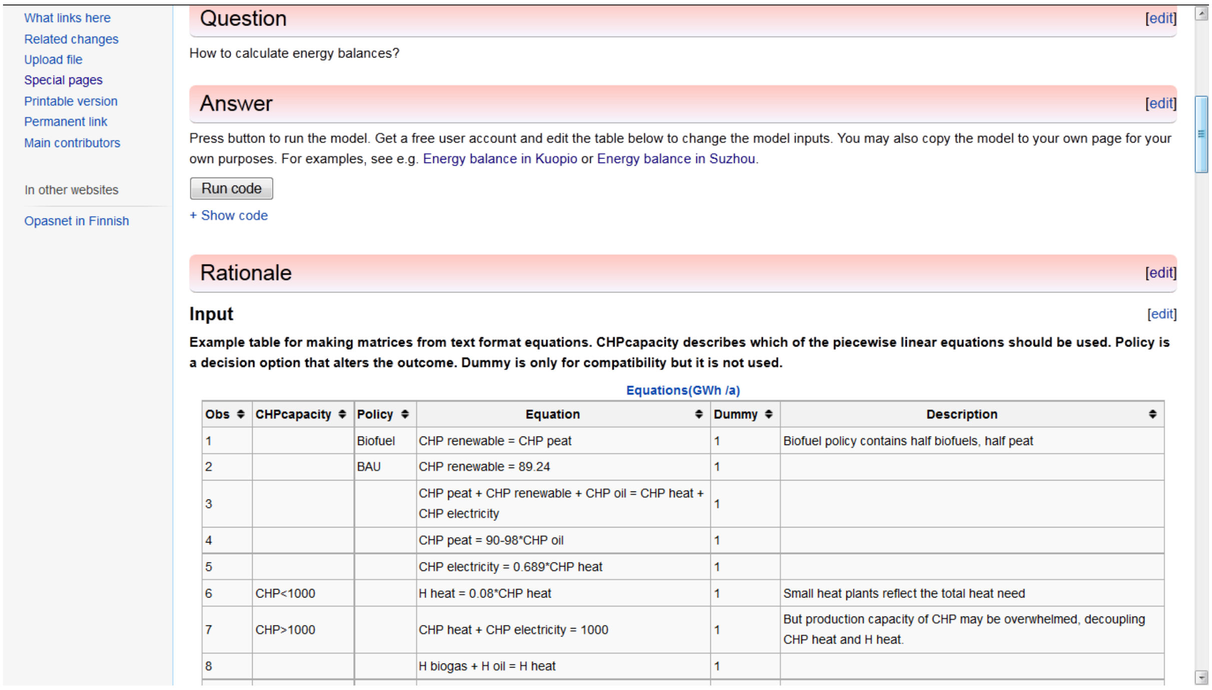


Figure 4. Final energy consumption by energy carrier for Switzerland in the year 2020

3. Results

Data was collected and model adjusted for two European cities: Kuopio (100,000 inhabitants, in Finland) and Stuttgart (600,000 inhabitants, in Germany) and one Chinese city Suzhou (2.38 million inhabitants). Figure 5 depicts a screenshot of the model page in Opasnet. One characteristic of the model is that it can be adjusted for new situations. New columns can be added for additional determinants such as time or a new policy. The imported energy carries for each city are shown in Figure 6. Both absolute and relative differences are large and it is quite evident the large dependency of the Chinese city Suzhou on coal.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Opasnet in Finnish

Question [edit]

How to calculate energy balances?

Answer [edit]

Press button to run the model. Get a free user account and edit the table below to change the model inputs. You may also copy the model to your own page for your own purposes. For examples, see e.g. Energy balance in Kuopio or Energy balance in Suzhou.

Run code

+ Show code

Rationale [edit]

Input [edit]

Example table for making matrices from text format equations. CHPcapacity describes which of the piecewise linear equations should be used. Policy is a decision option that alters the outcome. Dummy is only for compatibility but it is not used.

Equations(GWh /a)

Obs	CHPcapacity	Policy	Equation	Dummy	Description
1		Biofuel	CHP renewable = CHP peat	1	Biofuel policy contains half biofuels, half peat
2		BAU	CHP renewable = 89.24	1	
3			CHP peat + CHP renewable + CHP oil = CHP heat + CHP electricity	1	
4			CHP peat = 90-98*CHP oil	1	
5			CHP electricity = 0.689*CHP heat	1	
6	CHP<1000		H heat = 0.08*CHP heat	1	Small heat plants reflect the total heat need
7	CHP>1000		CHP heat + CHP electricity = 1000	1	But production capacity of CHP may be overwhelmed, decoupling CHP heat and H heat.
8			H biogas + H oil = H heat	1	

Figure 5. A screenshot of the model page in Opasnet
http://en.opasnet.org/w/Energy_balance

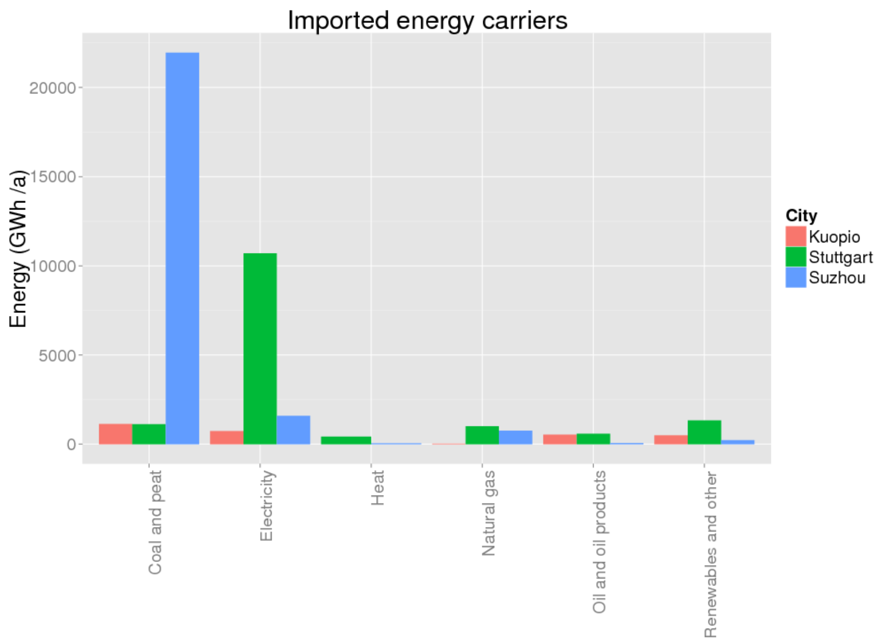


Figure 6. Energy carriers in the three cities

In Figure 7, the final energy consumption by sector and inhabitant is shown. It is interesting to note the large difference between personal and industrial use of energy in EU and China. Figure 8 depicts two alternative policies (Business as Usual and increasing use of biofuels), an estimate of the uncertainties attributed to the activities, and nonlinearities related to the maximum capacity of a major power plant.

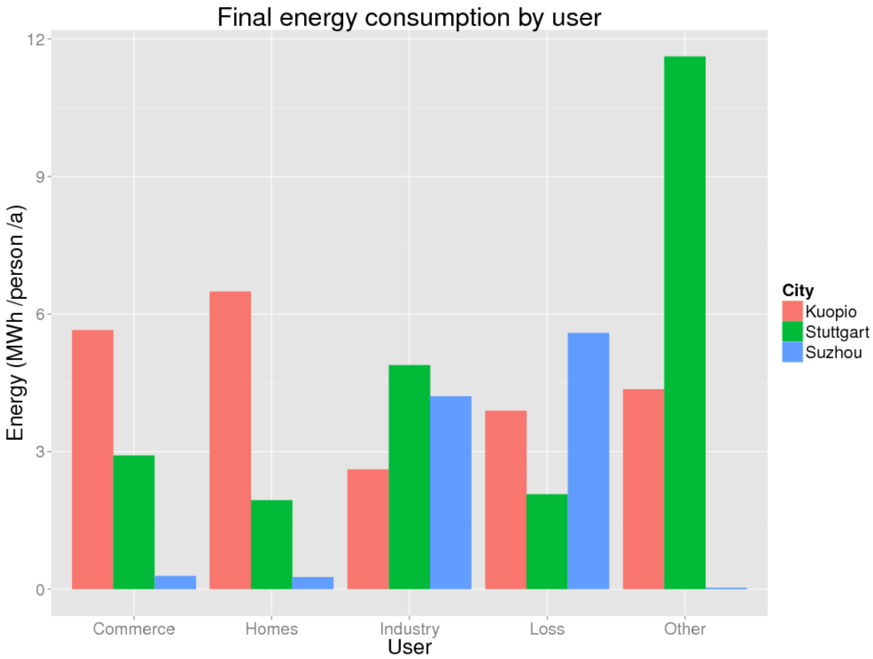


Figure 7. Final energy consumption disaggregated by sector.

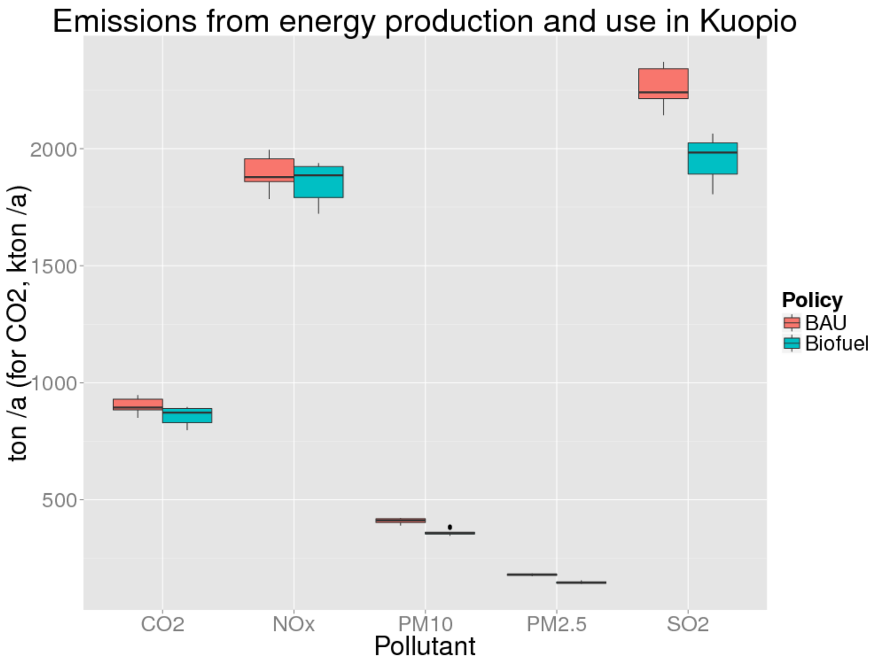


Figure 8. Emissions related to energy production and use in Kuopio.

4. Conclusions and Outlook

The energy balance model was tested using the energy balance data available for one Chinese and three European cities. The model is able to calculate input/output balances for different scenarios. Its object-oriented structure makes it possible to attach the model to emission data concerning up- and downstream processes. It should be noted that during the test phase two major functionalities were added based on feedback from the cities partners: inclusion of uncertainties (using Monte Carlo) and nonlinear functions (using piecewise linear equations). Uncertainty ranges facilitate a more accurate analysis of the results by the user. The piecewise linear equations on the other hand deal with nonlinear processes such as the capacity limit of a power plant. In the next months, the online model will be further improved and adapted to the needs and requirements of the city partners in the project.

References

Blesl, M. (2008) “EU 20-20 policy implications on the energy system of Germany – an analysis with TIMES PanEU”; in Nadia Maizi, Jean-Charles Hourcade: Carbone et prospectivees Presses des Mines 2008

Blesl, M., Kober, T., Bruchof, D., Kuder, R. (2008) “Contribution of technological and structural changes in the energy system in the EU-27 to achieve ambitious climate protection goals (in German)“; Journal of Energy Economics, Issue 4/2008, pp. 219 – 229

Department of Environment and Energy (2004) “Energy statistics Canton Basel-City” Internal report, Basel

Klöpfer, W. (1997), “Life Cylce assessment: From the beginning to the current state”, Journal Environmental Science and Pollutant Research, Issue 4, pp 223-228.

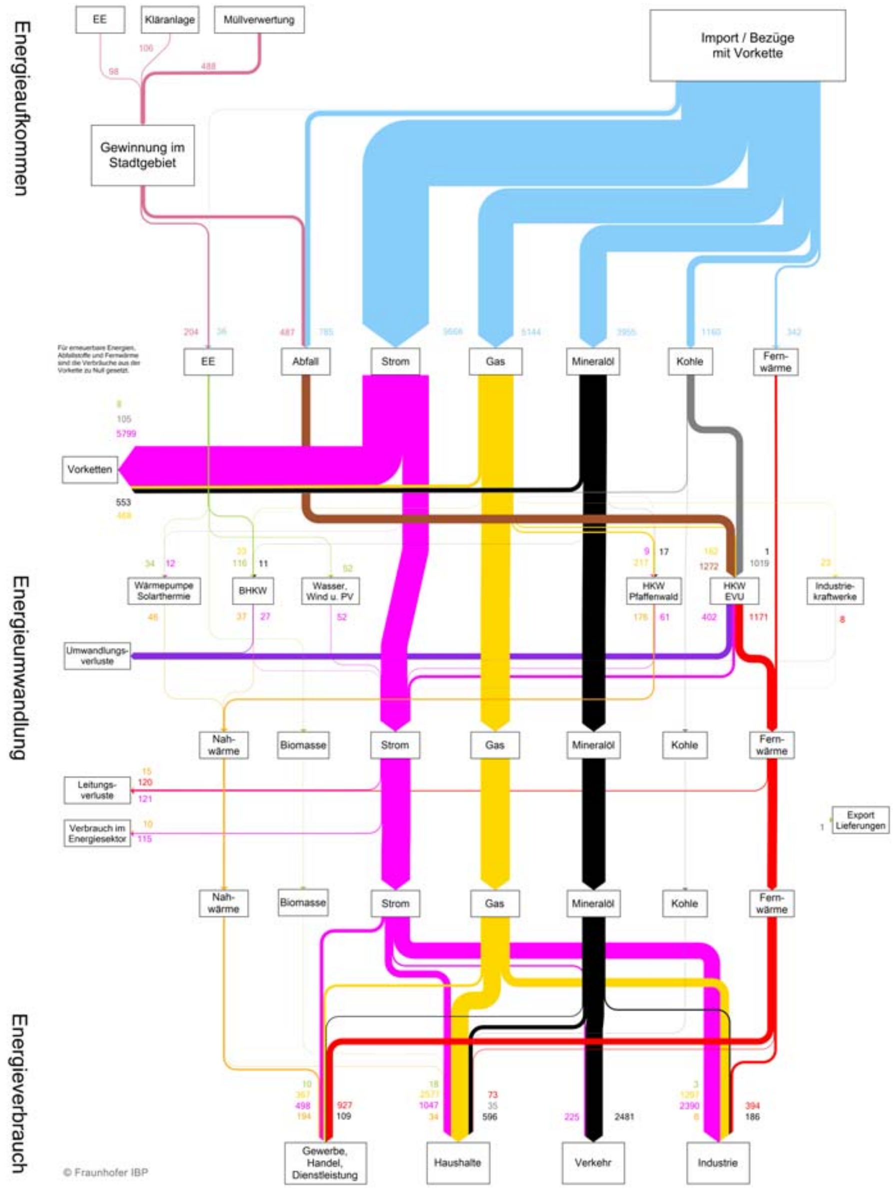
Schlenzig, C. (1998), “PlaNet: a decision support system for energy planning” Doctoral Thesis, Universtiy Stuttgart. Available online: http://elib.uni-stuttgart.de/opus/volltexte/2001/742

SEE Project, (2010) “Stadt mit Energie-Effizienz (City with Energy Effficiency, in German). Project report, Capital City Stuttgart
http://www.stuttgart.de/img/mdb/publ/19227/62226.pdf

Weisser, D. (2007), “A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies.”, Journal Energy Issue 32, pp. 1543-1559.

Annex

A.1. Energy Balance Stuttgart 2010 (Source SEE, 2012)



A.2. Energy Balance Kuopio (2010)