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Energy challenge and environmental sustainability

September 9-12, 2012 in Venice, Italy
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Welcome to Venice | Conference venue | Who should attend | Travel information

Home
Organisation
Programme
Registration
Accommodation
Students
Sponsors
Paper submission
Social events
Climate & weather
Contact

DOWNLOAD

Call for papers
Conference programme

The Conference Objectives

Recent events - such as the conflicts within several North African and Middle East oil and gas-exporting countries, and the nuclear disaster in Japan - have added elements of uncertainty in the already complex evolution of the energy situation in the world and in Europe in particular.
Security of supply, geopolitical aspects and environmental problems are once more at the forefront.
The Conference aims at providing a forum for an analysis of the new developments and a new vision of the future.
No better stage can be imagined for this discussion than the magic and fragile environment of one of the most beautiful cities in the world.

The first plenary sessions of the **12th IAEE European Energy Conference** will therefore be dedicated to the evolution of demand and to the new energy markets less dependent on major commodities.

A debate will follow on how to deal with climate change through better regulation of CO2 emissions and what opportunities Europe can get from these new regulations.
The last sessions of the Conference will deal with energy security in a geopolitical context that is getting more and more complex and difficult in all the main areas of the world .

Besides these main topics the 12th IAEE Conference will also discuss all the issues related to the environmental change and its new perspectives, such as energy efficiency, developing renewable sources, biofuels and sustainable transportation. 8 plenary and 80 concurrent sessions will be organized by the AIEE - together with the International Association for Energy Economics - IAEE in cooperation with Fondazione Eni Enrico Mattei and Ca' Foscari University of Venice.

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SCENARIOS FOR THE GERMAN HEATING AND COOLING SECTOR: A MODELLING APPROACH INTEGRATING BUILDINGS, INDUSTRY AND DISTRICT HEATING

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1. Introduction

For some considerable time, heating and cooling has been identified as the largest energy demand sector. However, energy policy on European and national level has just focused on the sector for the last few years by integrating efficiency and renewable energy targets (RED *Directive 2009/28/EC*, EPBD (recast) Directive 2010/31/EC).
Germany was one of the first countries in Europe implementing a renewable heat act (EEWärmeG). However, the main instrument of this act – a use obligation for renewable heat – is basically restricted to the construction of new buildings. Targeting the large stock of existing buildings in terms of thermal renovation and renewable heating/cooling will be essential in order to achieve long term mitigation targets. Besides the building related heating and cooling demand, the large sector of industrial heat demand needs to be tackled. Also in the industry as well as processes in the services sector exhibit a variety of policy instruments targeting energy efficiency in industry (e.g. commitment of energy intensive industries, MAP support for process heat and solar cooling, German Cooling Price for climate-friendly refrigeration technology).
Thus, the German government has initiated the development of an integrated analysis based on a quantitative modelling tool of the German heating and cooling sector in order to identify perspectives to reduce energy demand and carbon emissions and increase renewable heating and cooling. Moreover, the quantitative model investigates the impact of policy instruments on these future perspectives, which provides the ground for exploring new, innovative policy options.

Against this background, the core objectives of this paper are:
1) Set-up of an integrated model of the German heating and cooling sector including buildings (residential and non-residential), industrial appliances and district heating. The model allows to develop scenarios of the heating and cooling sector projecting energy demand and use of renewable energy sources as well as the impact of policy instruments.
2) Development and discussion of scenarios of the German heating and cooling sector up to 2020.
3) Discussion of the impact of various policy instruments.

The results of the paper consist of two parts. The first part describes the structure of the model itself. The second part shows scenarios and the impact of different combinations of policy instruments addressing the heating and cooling sector.

2. Methodology: an integrated model of the German heating and cooling sector

The methodology for setting up an integrated model of the German heating and cooling sector is based on a soft link of five sector-models. All these sector models can be classified as techno-economic bottom-up models. Invert/EE-Lab covers space heating, hot water and air conditioning; ProcServ and ProcIndustry model the process related heating and cooling demand of the service and industry sector; the District Heating /CHP Model represents the German district heating sector including the corresponding supply technologies, whereas the CHP-Industry-Model comprises industrial CHP applications.

Invert/EE-Lab is a dynamic bottom-up simulation tool that evaluates the effects of different promotion schemes on the energy carrier mix, CO2 reductions and costs of support policies which target renewable heating installations as well as energy efficiency of builidngs. The core of the tool is a myopical, logit based approach, which optimizes objectives of agents under imperfect information conditions. Invert/EE-Lab models the stock of buildings in a highly disaggregated manner, see e.g. Kranzl et al. (2010), Müller et al. (2010).

ProcServ: The process heat and cooling demand of the German service sector has been methodically derived by the ProcServ model building strongly on the existing survey Schlomann et al. (2011). ProcServ calculates the process relevant fraction of the service sector's fuel (12 energy carriers) and electricity demand, differentiating the results for eight branches, heating and cooling uses as well as for three different temperature levels of the needed process cooling up to 2020.
Furthermore ProcServ gives information about investments, energy costs, maintenance costs, etc. in the different scenarios.
ProcIndustry: The process heat and cooling demand of the German industry sector is calculated with the bottom-up model Forecast/ISI Industry . The process heat demand in the industry was derived bottom-up based on specific energy demands of different industrial processes, the statistical energy consumption as well as technological knowledge and measuring results. *ProcIndustry*, a submodel of *Forecast* model, calculates the industry sector's fuel and electricity demand, differentiating the results for heating and cooling uses as well as for different temperature levels, lost heat, investments, energy costs, maintenance costs in the various scenarios.
The District Heating / CHP-Model is based on a typification of existing residential buildings and settlements and on an allocation of heat demand of the service sector within different settlement types. This allows to estimate the costs of district heating distribution in all main German cities (the 614 largest cities of Germany). The cost calculation is based on statistical data on municipal level taking into account, among other, typical cost per pipe meter, the expected increases in house connections, the development of spacial heat demand and existing district heating networks.
CHP Industry potentials are calculated based on the combination of number of companies in the specific branches for each company size category (small, medium, big), the number of employees of each particular company size and the annual operating hours for the specific CHP plants. The resulting potential installable capacities are cross-checked with respect to the economic performance (economic, non-economic), depending on the total annual operating hours assumed. This is done for each industrial branch. With the help of stastitical data and under consideration of special conditions of industrial branches it is possible to estimate the heat demand and the annual operation period of a suitable CHP-plant. There will be a CHP potential if the electricity generation cost is lower than the market prize.

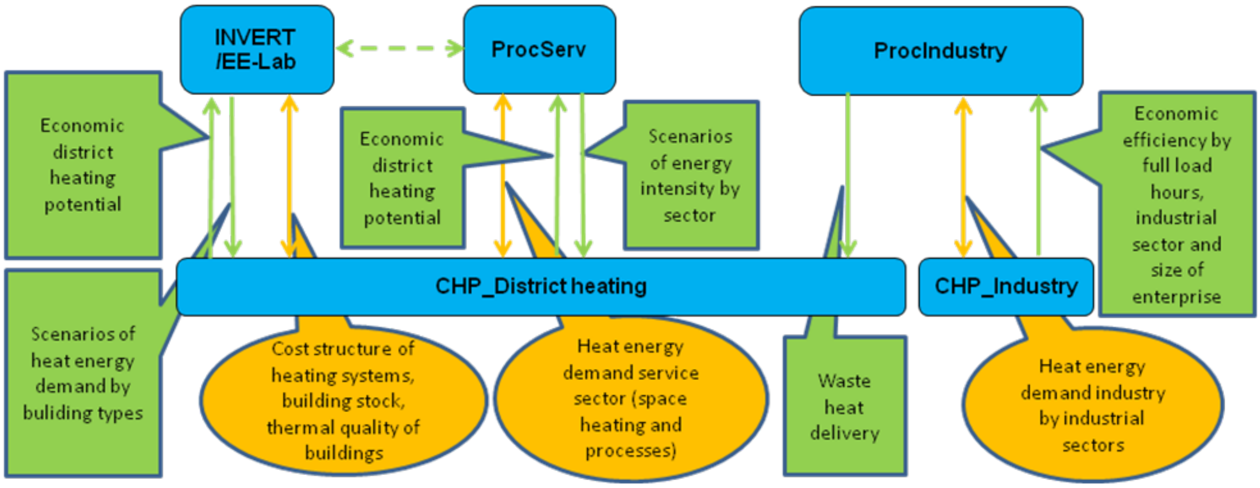

Figure 1: Structure of the integrated heating and cooling model

Figure 1 shows the structure of the integrated heating and cooling model and its interfaces. For each simulation run, one iteration takes place between the sector-models Invert/EE-Lab and ProcServ on the one hand and CHP_District heating on the other hand. In the first steps, Invert/EE-Lab and ProcServ calculate the heat energy demand lower than 100°C (i.e. suitable for district heating) of the sectors (heat energy demand by building types and energy intensity by tertiary sector, respectively) taking into account the uptake of energy efficiency measures. Based on these results (overall heating energy demand < 100°C) the model CHP_District heating derives economic district heating potentials for the space heating, cooling and hot water as well as for process heat and cold and delivers it to Invert/EE-Lab and ProcServ. As a next step, Invert/EE-Lab and ProcServ determine the overall energy carrier mix, uptake of different technologies etc. This also includes the exploitation of the district heating potential (which in general is not identical with the economic potential due to diffusion restrictions, competition with other heating and cooling technologies, agent specific behaviour modeling etc.).
CHP_Industry derives economic efficiency data for industrial CHP which is used by Proc Industry. The latter one delivers the amount of waste heat that can be used for district heating purposes to the model CHP_District heating. This result on waste heat delivery as well as the actual exploitation of district heating potentials is the basis for the model CHP_District heating to finally calculate the supply energy mix of the overall district heating sector.
The orange double arrows in figure 1 indicate the consistency check and use of same data basis regarding cost structure, techno-economic data, sectoral energy demand data etc. The dotted arrow between Invert/EE-Lab and ProcServ indicates the consistency check regarding heating and cooling energy demand in the tertiary sector: Invert/EE-Lab covers the space heating, AC and hot water demand of this sector and ProcServ deals with the process energy demand.

It turns out that the feed-back loops, e.g. between *Invert/EE-Lab* and the *District Heating / CHP-Model* can be covered in sufficient accuracy by one iteration between the models .

The following parts give an overview on the methodological framework of the different sector-models.

2.1. Invert/EE-Lab

Invert/EE-Lab is a dynamic bottom-up model for simulating space heating, AC and hot water demand in a region's or country's building stock and for evaluating the effects of different promotion schemes and energy price settings on the energy carrier mix, CO2 reduction and costs for RES-H support policies.
The Invert simulation tool originally has been developed by Vienna University of Technology/EEG in the frame of the Altener project Invert (Investing in RES&RUE technologies: models for saving public money). During several projects and studies the model has been extended and applied to different countries within Europe, see e.g. (Biermayr et al., 2007), (Haas et al., 2009), (Kranzl et al., 2006), (Kranzl et al., 2007),(Nast et al., 2006), (Schriefl, 2007), (Stadler et al., 2007). The last modification of the model in the year 2010 included a re-programming process of the tool, in particular taking into account the heterogeneity of decision makers in the building sector and corresponding distributions (Müller and Biermayr, 2011).
The core of the tool is a myopical, cost-based logit approach, which optimizes objectives of agents under imperfect information conditions and by that represents the decision making process concerning heating and hot water preparation. Invert/EE-Lab models the stock of buildings in a highly disaggregated manner.
The basic decision/selection process works on an annual basis and is defined as follows:
For each year of the simulation period Invert determines for each building segment the probability (expressed as share) that a building related component (regarding building shell and heating / domestic hot water system) remains as it is and the probability (share) that one or more of these components are replaced. The share of buildings applying changes (smeasure) is calculated based on the age distribution of the considered building elements (facade, windows, heating and hot water systems, etc.) within the whole building stock using a Weibull distribution. The demolition of buildings is calculated in the same manner, yet considers life time expanding measures such as refurbishment in previous periods.

The share on the actual installation (market share) of available types is calculated based on adjusted heat generation costs using the logit approach, an approved and most widely used approach in the field of discrete choice theory (Train, 2003), where decision makers have to choose from mutually exclusive alternatives. This approach has already been applied for modeling the heating sectors by other working groups (e.g. Giraudet et al. 2011; Henkel, 2010; Marnay and Stadler, 2008); their results indicate that this approach is also pertinent for our research questions. In principle, the applied logit model ensures that low-cost options, based on adjusted heat generation costs get the largest market share, but more expensive options hold some share, too.

In the model we consider two types of barriers for the change of the type of the heating system. First, we do consider non-monetary barriers basically associated with the comfort level which the existing heating system provides. This means that we do not allow a change to a heating system with a significant lower comfort and degree of automation.
Besides the non-economic barriers, we incorporate economic barriers as they might occur when the energy carrier is changed. Such costs are e.g. natural gas connection costs, oil tank, biomass storage, drilling costs for the bore hole for heat pumps with vertical heat exchangers. All barriers associated with the change of heating system type are summarized in a substitution matrix similar to Cost (2006), yet excluding the LRMC of the basic heating system.
In the Invert/EE-Lab model, the described MNLM approach is extended by a few additional mechanisms like the consideration of energy price development in recent years, an extension to a nested logit model, diffusion restrictions and other barriers.

The German building stock is modeled on a highly disaggregated level. We distinguish five residential building categories (singe family houses, terraced houses as well as small, medium and large multi family houses) and 30 non-residential building categories (e.g. different private and public office buildings, shops, hospitals, schools etc.). For the residential sector we take into account 14 construction periods and different levels of previous renovation activities. For non-residential buildings, 3 construction periods are used, according to (Schlomann et al., 2011). Combined with the different heating systems this results in a number of more than 4400 building segments.

Typical investment behavior of various agent groups are taken into account in the modeling approach. Thereby each agent is assigned with weighting factors for different decision parameters. These include total annual costs (annuity payment), amortization time, total investments, energy costs, comfort level as well as sustainability. The different agent types with their individual objectives and barriers are derived through a comprehensive literature review, e.g. Schätzl et al., (2007); Stieß et al., (2010) which is documented in Schulz et al., (2011); Bürger et al. (2012).

2.2. ProcServ, ProcIndustry

The projection and future development of heat and cold demand for processes in both the services and industrial sectors models only a part of the useful energy demand of these sectors meaning that other forms of useful energy for processes (e.g. compressed air, mechanical process techniques, finishing processes or electrolysis) are not explicitly considered. Projecting energy demand exhibits challenges among others the calibration and set up of the data for the base year (2008).

In addition to the challenges, a lack of data with respect to the temperature levels for heat and cold demands is observed and these are important when identifying technologies such as waste heat or co-generation as well as for their quantitative assessment. These challenges pose uncertainties on the modelling that depending on the process and type of process heat or cold could amount from 5 % up to 30 %.

The classification and structure of the services sector in the **ProcServ model** follows the classification of the study " Energy demand of the services sectors in Germany for the years 2007 until 2010" (Schlomann et al. 2011). The main 8 sectors exhibit a heat and cold demand with respect to their processes. With respect to trade and agriculture, the analysis in this respect relates to special sub-sectors as for example the trade and retail of food and beverages, or the retail of flowers and plants, etc. Similar priorities were set for the wholesale sector. For agriculture the modelling focuses on the operation of greenhouses as well as the production of milk, due to their high heat and cold demand.

The energy demand of the processes from individual branches (i) was calculated as follows:

$$PEGes_i^t = PEBr_i^t + PEStr_i^t$$

$PEGes_i^t$ *Total Process energy demand at time t*
$PEBr_i^t$ Process energy demand for fuels at time *t*
$PEStr_i^t$ *Process energy demand for electricity at time t*

For the projection of the process energy demand until 2020 the basis for modeling at branch level is estimated with the specific energy demand of the base year as illustrated exemplarily in the following equation:

$$spezBrPW_i^{Bj} = (PWBr_i^{Bj} + PWWBr_i^{Bj})/L_i^{Bj}$$

$spezBrPW_i^{Bj}$ specific fuel demand for process heat production in base year
L_i^{Bj} *employees of the branch i in basis year*

The efficiency improvement of the specific energy factor considers the technological dimension as well as the workforce productivity.

In the frame of the **ProcIndustry model** the energy demand for heat and cold of the industrial sector is calculated for 14 branches following up the classification of the energy balances of the AGEB (AGEB, 2008).

The first module represents the process heat and cold demand derived from the end energy use at branch level calculated with help of the FORECAST Industry model from Fraunhofer ISI. The module calculates the demand in various temperature levels. In addition, the end energy use in the industry is calculated across the company's size (small, medium and big) with the objective to differentiate on barriers and policy instruments for both major groups ("small and medium" and "big") companies (Jochem, et. al., 1996, Herbst, Toro, et.al., 2012, Herbst, Reitze, 2012, Schlomann, Toro, 2011) internal IREES calculations, 2012).

A second module that describes the industrial co-generation for the base year as well as the possible projections with respect to the heat production for the low and partly the middle temperature process heat demand level.

The division of the industrial sector in ISIndustry and ProcIndustry includes 14 branches as follows: 1) mining, 2) food and tobacco,3) paper production, 4) basic chemicals, 5) other chemicals, 6) rubber and plastic industry, 7) glass and ceramics,

8) non-metallic mineral processing, 9) iron and steel production, 10) non-ferrous metals, 11) metal processing, 12) engineering, 13) vehicle manufacturing and 14) others (StaBuA 2010).

The major drivers for estimating energy demand refer to the development of the value added at branch and company size level. The projection of these data is based on the statistical office in Germany as well as the Prognos 2010 study for the energy concept of the Federal Government (PROGNOS et al. 2010). The energy intensity is divided for fuels and electricity across the company sizes. The development of the GVA across branches was also analyzed historically. In addition to the GVA, a second important driver for the projection of energy demand in industry relates to the production in physical units (e.g. tons). This allows to consider technological efficiency improvements affecting directly the specific energy (fuels and electricity) per produced ton for over 70 different products and processes among the branches considered.

The modelling of the energy demand is calculated by the multiplication of activity level (GVA or physical production) with the specific energy factor for fuels and electricity. The FORECAST-Industry platform calculates the end energy use both on a bottom-up and top-down approach (StaBuA 2006, 2009).

2.3. District heating/CHP, CHP-Industry

The District heating/CHP model of the Bremer Energie Institut was first applied in 1994. Since then it has been continuously improved in several works up to now. As first step within the model, the distribution costs are estimated based on local heat demand. The heat demand in the residential sector as well as in the tertiary sector is spread to local substructures based on residential building type and on the specific heat demand per employee. The buildings are classified by year of construction and by number of apartments per building. The resulting typology contains information about actual and future heat demand per m² residential area. Distinct building types and employees in the CTS sector are then allocated to 10 different settlement types. This allocation is performed for the 614 largest cities of Germany based on municipal statistical data. The resulting relation allows spreading the overall heat demand to the different settlements of the cities under examination. The typical length of district heating network is known for each settlement type. In combination with the existing district heating this lays the foundation to estimate the distribution costs. In a second step the economically feasible district heating potential is determined by summing up distribution costs per kilowatt hour and heat generation costs per kilowatt hour. There is a potential for district heating CHP if this sum is lower than the heating costs of a single heat-only boiler. The calculation is applied for each of the 614 cities. With rising load, heat generation costs are assumed to decrease. In a third step a realistic development of district heating connection towards the assessed potentials is regarded considering the existing framework conditions and support mechanisms. At the end of one simulation run the annual growth of district heating connections according to the economic potential is transferred to the Invert model. Thus, the district heating/CHP model allows to study the effects of support systems for CHP and district heating.

CHP-Industry provides an assessment of onsite CHP potentials for industry. It relies on national statistical data and energy balances. The most important components of the model are a classification of factories according to their number of employees and the heat demand per employed person. Since the annual production period of a factory depends on the number of employees the classification allows to estimate the annual operation period of a CHP plant for each case reflecting one statistical group. Based on an estimation of the heat demand of the same case, a suitable capacity of the CHP plant can be determined. This allows to calculate the heat and power generation cost and determine the CHP potential. There will be a CHP potential if the electricity generation cost is lower than the market prize. The sum of CHP potentials over all statistical groups leads to a national potential. Furthermore the existing onsite CHP of the industrial branches is taken into consideration. Finally the results for the industrial branches are transferred to the ProcIndustry model. Like the District heating/CHP model it allows to assess the effects of support systems on CHP perspectives.

3. Overview on German policies addressing heating and cooling

The German government has set itself the target of reducing GHG emissions by 40% up to 2020 compared to the base year 1990. According to the German Energy Concept from September 2010 (BMWi 2010) the primary energy consumption should decrease by 20% in the same period compared to 2008 levels while the overall heat demand should be reduced by 20%. The share of renewable energies in final energy consumption for heat (space heating, cooling, process heat and hot water production) should be increased to 14%.

The heating and cooling sector is addressed by a couple of cross-sectoral instruments. This includes the energy tax on fossil fuels and electricity that effects the sector-relevant energy prices thus having an impact on overall consumption or investments in efficiency technologies according to the specific price elasticities within the different sectors. Another instrument addressing different sectors is the emissions trading scheme which has an effect through the CO_2- price signal. Additional cross-sectoral instruments addressing the heating and cooling sector comprise the minimum efficiency standards set by the Ecodesign Directive (2009/125/EC), energy labelling (according to Directive 2010/30/EU), immissions control regulations, financial support programmes such as a scheme supporting efficiency measures at commercial cooling devices or efficiency measures for SMEs in general and specific regulations for CHP. Furthermore, there are programmes that aim at increasing the information and motivation level of the different decision making groups in the heating and cooling sector as well as training and education of those who produce, trade, sell, purchase, operate and maintain the respective efficiency and renewable energy technologies and those who provide advice. Especially in the commercial sector also initiatives within or across the branches need to be considered, especially energy efficiency networks that bring together a handful of SMEs that agree on a collective energy savings target as well as joint activities in order to identify and exploit existing efficiency potentials.

3.1. Regulations and support schemes for the building sector

The minimum efficiency requirements for buildings are regulated by the German Energy Saving Ordinance (hereafter EnEV). For each new building, the EnEV defines a building-specific level of primary energy demand that must not be exceeded. In addition a certain level of the specific transmission heat loss needs to be met for the building envelope. For existing buildings the EnEV sets component-specific minimum efficiency requirements which have to be complied with once a building component (e.g. the roof, the windows or the exterior wall) is modernised. However, the modernisation standard is only conditional, where no renovation takes place there is no requirement to fulfil any performance standard at all. In addition the compliance rate in particular of the requirements in the building stock is rather low. All standards set by the EnEV underlie a strict cost-efficiency rule. According to the Act on the Promotion of Renewable Energies in the Heat Sector (hereafter EEWärmeG) new building are subject to a use obligation for renewable energies for heating purposes (especially space heating and domestic hot water supply). The minimum renewable energy shares are fixed according to technology. Their range is between 15% (solar thermal) and 50% (e.g. solid biomass or heat pumps). In addition, the EEWärmeG applies technology-specific restrictions such as accepting biogas only when the heat originates from a CHP plant. Building owners can fulfil the obligation also by a range of alternative measures such as achieving an efficiency level for their buildings that is 15% below the minimum standard set by the EnEV for the building in question. This use obligation applies to both residential and non-residential buildings. In terms of financial support two key programmes address the building sector. The programme “Energieeffizient Sanieren”, run by the German Development Bank (KfW), provides soft loans and subsidies for the energetic modernisation of buildings. Investments in renewable heat devices are mainly supported through the market incentive programme (hereafter MAP). Financial support is also granted for the efficienct and renewable heat supply through new or expanded heating grids.

3.2. Regulations and support schemes for process heat and cold

Currently several of the applied policy measures do not necessarily focus on the energy efficiency and substitution possibilities in the heat and cold sectors but are more technology comprehensive. Furthermore, there are special programs and measures developed for the economy covering also measures implemented from both sides namely the Federal Government as well as the economic associations including for example the provision of information and training, voluntary agreements in selected branches and initiatives impulse by the economy such as the creating of technical working groups in the industrial associations.

The main existing measures mapped and grouped in the project include: 1) short consulting and training, 2) voluntary agreements from energy intensive branches, 3) initiatives from the economy as well as the market incentive program (MAP) for process heat and solar cooling.

1) **Short consulting and training**: as a consequence of the climate protection program of the Federal Government, a partnership for climate change, energy efficiency and innovation was established between the Economics and Environmental Ministries as well as the industrial chambers of commerce as representatives of the economy. The chambers of commerce in the framework of a project execute the following activities:
    a. The recognition and reward of climate friendly companies in the group of Climate and Energy Efficiency (KEG; Paragraph 4.2.10.3),
    b. An information campaign for individual companies through short consulting including a site visit from an energy-coach as well as
    c. Training activities for the European Energy Manager for the energy responsible in the different companies or consulting engineers.

2) **Voluntary agreements from energy intensive branches**: The voluntary agreements of the German industry remotes to the year 1995 and has set up objectives for specific energy consumption and CO_2 emissions reduction at specific branches. These targets were explained by each branch in order to avoid planned monetary instruments from the

Federal Government with respect to climate protection. The targets are yearly monitored and the last update took place in 2010 (FhG ISI, Dr. Ing. A. Hassan & IREES, 2011).

In the framework of the agreement the German industry has committed to reduce the specific CO2 emissions on 28% compared to 1990 until 2012. The various subsectors from the energy intensive industry in Germany committed to individual reductions in the framework of the voluntary agreements.

Most of the energy policy instruments are valid across all branches. Several instruments such as national laws and regulations in energy efficiency influence the German industry indirectly or directly, as for example the promotion for co-generation, the law on renewable energies, the energy and electricity tax as well as the incentive for innovative technologies with the help of subsidies or tax rebates.

3) **Initiatives from the economy: s**everal initiatives as well as research associations are originated by the industry in Germany with particular focus on cold and heat technologies. As an example the following technical groups and associations covers several aspects within the heat and cold branches: 1) the technical working group on cold technologies with a focus on efficiency technologies, 2) the German Cold and air condition technology association, 3) the energy efficiency association for heat, cold and co-generation (AGFW), 4) the technical group on refrigeration, 5) the research council on cold technologies and 6) the working groups on cold and heating from the German association for Machinery and Equipment construction (VDMA).

4) **The market incentive program (MAP)** for process heat and solar cooling similar as explained in the section above.

4. Scenarios of the German heating and cooling sector

The scenarios show the development of overall and sectoral energy demand, energy carrier mix, share of renewable energy, CO2-emissions as well as investments and policy programme costs. Different policies are modeled that change the framework conditions in the heating and cooling sector. This concerns cross-sectoral instruments (such as ETS, energy taxes, technology standards) as well as approaches being target group, sector and technology specific. The list of modeled measures includes instruments that are currently on the political agenda (e.g. instruments proposed by the governmental energy concept from September 2010), approaches that proved to be successful in other countries as well as measures proposed by the project team.

As described in section 2, an explorative bottom-up approach is applied in order to assess effects of different combination of policy instruments. Thereby, the external environment describing the projection of economic development, gross value added, trends in household size and living space is assumed to equal in all scenarios. However, two different energy price projections are assigned in each scenario as sensitive analysis accounting for the influence of energy prices on the overall results.

The *Low Price* projection is derived from (PROGNOS, GWS, & EWI, 2010). The projection assumes for instance an increase of 28 % in the consumer price for heating oil from 2010 and 2020 and a decrease in consumer price for electricity of 4 % in the same period. On the other hand, the *High Price* projection derived from (Nitsch et al., 2011) projects that heating oil price will increase by 53 %, electricity consumer price by 38 % up to 2020.

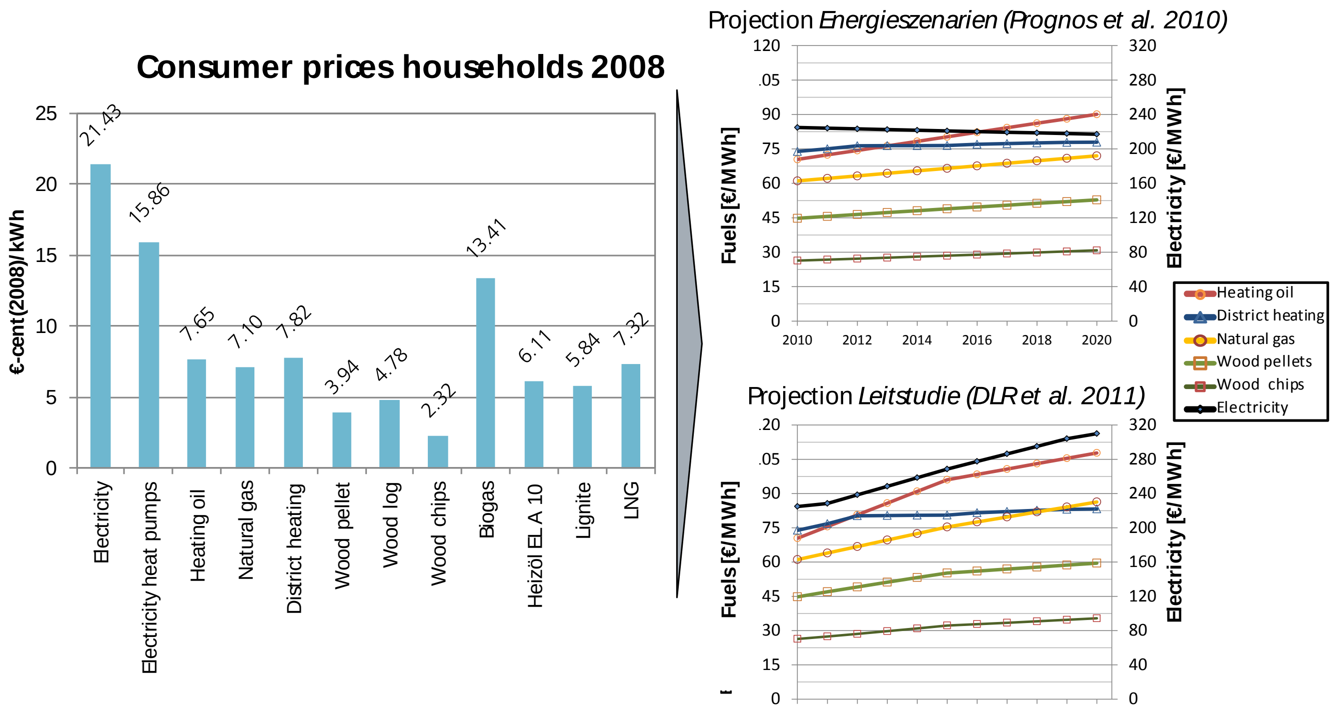

Figure 2: Current energy price housholds and projections (Prognos et al. 2010, DLR et al. 2011)

Against this background, three overall scenario variants regarding different support scheme and regulatory policy settings are defined and will be outlined in section 4.1. In addition, sensitivity analyses of policy measures are conducted in each scenario by modifying certain design elements of important policy instrument.

The start year of the simulation runs is 2008. Core result data like energy mix and renewable energy mix have been calibrated in the Hesitant Consensus high price scenario based on the period 2008-2011.

Paragraph 4.2 describes the policy scenario variants, followed by the presentation of the results of two scenarios.

4.1. Storylines of overall background

The study allows the Ministry of Environment to assess the impact of various explorative policy proposals through the analysis of the technical possibilities, barriers as well as the major stakeholders and actors and the quantitative simulation modelling. The policy proposals include various types of instruments such as regulations and laws, financial and subsidies measures as well as information campaigns, training and professional advanced education, energy efficiency networks, etc, that have an impact on the heat and cold areas.

For the purpose of the quantitative analysis of policies, their impact in energy demand and CO_2 emissions reductions and recommendations for action, three major scenarios have been defined reflecting also further developments with respect to climate change and energy efficiency worldwide under the effect of low and high energy prices.

The first scenario corresponds to the "**hesitant consensus**" which takes into account the current policy measures across all analyzed sectors and projects them similar a reference or business as usual case, however for two cases the high price and low price projections. The hesitant consensus reflects a climate policy in the EU that is not adopted in the international community. The scenarios below assume that in this scenario no changes in policy settings will occur (basis end of 2011). A second scenario named "**the climate policy of the two-tempi**" reflects the fact that some countries such as the EU, Japan, China and some Asian countries will commit themselves for an ambitious climate policy from 2017 and which is adopted lately by 2015. The final variant of the scenarios corresponds to the "**global consensus**" which means that all important industrial and emerging industrialized countries (e.g. BRICS) will agree until 2017 on a -2°C climate policy.

Within these scenarios several measures have been defined for all cross-sector measures as well as for specific sectors such as buildings as well as industrial and services processes. The cross-sector measures relate to the CO_2 emissions certificate price, as well as the energy and electricity tax law, the energy efficiency fund, the directive on energy efficiency as well as white certificates, the eco-design directive and labelling as well as the promotion for co-generation. Furthermore, the policy on education and training is cross sectors as well as the energy efficiency networks for companies and communities, the climate protection concepts for cities and communities as well as the development plans for district heating supply and networks development. Finally the energy research program with their pilot and demonstration projects as well as venture capital is considered the last of the cross-sectors policies. Each of these measures have been defined across the major three scenarios and modelled accordingly.

4.2. Description of policy settings in the scenario framework "climate policy of the two tempi"

Different policies and policy combinations are modeled that change the framework conditions in the heating and cooling sector. In addition to several cross-sectoral instruments (see section 4.1) policy approaches being target group, sector and technology specific have been taken into account for the building and process heat/cold sector. The list of modeled measures includes instruments that are currently on the political agenda (e.g. instruments proposed by the governmental Energy Concept from September 2010), approaches that proved to be successful in other countries as well as measures proposed by the project team. For the more ambitious scenario (climate policy of the two tempi) the instrument combinations have been analysed as described in the following section. (The policy variants in the case "global consensus" are not part of this paper.)
In the scenario framework "climate policy of the two tempi" for the building sector we assume that the policy framework until 2020 will be amended as follows:

- The minimum efficiency requirements for new buildings will be tightened by 30% in 2012 and will be further developed in order to reach the nearly zero energy building (NZEB) standard in 2010 as required by the EPDB. For new public buildings the NZEB standard will be applied immediately.
- For existing buildings the thermal renovation standards will be tightened by 30% from 2015 onwards. For public buildings the modernisation rate will be expanded by a factor of three. Furthermore the compliance rate of the modernisation requirements will be increased.
- As of 2015 the use obligation for renewable heating and cooling installations will be extended to existing buildings. For this policy variant two different options according to which a property owner is obliged to use renewables have been modeled: application of the obligation a) in the case of a building being subject to a major renovation and b) when an existing boiler is replaced.
- Existing financial support programmes, especially those addressing the energetic modernisation of buildings (programme "Energieeffizient Sanieren") as well as the MAP for investments in renewable heating installations will be carried forward applying similar funding conditions as today and with an identical total programme volume.

For the industrial and services process heat and cold the approach based on the barriers analysis was to define five major measures and policy bundles with an impact aligned with the climate policy the two tempi as follows:

- First bundle **on concentrated actions on information, professional training and awards** bundles 10 different measures differentiated for cross sectors and target group specific such as the emission trade system, the environmental and energy efficiency program (A and B) as well as the energy partner and work force motivation program including internal appraisal of achievements. Furthermore some measure for specific technologies such as the preparation from expert knowledge and empirical surveys and the preparation of training courses as well as the German Prize for climate friendly cold technologies are also included in the bundle. All in all the measure attains
- Second bundle **on innovation initiatives** covers cross sectors with target group specific measures as for example the industrial common research (IGF) as well as the research society for industrial ovens (VDMA, FOGI).
- Third bundle **on financial initiatives** covers both technology specific measures such as the impulse program for climate protection measures for industrial cold devices as well as the introduction of a competitive tendering system for efficiency in existing cold devices as well as for internal waste heat recovery and external use. In addition, the market incentive program as well as further financial incentives for absorption cold production as well as insurance solutions for waste heat feed in district heat networks are part of the bundle. The cross-sector but target specific measures for the financial incentive bundle covers energy efficiency funds with the participation of citizens as well as contracting initiatives among others.
- A fourth bundle includes **technical standards and others** measures differentiated on technology specific measures as well as cross-sector and specific to target groups including further proposals on eco-design directive for

example as well as the voluntary agreements, further impulse programs and the relationship to the renewable energy and co-generations laws.

4.3. Results for the *Hesitant Consensus* Scenario

The *Hesitant Consensus* scenario analyses the effect of an extrapolation of the current policy framework in Germany until 2020 (frozen policy settings).

The results of this *Hesitant Consensus (high price)* scenario show a decline of total final energy demand for heating and cooling by 128TWh from 1 514 TWh (in 2008) to 1 386 TWh (in 2020). In the building sector, energy savings of 14.6 % are realised up to 2020 whereas final energy demand savings of industry and service processes decreases by 2.7 % in the same time. Energy demand in the industry sector is majorly driven by the economic development. Figure 3 illustrates the effect of the economic crisis since 2008 on energy demand of industry processes. Thus, the increase in final energy demand from 2012 onwards is mainly driven by the assumed increase of gross value added in the industry sector by 8 % up to 2020 according to PROGNOS et al. (2010). Thus, the results show that a constant level or even a decline in process heating and cooling demand is not feasible in case of a normal economic development without tackling this sector with additional policy measures to enhance energy efficiency investment and reduce energy consumption.

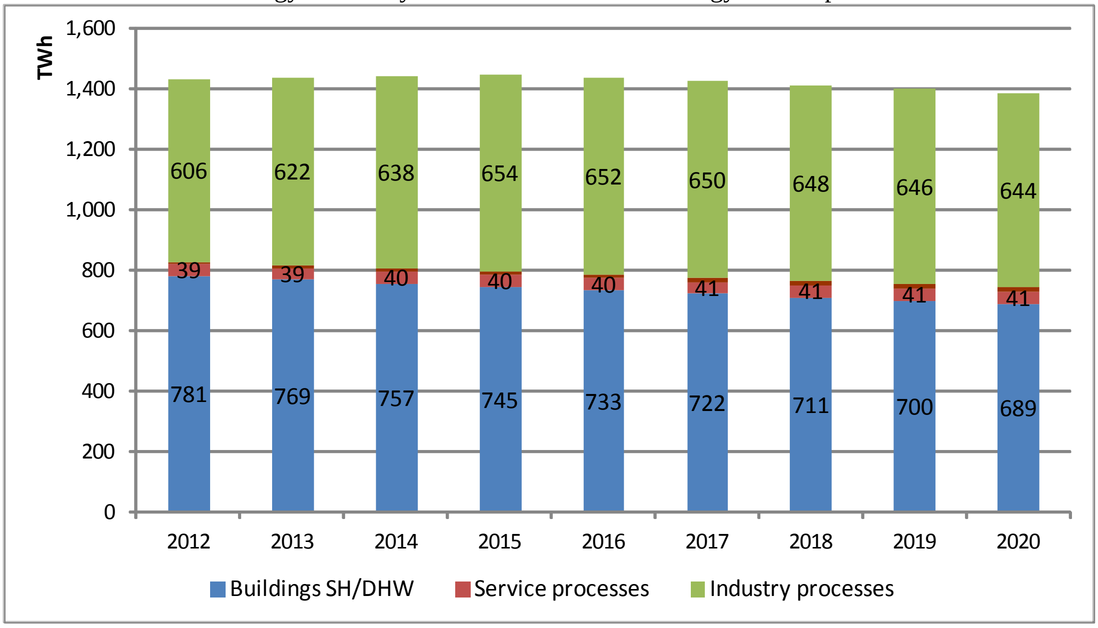

Figure 3: Projection of final energy demand for heating and cooling in *Hesitant Consensus Scenario (high price)*

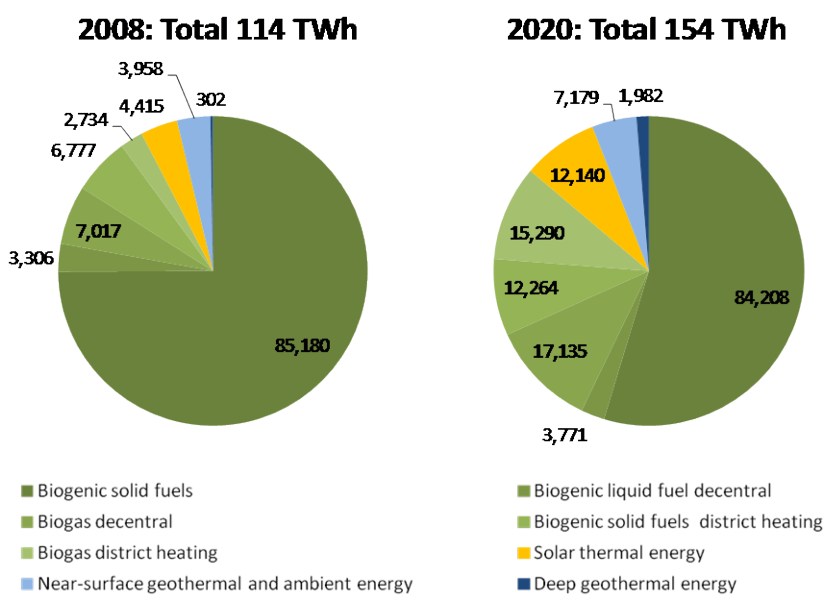

Figure 4: RES-H/C contribution in year 2008 and 2020 in *Hesitant Consensus Scenario (high price)*

The share of renewable energy source on heating and cooling demand increases to 11.1 % in 2020 (about 7.5 % in 2008). In the building sector the share of renewable heating increases to 15.1 %. Figure 2 compares the RES-H contribution in 2020 with the year 2008. Thereby, biomass is still the major renewable energy source for heating. However, the analysis highlights the shift from the today's major biomass use through small stoves or fireplaces to centralised district heating installations based on solid biomass and biogas. Even without further support policies, solar thermal collectors as well as heat pumps (geothermal/ambient energy) exhibit a remarkable increase by 2020.
Nevertheless, the total expansion of RES-H/C is not sufficient considering the target of 14 % on final energy demand for heating and cooling in 2020 set by the Federal Ministry of Environment.

The influence of energy prices on final energy demand and RES-H/C expansion can be captured by comparing the described *high price* results with the *Hesitant Consensus –low price* scenario (see beginning of section 4). The *low price* scenario exhibits a total final energy demand for heating and cooling of 1442 TWh in the year 2020 which is 4 % higher than in the *high price* scenario. The RES-H/C share on final energy demand is 10.6 % which is not significantly less than in the *high price* scenario. Furthermore, the lower share of RES-H/C is also result of the higher total energy demand. The difference in absolute terms is only 1.6 TWh. Thus, the comparison suggests, that the influence of energy price over a short period of 8 to 10 years is limited.

4.4. Climate policy of the two tempi

As described in 4.2.1, the definition of the"2 Tempi" scenario aims in analysing the impact of additional policy measures targeting energy efficiency and RES-H/C expansion. In this scenario different variants are calculated for the building sector. Thereby, the combination of support instruments represent general policy settings; e.g. focus on regulatory instruments, focus on financial support etc.. The results presented in the paper at hand correspond to the"2 Tempi" scenario with focus on a regulatory policy setting in the building sector.

In this projection, the final energy demand for heating and cooling declines to 1 326 TWh by 2020 which represents a decrease of 11.6 % in the period 2008 to 2020. The majority of the savings are realised in the building sector. Energy efficiency measures in buildings accounts for 129 TWh or 16 % of the sector's final energy demand in 2008.
Energy savings of 54 TWh are realised in industry and service processes which corresponds to savings 7.8 % compared to 2008. The combination of all bundles results in approximately 20 TWh savings for both electricity and fuels for process heat and cold in industrial and services processes (compared to the scenario hesitant consensus). A major contribution is expected by the first bundle on concentrated actions on information, professional training and awards followed by financial incentives and technical standards.

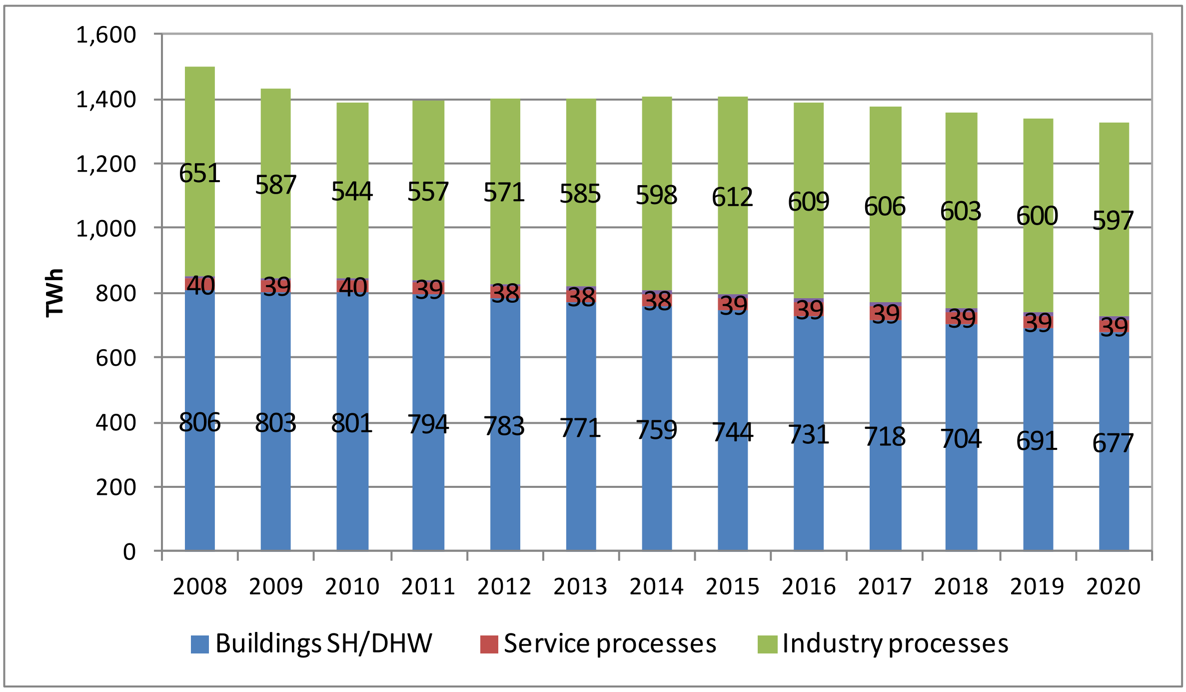

Figure 5: Projection of final energy demand for heating and cooling in *Hesitant Consensus Scenario (high price)*

The share of renewable energy source on heating and cooling demand increases to 12.1 % in 2020. In the building sector the share of renewable heating increases to 15.9 %. These results correspond to the scenario variant in which the *RES-H/C use obligation* applies in case of major renovation. As introduced in 4.2.1, a second variant is defined which analysis the impact of a different design of the policy instrument *use obligation*. In the second variant, the *use obligation* applies in case of heating system replacement. This scenario variant results in a RES-H/C share of 15.3 % on total final energy demand for heating and cooling. In the building sector the RES-H/C contribution accounts for 21.8 % of space heating and hot water energy demand.

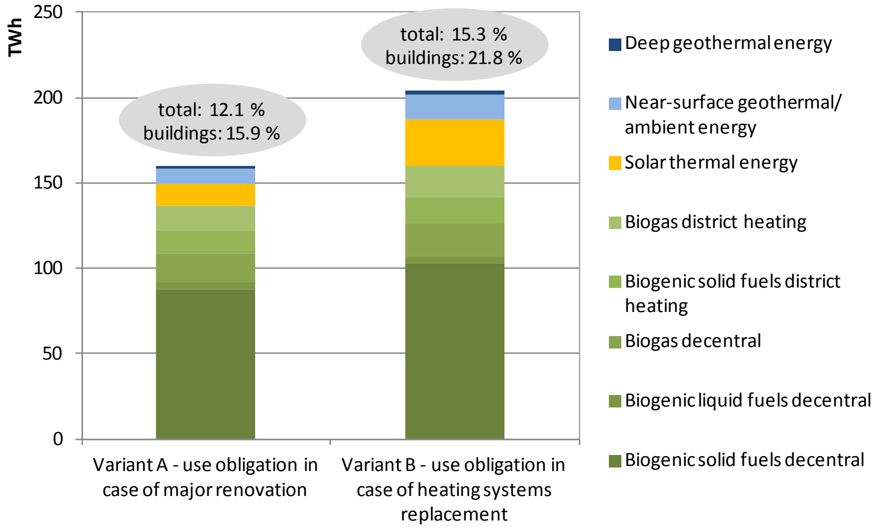

Figure 6: RES-H/C contribution and share on total and building's energy demand in both variants of *2 Tempi* scenario

5. Discussion of results and conclusions

This paper shows the basic structure of an integrated modelling framework of the German heating and cooling sector and selected scenarios. In this section we want to discuss the results and derive conclusions for following aspects: (1) Modelling and methodology, (2) space heating, cooling and hot water, (3) process related heating and cooling energy demand, (4) general conclusions and outlook.

5.1. Modelling and methodology

The soft link of five sector specific techno-economic bottom-up models allows a comprehensive investigation of the German heating and cooling sector. In particular, the following links were identified as crucial for a proper development of scenarios and the investigation of the overall policy framework:

- CHP_District heating and Invert/EE-Lab: On the one hand, Invert/EE-Lab provides the development of space heating and hot water energy demand taking into account the uptake of renovation measures and efficient new buildings. This is highly relevant information for the development of the economic district heating potential. On the other hand, CHP_District heating provides the economic district heating potential based on a detailed spatial model of 614 cities in Germany. This result provides a solid basis for the district heating related simulation results within the model Invert/EE-Lab. Thus, the link of these two models substantially contributed to the quality of the scenario development of the German district heating sector.
- It turned out that one iteration between these two models is sufficient to analyse this link between supply and demand side in the district heating sector.
- CHP_District heating and ProcServ: a similar link was implemented between these two models. However, the simulation runs showed that for the process heat this link was less relevant due to the lower uptake of district heating in the process sector.
- We neglected the link between AC and district heating (i.e. district cooling). Until 2020 we assume that this is justifiable. However, beyond 2020 and 2030 this could become a more relevant aspect which should be taken into account properly.

- The linkage of the models ProcIndustry and CHP_INDUSTRY provided a further detailed analysis and assessment of the heat demand that can be covered by industrial CHP. The potentials for industrial CHP was estimated and cross-checked with the heat demand below 200°C. In addition, the economic assessment was performed for various CHP technology types.
- The use of waste heat from industrial processes was allocated either for internal process use, industrial space heating or for injection into district heating networks. However, this topic deserves further future research especially on social related fields in order to model better the observed barriers.
- Using the same basis regarding techno-economic data is a key precondition for consistent results. However, in typical sector specific stand-alone analyses this is not the case. The establishment of a common database regarding input data and starting values regarding specific energy demand etc. can be regarded as a key progress in this field.
- The tertiary sector is generally characterized by poor data availability and reliability. We carried out a proper split of this sector in process heating and cooling (modeled in ProcServ) on the one hand and in space heating, cooling and hot water energy demand in non-residential buildings (modeled in Invert/EE-Lab) on the other hand. The set up of a clear interface and consistency check of these two elements of tertiary heating and cooling energy demand provided the basis for a comprehensive and clearly defined analysis of this sector (dotted line in Figure 1).

What remains open is the macro-economic feed-back loop from the activities in the building sector, the tertiary sector and the industry. In the project "heating and cooling strategy", the macro-economic activities will be assessed by the macro-model ASTRA. Based on these results we will discuss the relevance of such a macro-economic feed-back loop.

5.2. Space heating, cooling and hot water

A further tightening of the EnEV (German energy saving ordinance) could have a significant impact on the energy demand. In particular, it would be essential to improve the execution of this ordinance through the regions (Bundesländer). If the EnEV-requirements would be increased by 30% in the year 2015, total energy demand would decrease by additional 4% by 2020.

The comparison of the two variants within "climate policy of the two tempi" shows the impact of regulatory instruments. Such instruments (e.g. an enhancement of the current RES-H use obligation) could be a suitable path for achieving considerably higher market penetration of renewable heating. However, the following highly relevant issues have to be taken into consideration:

- The design of a RES-H use obligation has a huge impact on its effectiveness. A RES-H use obligation that has to be fulfilled in case of a major renovation (Variant A) increases the RES-H share in 2020 by 1%, compared to the Hesitant Consensus scenario. If the RES-H use obligation has to be fulfilled in case of each exchange of a heating system (Variant B), the additional RES-H share would amount to 7% in 2020.
- A balanced combination of regulatory and financial incentives is crucial (push & pull principle). In both variants of "climate policy of the two tempi" we assumed that the investment subsidy rates in the frame of the MAP (market incentive programme) remain in place without a cap on the available budget. Due to the increasing number of installations, the MAP budget increases significantly. So, what we actually see in both variants is a combination of investment subsidies with different regulatory scheme design. It can be assumed that the public acceptance of regulatory schemes without corresponding financial support measures is quite low. Thus it remains questionable whether (or under which circumstances) a government would be able to implement strict regulatory instruments for renewable heat and building renovation without corresponding financial support in the current political system.

The building sector has a huge inertia. Therefore, a fast implementation of measures is required. Most of the activities which are set now and in the next few years will show their major impact not before the year 2020.

5.3. Process related heating and cooling energy demand in industry and tertiary sector

Due to long lead times of investments in energy intensive production sectors, the efficiency potentials cannot be exploited by 2020. Also boilers for low temperature applications and cooling appliances have a high life time. Therefore, policy measures should mainly take care of the following aspects:

- Investors should have full information: according information activities, networking and campaigns are required
- Investors should decide not only according to the risk criteria but also according to the profitability criteria: on the one hand, policy can address this question in the above mentioned information programs. On the other hand policy instruments and incentives should take into account the specific criteria of decision making processes.
- In case of large efficiency potentials, incentives for early re-investment should be taken into account

The simulation runs show that the structure of renewable energy use in industrial applications changes (which is supported by the trend in the last few years): currently important resources like bark, black liquor, saw residues are losing their relevance in favor of pellets and heat pumps (mainly in the tertiary sector).

A considerable potential of waste heat is available in many industry branches. This could play an increasing role in the next few years for district heating, if the corresponding economic conditions and policy framework is in place.

5.4. General conclusions and outlook

The results show that currently implemented measures (status end of 2011) are not sufficient to achieve the ambitious targets of the German government regarding renewable heat, reduction of energy demand and corresponding greenhouse-gas emissions.

So, what is highly needed are smart policy packages providing tailor made incentives addressing the interest and needs for the different groups of people ensuring the acceptance of measures and policy targets.

Further analyses and model simulation runs carried out until end of October 2012 in the project "heating and cooling strategy" commissioned by the German federal ministry of environment will address open questions and the comparison of further policy instruments. In particular, more specific conclusions and recommendations will be provided regarding the setting of different policy packages.

6. Acknowledgements

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