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Projections of Energy Demand: Different Approaches and their Synthesis

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Introduction

In interdisciplinary research as it is practised at the European Institute for Energy Research (EIFER), projections of energy demand have to respond to various demands. Consequently, approaches highly differ according to disciplinary perspectives and / or demands imposed by clients. We identified two major approaches to energy demand projections at EIFER: sectoral and climatological projections.

In this paper, methodology and recent findings of both approaches will be outlined.

In the sectoral projection a comparative analysis was launched on the different national estimations upon the German energy demand until 2030 in the residential, the tertiary and the industry sector. The estimation was performed with the help of the energy planning tool PlaNet MESAP.

In the climatological projection the effect of rising temperatures on the electricity demand in the German federal state Baden-Württemberg was analysed. The analysis was conducted by using climate model temperature output as input into an electricity forecast model which was calibrated on the region.

In a synthesis, the approach of System Dynamics will be exemplarily presented for the residential sector. It is a solution to integrate both types of projections into an overall model which responds to four identified needs at EIFER: 1. User-friendliness, that means it should be applicable for experts without model experience, 2. It should allow to estimate future energy demand by taking into account feedback loops and 3. It should also allow analysing interdependencies and sensitivities between various factors influencing energy demand. 4. It should allow observing the system's behaviour during longer time periods.

1 Sectoral projection

Detailed energy demand side analysis for Germany is needed for the residential, the tertiary and the industry sector, in order to estimate the future economic potential of decentralised generation (DG) in Germany until 2025. For the national approach a study in itself was launched in order to estimate the energy demand from today until 2025.

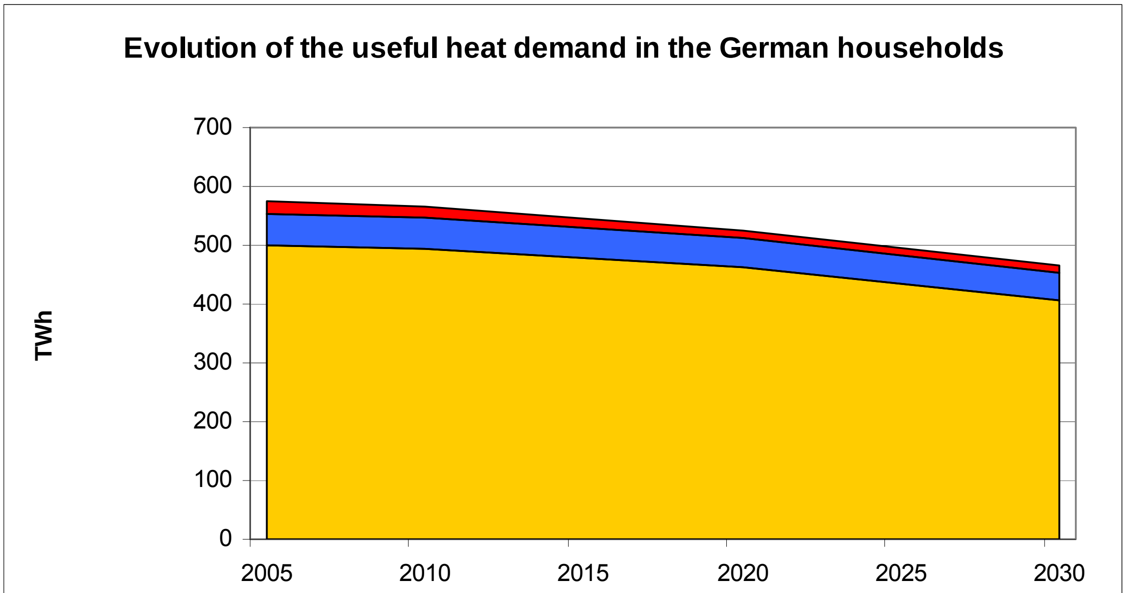
The energy demand is analysed by detailed literature reviews and recalculations in terms of useful energy demand in an energy planning tool - PlaNet MESAP (Chopin et al. 2008).
The structure of the final energy consumption of the country is broken down in a consistent manner, subdividing the economy into major consuming sectors and sub-sectors, i.e. residential, tertiary and industry.
Energy consumption in each sub-sector is disaggregated into a multitude of end-uses, i.e. space heating (incl. domestic hot water), cooling, process energy and electricity.

1.1 Residential sector

The residential sector is divided into five house classes (SFH = single family house, RDH = row double house, SMFH = small multi family house, LMFH = large multi family house and HRB = high rising building) and an additional three age groups (<1980, 1980 – 2002 and > 2002), coherent with the insulation standards in Germany (Konrad et al. 2009).

Label	years	specific heat demand	Average size of accommodation unit	number of housing units in 2005	number of accommodations in 2005
		[kWh/m² a]	[m²/AU]		
SFH	until 1980	204,2	112,0	6.849.742	8.286.322
SFH	1981-2001	129,2	134,7	2.447.143	2.920.401
SFH	2002 - 2030	85,0	125,3	518.230	616.693
RDH	until 1980	168,7	86,9	2.109.129	4.003.910
RDH	1981-2001	118,3	100,0	901.791	1.700.161
RDH	2002 - 2030	85,0	125,3	326.752	455.950
SMFH	until 1980	162,3	69,0	1.271.459	5.805.218
SMFH	1981-2001	97,6	76,2	389.952	1.755.579
SMFH	2002 - 2030	65,0	70,0	103.703	178.637
LMFH	until 1980	143,6	62,2	728.749	6.305.293
LMFH	1981-2001	89,5	66,8	218.393	1.856.862
LMFH	2002 - 2030	65,0	70,0	58.451	179.645
HRB	until 1980	125,9	57,9	128.885	2.884.863
HRB	1981-2001	85,0	61,7	36.744	808.466
HRB	2002 - 2030	65,0	70,0	10.257	82.490
			total	**17.013.841**	**37.719.528**

Table 1: Residential sector – current specific heating demand and accommodation unit size per objects



	2005	2010	2020	2030
Process Heat	19,2	18,9	14,7	13,2
Hot Water	53,5	52,7	50,0	46,8
Room Heat	501,1	495,2	461,4	405,6

Figure 1: Evolution of the useful heat demand in the German households [**in TWh**] calculated by the MESAP-Planet energy planning tool.

The basic assumptions concerning the renovation of existing buildings are: with a lifetime of 40 to 50 years for facades and roofs we expect that every year 2% of the buildings will be renovated. We assume that roughly 50% of these buildings will undergo improvements of the insulation. Thus renovated buildings will increase by 1 % per year to 30% in 2030. Buildings built between 1981 and 2001 will not be renovated until 2020, and reach 10% in 2030.

Figure 1 shows that the room heat demand in the German residential sector is estimated to decrease down to 19% until 2030 in comparison with 2005.

The following step is the calculation of the potential of heat and power generated by DG technologies. Our methodology uses the calculated useful energy demand in the described sub-sectors and classes (e.g. HRB, before 1980) and the specific number of thermal full load hours (FLH) of specific building types using the guideline VDI 4655 – developed by the Association of German Engineers. The reference load profiles have a regional climatic resolution. In the case of the aggregated national study an average over the climate zones was taken.

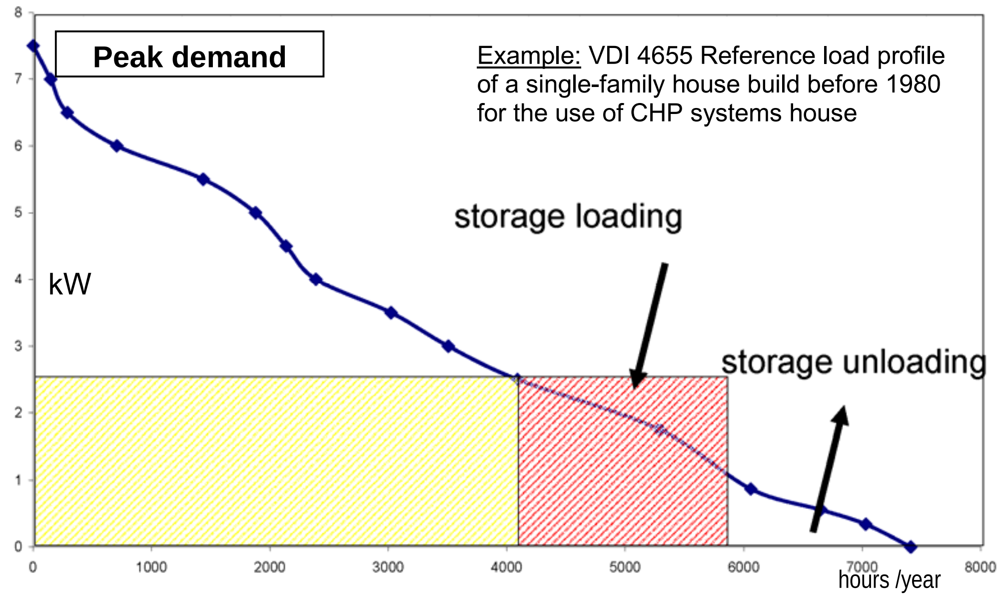


Figure 2: Residential/tertiary sector – Reference load profile for the identification of full load hours for a CHP technology

Figure 2 shows a typical dimensioning (~30% of max. thermal power) of a CHP-installation and the resulting full load hours, which enable together with the results of the demand site estimation the calculation of the DG-Potential in the specific classes and the according age structures.

1.2 Industrial sector

The industry comprises ten sub-sectors with an additional six classes related to the number of employees.

Figure 3 shows the current industry segments weight in final energy demand in Germany. The metal industry together with the chemical industry represents already 55% of the energy demand of the German industry.

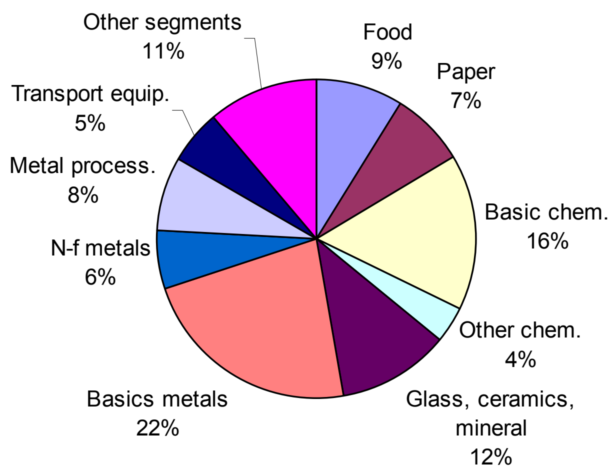


Figure 3: Industry sector –share of final energy demand per segment, 2005

The energetic classification of the industry is further refined by taking into account the number of employees (the operation of a factory in one, two or three shift directly impacts its number of operating hours). 6 size classes are considered:

1) 1-49
2) 50-99
3) 100-249
4) 250-499
5) 500-999
6) >1000

The following table as well as the following charts present the main model results: the useful energy demand for the industry sector, disaggregated per segment and per uses for 2005.

Segment	Units	Employees	Space heat	Proc. heat <100	Proc. heat 100-500	Proc. heat 500-1000	Proc. heat >1000	Air Cond	Cooling	Tot. heat (cold incld.)	Total Elec	ratio heat / power
Food	5 890	542 921	8 269	12 703	12 893	-	-	1 517	25 651	61 033	14 705	4,2
Pulp & Paper	1 014	140 669	3 530	5 763	12 983	-	-	387	-	22 663	18 879	1,2
Basic Chemicals	541	189 209	3 428	8 287	10 465	20 166	4 778	453	1 966	49 542	53 038	0,9
Other Chemicals	1 329	293 456	886	2 415	3 093	5 353	1 268	802	-	13 817	8 153	1,7
Glass, Ceramic, mineral process.	3 425	217 798	1 948	649	930	13 103	26 034	581	-	43 245	12 083	3,6
Basics metals	94	79 720	2 651	515	1 500	17 101	80 803	223	-	102 793	24 454	4,2
nf-metals	662	133 757	383	170	242	2 186	8 239	361	-	11 581	26 470	0,4
Metal processing & machinery and equip.	18 379	1 591 970	10 179	3 820	2 765	1 344	3 376	4 538	-	26 021	21 481	1,2
Transport equip.	1 731	939 027	6 318	2 277	1 528	675	1 832	273	141	13 045	18 389	0,7
Other Industries	17 527	2 023 490	10 482	8 212	5 136	736	2 086	5 450	3 638	35 739	37 498	1,0
Total	50 592	6 152 018	48 073	44 810	51 534	60 663	128 416	14 586	31 396	379 477	235 148	

Table 2: Industry sector – useful energy demand per segment and uses, GWh, 2005

The industry sector is further analysed with the help of obtained industrial data from France about the consumption, the maximal power, the size of the companies and their activity sector. The data is evaluated in order to assign the number of hours during which there is a need for energy. Curves presenting the number of full load equivalent thermal hours are drawn for each sector (Figure 4). The following methodology for the estimation of the DG-potential until 2025 is then parallel to the method described for the residential sector.

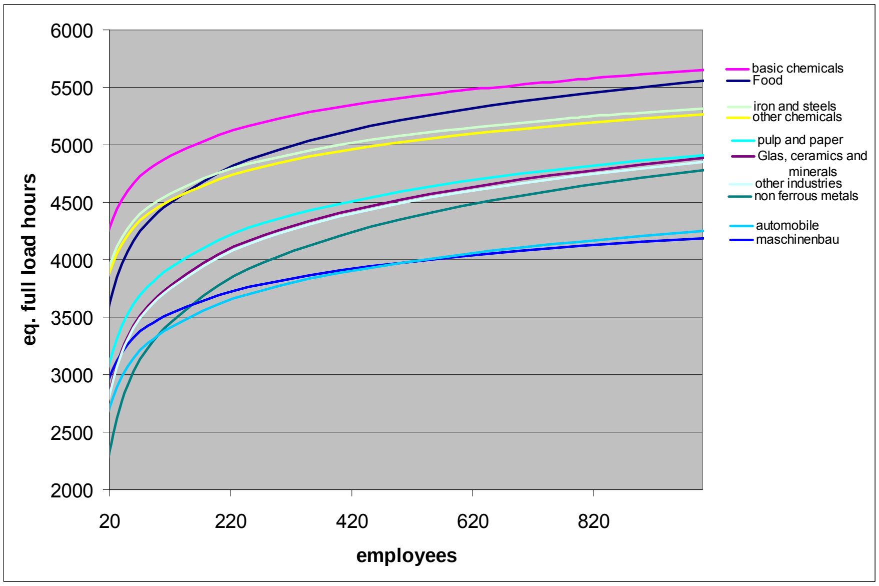


Figure 4: Industry sector – equivalent thermal full load hours

1.3 Tertiary sector

Finally the structure of the tertiary sector is established. As there is no direct available data for this heterogenic sector, the tertiary sector is classified in the following categories: segments with preponderant heating needs, and the segments with preponderant process needs. Finally a decision tree is built in order to choose which sub-sectors and classes are comparable with the residential and the industry sector.
The methodologies defined for the industry and the residential sector were applied to the tertiary sector. Figure 5 shows the share of useful energy demand per uses in 2005.

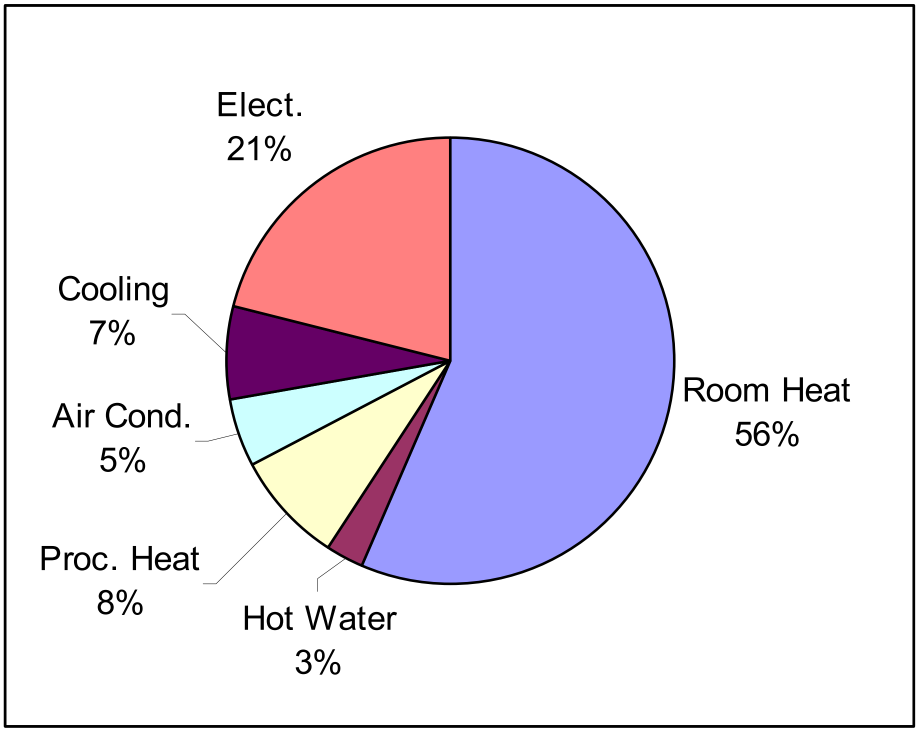


Figure 5: Tertiary sector –share of useful energy demand per uses, 2005

Those with preponderant heating needs (at least 90% of the thermal demand) were therefore treated using the residential methodology based on the VDI method. Those with preponderant process needs (as a matter of fact it always corresponds to at least 50% of the thermal demand) were treated using the industry methodology. A specific analysis was carried out for segments with high cold / air conditioning needs and for segments with preponderant heating needs but not assimilated to a residential building type.
Altogether 14 sub-sectors are identified for the tertiary, with an additional four classes related to the number of employees.

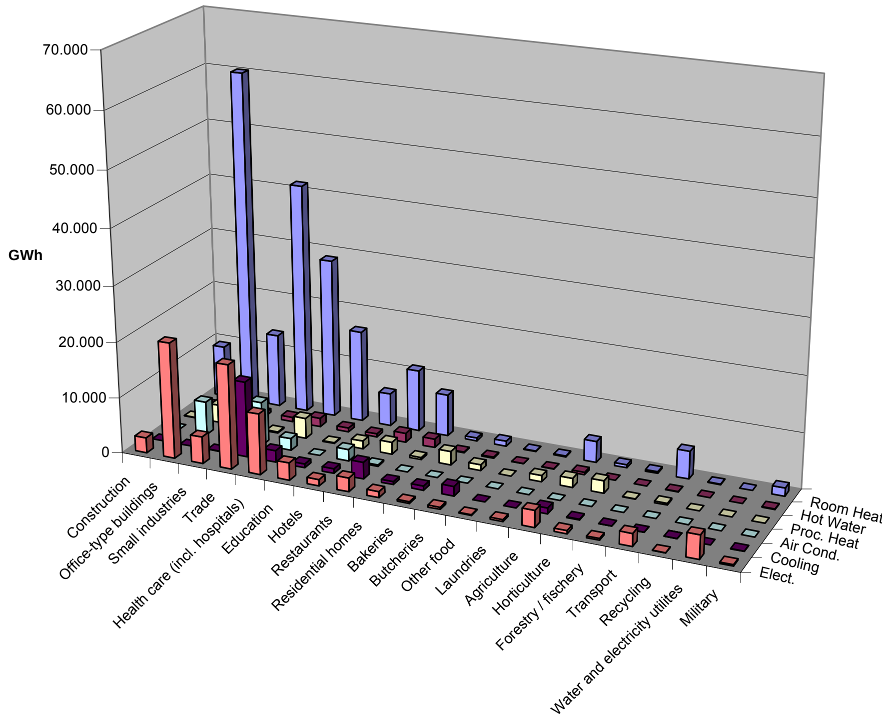


Figure 6: Tertiary sector –breakdown of the useful energy in segment and uses, GWh, 2005

The method used for the residential sector was used in this case: each segment according to its size (number of employees or surface) is assimilated to a type of building (e.g. single family house). The VDI method was adapted to take into account the different distribution of the heating need during the week between households and tertiary buildings (workdays / week-end days).

In the tertiary, the sub-sectors construction, office type buildings, small industries, trade, hospitals and education represent already 71% of the useful energy demand in 2005 (Figure 6). In total the tertiary sector also experiences a reduction of the useful energy demand from 2005 until 2030 of 22%.

2 Climatological projection

Recent findings in climate change impact studies on electricity demand state a shift from heating to cooling demand due to rising mean temperatures (e. g. Sailor 2001 for eight US states or Wokaun et al. 2007 for Switzerland). Whether the shifts result in a net increase or decrease in total load is dependent of the region‘s demand profile.

In the context of a thesis conducted within a project called IMPEC on the impact of Climate Change on the energy sector at EDF R&D an assessment of the future demand in the German federal State Baden-Württemberg (BW) until 2095 was undertaken. The objective was to quantify changes in load demand due to rising temperatures by fixing all other load influencing factors (e. g. numbers of electrical appliances in household, consumption patterns, electricity prices, etc.).

2.1 Calibration of the electricity forecast model “Eventail” on Baden-Württemberg

In a first step, the electricity forecast model „Eventail“ (developed at EDF R&D) was calibrated on the BW region by using observed temperature and load data (vertical system loads Energie Baden-Württemberg AG (EnBW)[1]) from 2003 to 2007. „Eventail“ is a mid-term regression model that estimates the relationship between the load and other variables (such as temperature and calendar events) by nonlinear regression (Bruhns et al. 2005). It estimates a weather independent and a weather dependent part (consisting of heating and cooling related demand). According to the model’s results, the weather dependent part accounts for about 0.05 % of the total load for the time frame 2003 - 2007. It is further divided into a heating and a cooling part. “Eventail“ estimated the heating and cooling gradients with -59 MW / °C and 84 MW / °C respectively.

In an error analysis of the model’s output the indicators Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE) were used. Figure 7 shows both indicators for months and hours. The RMSE represents the error in absolute values and it highest in December. This is due to Christmas when electricity demand forecasts are most difficult to conduct. The MAPE relates the errors to the corresponding level of electricity consumption. Over the different months, the highest error occurs again in December. The summer months are characterised by a low MAPE which rises again during the above mentioned transition time. In relation to the different hours of the day, the MAPE behaves contrary to the normalised load curve indicated in the Figure 7d. When consumption is lower, as it is during the night, the MAPE is higher. It decreases during morning hours when consumption rises and increases again during afternoon when the load curve slopes down. However, under the assumption that the stated model bias is stationary it is not taken into account in the analysis of load changes between simulated past and future loads.

[1] Vertical system loads represent the amount of electricity being transferred from the transmission grid (380kV to 110 kV) to the distribution grid (20 kV).

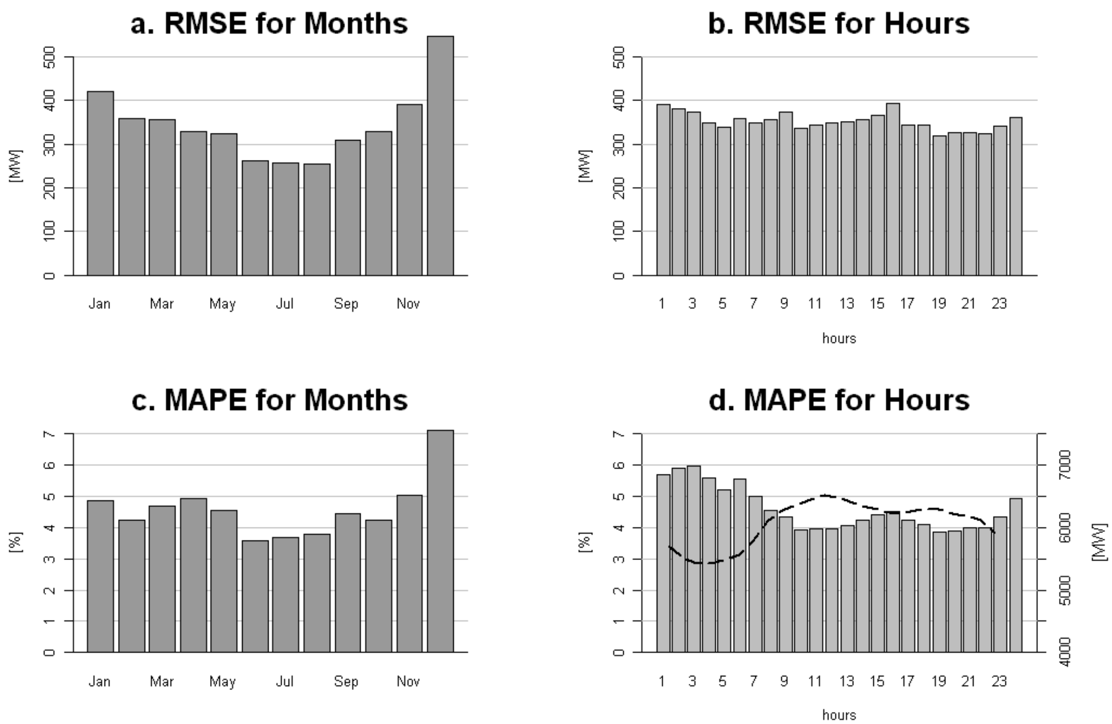


Figure 7 a.-d.: Calibration results "Eventail", MAPE and RMSE for months and hours, averaged daily load curve indicated in lower left graph, 2003 - 2007

2.2 Simulation and analysis of load curves for the past and future

In a second step, the forecast model was fixed on the reference year 2006 and only temperature was varied so that the consumption of 2006 was simulated with another climate. Temperature data was taken from the regional climate model REMO (developed at the Max-Planck-Institute for Meteorology) for the control run and emission scenario A1B (Jacob 2005a, Jacob 2005b)[2]. Control run data was taken for the simulation of load curves for the control period 1971 – 2000. A1B scenario data was taken for the simulation of load curves for the future period 2006 – 2095 which was subdivided into three time slices 2006 – 2035, 2036 – 2065 and 2066 – 2095.
A preliminary analysis of climate model temperature data showed that the mean temperature increases by 0.4 °C until 2035, by 1.8 °C until 2065 and by 3.3 °C until 2095. Figure 8 shows that monthly mean temperatures increase except for 2006 – 2035 where there are decreasing temperatures in March, April and May.

[2] The climate model temperature data was taken for six grid points corresponding to the six weather stations for the observed temperature time series. The grid point time series were validated by comparing them to the weather stations time series and testing for significant differences.

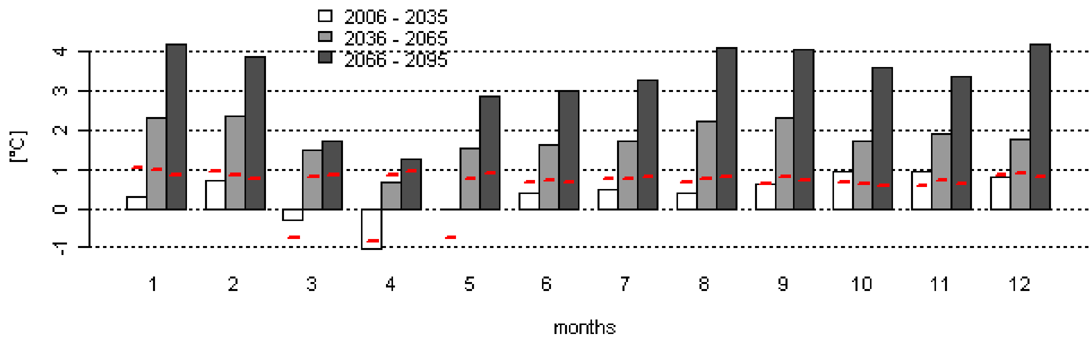


Figure 8: Monthly mean temperature changes between 1971 – 2000 and 2006 – 2095, confidence boundaries (α = 95%) are indicated by red marks

The analysis of load changes between 1971 – 2000 and the three future time slices showed, that the total load decreases by 8 MW (0.1 %) until 2035, by 35 MW (0.6 %) until 2065 and by 44 MW (0.7 %) until 2095. The heating load decreases by 12 MW (4.3 %) until 2035, by 61 MW (21.7 %) until 2065 and by 104 MW (37.0 %) until 2095. The cooling load increases by 4 MW (44.4 %) until 2035, by 26 MW (288.9 %) until 2065 and by 61 MW (677.8 %) until 2095.

Figure 9 shows computed daily mean curves 1971 – 2000, 2006 – 2035, 2036 – 2065 and 2066 – 2095 for the heating load part for the seasons January and February (JanFeb), March and April (MarApr), May and June (MayJun), July and August (JulAug), September and October (SepOct) and November and December (NovDec). Except for MarApr and MayJun the heating load decreases with time. MarApr and MayJun show increases for 2006 – 2035 due to temperature decreases in March, April and May (see also Figure 8).

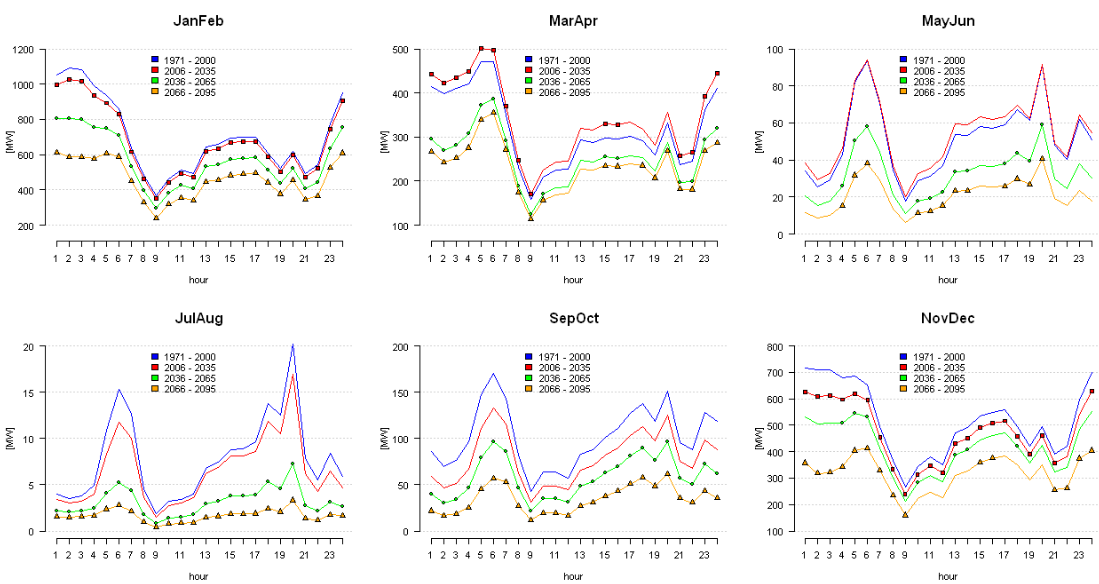


Figure 9: Mean heating load curves 1971 – 2000, 2006 – 2035, 2036 – 2065 and 2066 – 2095 for JanFeb, MarApr, MayJun, JulAug, SepOct and NovDec, significant values (α = 95%) indicated by symbols

Figure 10 shows computed daily mean curves for the cooling load part. These curves show a zig-zag-pattern due to an inconsistently estimated cooling gradient shape in

„Eventail“. While this calibration weakness only shows low effects in 2006 – 2035, the magnitude increases from 2036 onwards, so that especially during the seasons MayJun, JulAug and SepOct, the MW values rise up to nearly 400 MW.

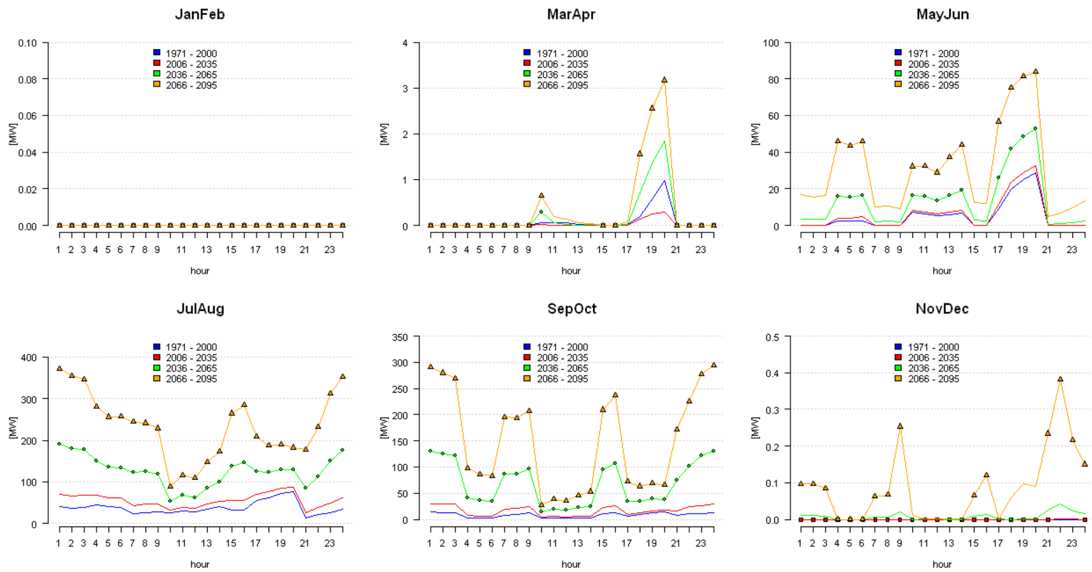


Figure 10: Mean cooling load curves 1971 – 2000, 2006 – 2035, 2036 – 2065 and 2066 – 2095 for JanFeb, MarApr, MayJun, JulAug, SepOct and NovDec, significant values (α = 95%) indicated by symbols

To conclude, the analysis of load changes between 1971 – 2000 and 2006 – 2095 confirmed earlier findings on a shift from heating to cooling load. For the region of BW, rising temperatures lead to a net decrease in total electricity load. This is due to a higher decrease in heating load increase in the cooling load. The isolated impact of temperature evolutions on the demand for electricity in Baden-Württemberg is rather marginal until 2035. But from 2036 up to 2095 the changes become significant. As far as this analysis could show, no increase in peak demands takes place in the summer due to rising mean temperatures. However, for this study only one emission scenario was applied. Further research is required to examine the scope of different scenarios. This will be done in an ongoing study which is currently conducted in the context of the project ICE on Impacts of Climate Change on energy at EDF R&D. Here, the same assessment will be carried out for the whole of Germany and by applying emission scenarios A1B, A2 and B1 from REMO.
For now, first results are already available from the calibration of “Eventail” on Germany. Here, the proportion of the weather dependent part in total load is about 3.3 % which is a higher share than in BW. To estimate if that proportion will change in the future it is important to know about tendencies of other load influencing factors.

3 Synthesis

The scope of this paper was not only to present two different types of approaches to project future energy demand but also to discuss the possibility to integrate both approaches into an overall model. In System Dynamics we found an approach that responds to four major needs identified at EIFER:

1. User-friendliness:
   The model should be applicable for experts without model experience.

2. Feedback loops:
   The model should take into account feedback loops. Many complex topics like energy demand consist of factors that retroact with their causes.
3. Possibility to assess interdependencies and the sensitivity:
   The model should allow examining interrelation and the sensitivity of different factors influencing the energy demand, e.g. temperature effects vs. energy price effects.
4. Flexibility in time horizons:
   The model should be flexible regarding different time horizons. A topic like energy demand consists of dynamics that come into effect in short-term (e.g. life style changes) but also in mid- (e.g. energy policies) or long-term (e.g. rising mean temperatures).

The construction of a System Dynamics model takes place as an iterative process (Sterman 2000) (see also Figure 11):
Firstly, key parameters for the individual approaches (i.e. sectoral and climatological) are identified by the experts. Secondly, the mental models are depicted by the creation of a causal-loop-diagram (CLD) containing the key parameters and their relations and feedbacks. Thirdly, the sectoral and the climatological approach are combined by elaborating the relationships between the involved parameters.

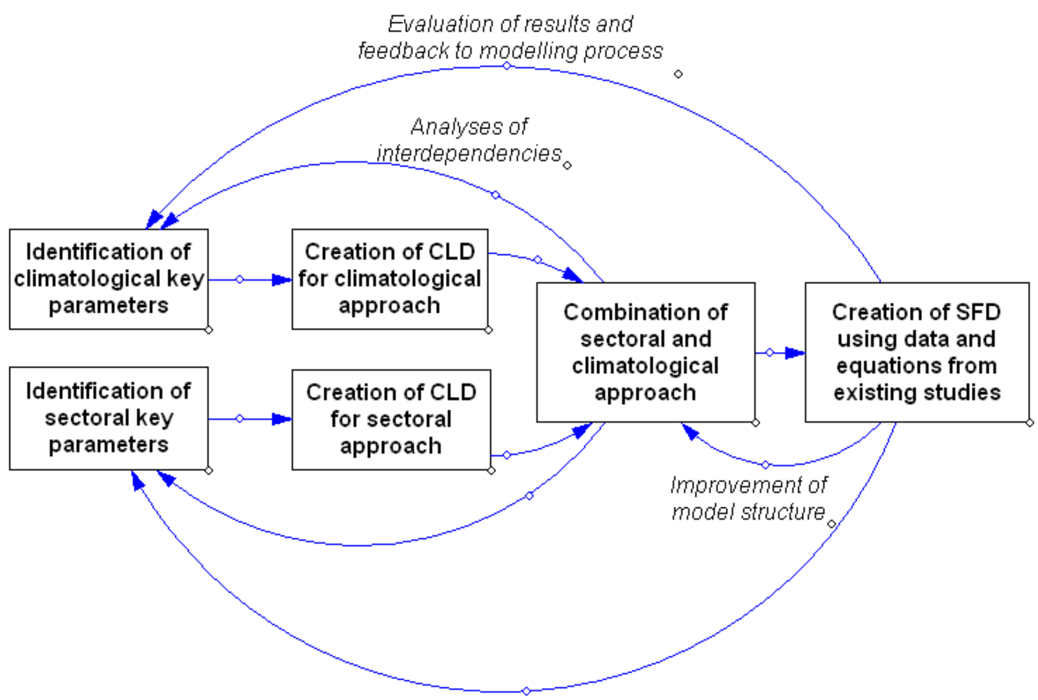


Figure 11: Model building process for an integrated projection of energy demand

So far, the described steps have been conducted. In a next step, a stock-and-flow diagram (SFD) containing initial values and equations will be created. Those initial values will be provided by the data generated during the two regarded studies.
By means of the quality of the gained results, the modelling process can be restarted. Other relevant parameters can be integrated in order to improve the model's validity.
Figure 12 shows a first model for the projection of energy demand exemplified for the residential sector. The key variables are the cooling and heating related energy

demand which is influenced by various factors. These influences either affect the key variables directly or indirectly. Thereby, the relations are depicted by positive or negative algebraic signs to indicate the direction of the relationship.

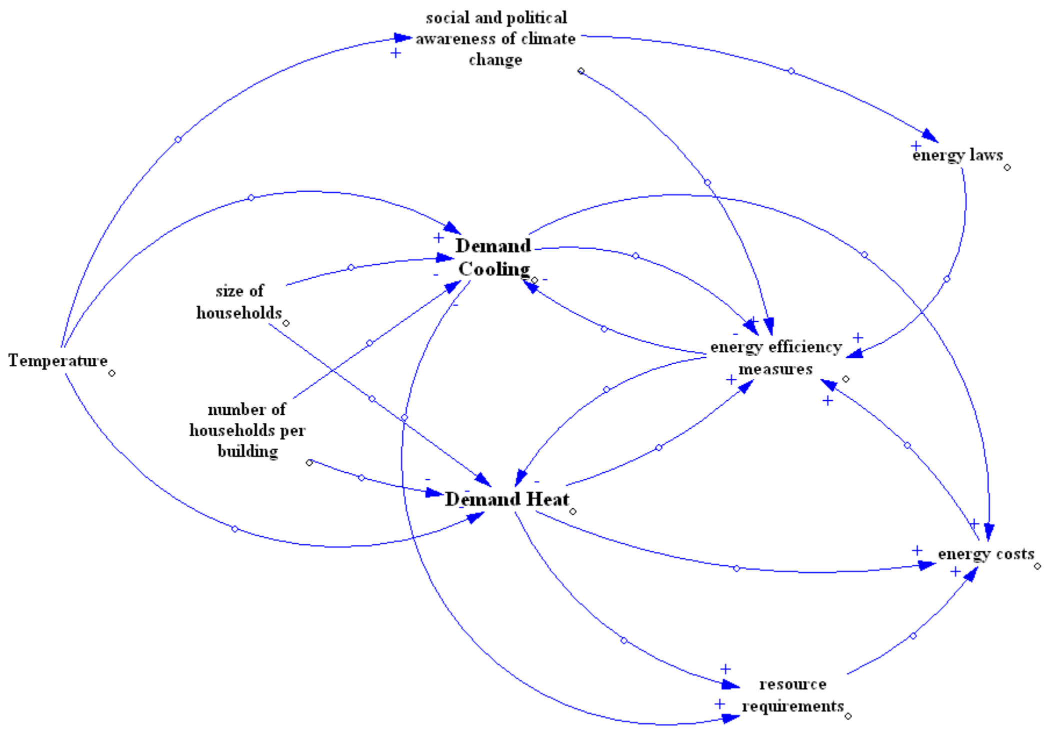


Figure 12: A first model for the projection of energy demand within the residential sector

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