Balancing efficiency and renewables in the federal building strategy: Results from modelling potentials and restrictions in a national heat market with high spatial resolution

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Abstract
In the discussion of the nearly zero energy building stock, an important question is the right balance between energy efficiency (EE) measures and renewable energy sources (RES): Whereas the "efficiency first" principle requires lowering the building energy demand prior to implementing a RES supply, other stakeholders argue that RES are available cheaply and abundantly and could help avoid deep interventions in the building stock.

Within the context of the German Federal Building Efficiency Strategy (ESG), a detailed modelling of the German building target (minus 80 % nonrenewable primary energy demand until 2050) has been carried out by the authors, identifying the restrictions and potentials of EE measures based on detailed statistical, GIS based and empirical information. Guiding questions were: What is the absolute minimum of U values of buildings from a technical, life-cycle and economic point of view? Which reduction of energy demand can be achieved? How long will the refurbishment of the whole building stock take at least? In addition to this EE perspective, the rather generic studies of RES potentials available in the literature were critically re-assessed, trying to improve the data quality of the potential contribution of RES to the target. This implies detailed, spatially resolved analyses of solar thermal energy, heat pumps, biomass, and district heating.

Two building models were combined to answer the questions: first, the geodata based 'German Heat Atlas' WaD which allows locating energy demand on a single building level, including EE (e. g. historic or semi-renovated buildings) and RES restrictions (e.g. inadequate locations for geothermal heat pumps or heating networks), and second the building scenario model GEMOD which calculates the future development for different conditions. The combined models allowed detailed analyses of RES whose potentials depend on the density of heat demand or building density, such as district heating, deep drilling geothermal energy and brine/water heat pumps. The potentials of solar heat and biomass were quantified by regarding their specific restrictions.

As a major result, one can state that there is only a narrow corridor left to reach the 80 % target within the technical boundaries. This requires about 50 % reduction of energy demand combined with 60 % renewable heat generation. Moreover according to the COP21 targets, it will be necessary to enhance the ambition of the building sector. The model results show that assuming the foreseeable technology evolution, such a decarbonisation target will hardly be achievable with EE and RES. To reach the target nonetheless, it is necessary to implement sufficiency as a third strategic dimension.

Introduction
The Federal Government's climate protection concept provides for a reduction in greenhouse gas emissions of 80 % compared to 2008 in the building sector. The United Nations Framework Conventions on Climate Change in Paris and Marrakech require an even higher reduction of about 95 %. In the building sector there are basically two approaches available to reach these targets: energy efficiency (EE) – i.e. insulation, air tight-

ness and heat recovery – and renewable energy sources (RES). Theoretically, there are many ways to combine these two. However, there are technical restrictions that limit the scope for action. On the side of EE, restrictions result, for example, from the protection of monuments, building physics or building geometry. But even buildings that can be insulated and tightened need heat – albeit in smaller quantities. Restrictions for RES are very specific for each single source and need to be analysed individually.

The right "balance" of efficiency and renewables has, in many contexts, been a matter of discussion (see for instance Pehnt 2009, GSR 2014). In the discussion of the "Efficiency first" principle, concerns have been raised by some stakeholders that in some instances, it might be more adequate to use RES instead of reducing energy demand to the absolute minimum, leading to a more balanced approach and modifying the Efficiency first approach to a more moderate "Think about Efficiency first" (see for instance Monitoring-Kommission 2017). We will show that based on our model results, reducing energy demand to the "best possible" level is crucial for achieving the reduction targets. "Best possible" in this context means very ambitious insulations layers that are still affordable though. Also, we want to investigate not only the separate potentials for GHG and primary energy reduction from EE and RES separately, but also the potential of RES as a function of EE: EE also works on the one hand as an enabler for RES, allowing higher shares (e. g. higher solar shares due to reduced demand) and higher efficiency (e. g. higher heat seasonal performance factors (HSPF) of heat pumps in insulated buildings with low temperature heating systems). On the other hand, EE reduces the possibility of district heat based infrastructures, thus making the use of RES more difficult.

In the past, ifeu and Beuth Hochschule have analysed the limits of both approaches as well as interactions between EE and RES. The results of the first stage of these modelling efforts have already been presented (Mellwig et al. 2013 eceee publication; Jochum et al. 2015 final report).

Since then, the analysis was complemented by a detailed and spatially resolved analysis of renewable energy potentials with the aim to derive a plausible development trajectory of the building stock. Toward this end, the ifeu national building model GEMOD was linked to geographical information system which depicts every building and its heat consumption characteristics in Germany ("heat atlas"). Results of this effort were also used to define the scenarios of the German Federal Building Strategy (Effizienzstrategie Gebäude, ESG) as well as policy instruments to achieve the target (Prognos, ifeu, IWU 2015). This paper presents selected findings and tries to shed some light on the frontiers of EE and RES.

Potentials for efficiency

In a first step of the analysis, the question how far heat consumption can be lowered in existing buildings must be tackled. This depends on both an economic and ecological assessment (which both lead to very similar results): From an environmental point of view, the maximum savings are achieved when the cumulated energy demand for production, transport and assembly of an insulation layer is equal to the heat savings achieved. For insulation layers the maximum lies at a U-value of 0,08–0,15 W/m²K (Beuth, ifeu 2015), depending on the material. If it were possible to optimally insulate the entire building stock in Germany overnight – except buildings with restrictions – and provide it with heat recovery, 81 % of useful energy could be saved (Beuth, ifeu 2015). However, additional obstacles may arise from the speed of implementation. Useful lives of building components range from 30–80 years. Renovation measures are usually only rational at the end of the useful life. This leads to a very small renovation rate. Even under the assumption of highly ambitious owners, who renovate all components 10 years before useful time ends in a targeted manner, useful heat savings of only 65 % can be achieved until 2050.

To visualize the "range of possible trajectories", an "action diagram" was designed (Figure 1) which shows the possible combinations of demand reduction and use of RES. On the X axis, the reduction of heat demand is shown, on the Y axis the reduction of system expenditure. System expenditure is a technical term containing the losses of heating systems for generation, storage, distribution and upstream chains (nonrenewable primary energy factor). Thus system expenditure is a good measure for the share of RES. To achieve an 80 % primary energy reduction, all the combinations on the narrow dotted line are possible. The maximum reduction of efficiency is shown in the black dashed/dotted line (Figure 1). In the upper area of higher shares of RES, this limit tends to the left and further reduces the scope for action. This curve results from the ecological balance of the insulation materials: Along the ordinate, the share of renewable energies rises. The greenhouse gas savings of insulating layers are correspondingly lowered. If the effort for production, transport and assembly of the insulation materials remained constant in time, the curve would follow the shape shown. A constant effort could not balance decreasing savings. Even in this case the curvature only begins with a RES improvement of 70 %. This means that only very high shares of RES allow reduced insulation. However, three aspects influence the shape of the curve. First, in a world with a high use of RES (which lies in the upper area), the cumulated energy demand for insulation most likely would also decrease because renewable energies are used for production, transport and assembly. Secondly, many renewable energy sources can only be used reasonably if the buildings are well insulated. Thirdly, the balance shifts when other sectors like process heat and transport are included. If more efficiency in buildings allows more RES flowing into these sectors, they can substitute gasoline and coal which cause much higher emissions.

Potentials for renewables

In a second step, the possible contribution of RES must be analysed: Could we simply supply all buildings using RES without prior reduction of the energy demand? Whereas an exact determination of the RES potential for building fuels is not possible, we try to narrow down the possible contributions of RES and to quantify the restrictions as good as possible. Each renewable energy source has its own specific restrictions. The aim of the following analyses was to identify the limiting restriction for each RES and to quantify the potential over time. A distinction was made between theoretical, technical and economic potentials, as well as supply and demand potentials. Such an analysis is not possible without a very detailed GIS data model: The po-

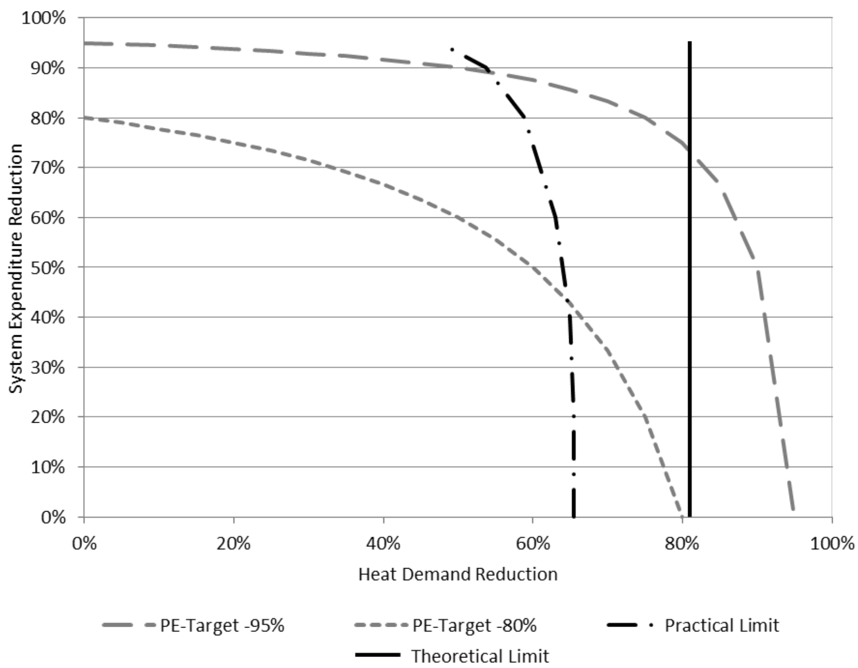

Figure 1. Field of action for the German building stock with limits for the reduction of heat demand.

tentials for an expansion of existing and new heating networks, for deep geothermal energy and for brine/water heat pumps need a consideration of the location and the geographical surroundings. For this purpose, the two building models GEMOD and German Heat Atlas (Wärmeatlas Deutschland WAD) (for details, see GEF Ingenieur AG Geomer GmbH Caso Geo Data + Services GmbH 2014) were combined. The Heat Atlas allows a regional location of heat demand in residential buildings. GEMOD is based on a typology of 234 residential and nonresidential buildings. It models the energy consumptions depending on the buildings component's useful life and renovation depth. It provides the Heat Atlas with temporary development of the building stock and energy consumption. The result is a spatially high-resolution model of heat consumption in buildings, which also models specific drivers and restrictions of RES. This approach is used for technologies whose expansion potentials depend to a large extent on the spatial arrangement of buildings or thermal density. In the following, we will give some insight into the modelling approach, using the example of district heating, heat pumps, geothermal and solar energy.

DISTRICT HEATING

District heating systems can be a vital infrastructure for integrating RES, especially in densely populated urban areas where we often find insulation restrictions such as lack of space for an insulation layer, or architecturally valuable facades, The potential of heating networks largely depends on heat demand and its spatial density. The following calculation steps were taken for the years 2011, 2030 and 2050 in order to determine the potential of possible heat supply by district heat in the course of time. In a first step, areas with existing district heating were filtered out. These areas cannot be equipped with additional heating networks. The heat quantity in existing networks was estimated as nearly constant over time. Therefore, network operators need to continuously compensate the decreasing heat demand by increasing the degree of connection (from around 30 % today to 60 % in 2050).

New heating networks must be amortised through the revenues from the sale of heat during the depreciation period. While the specific installation costs per meter are constant, the revenues depend on the required heat load per square kilometer. This leads to a minimum heat load per square kilometer that is needed to run a heating network economically. Using the GEMOD/heat atlas combination with spatial distribution and development of the heat demand, the suited areas were identified. Their heat demand represents the heating network potential.

In addition to literature research, about 30 local heating cooperatives and private operators of small local heating networks were surveyed. As a result, a relatively low minimum sales density of 0.48 MWh/(m*a) was derived for rural heating networks. For urban heating networks at least 0.61 MWh/m*a are demanded. A real interest rate of 4.5 % was assumed on the financing of network costs. The amortization period was set at 20 years in both urban and rural areas.

Resulting potential of new heating networks

As the modelling results for Germany show, the largest part of the new heating network potential lies in small town areas. In a moderate renovation scenario, a total of 19 % (77 TWh) of the useful energy consumption for space heating and hot water in residential buildings can be covered in the long term by new heating networks. The ambitious renovation scenario sees a potential of 12 % (39 TWh).

New and existing heating networks together can cover a total of around 29 % (118 TWh) in a moderate renovation scenario. With ambitious renovation, the share is 27 % of the useful energy consumption for space heating and hot water in 2030.

For 2050 however, the economic potential of heating networks reduces significantly, showing the importance to install this infrastructure sooner rather than later to allow a refinancing of the investment costs

DEEP GEOTHERMAL ENERGY

The use of deep geothermal energy requires considerable investment. It needs heat sinks with high heating loads (1 to 10 MW) – usually local heating networks. In Germany, 26 hydrothermal plants with an installed thermal capacity of approximately 300 MW are currently in operation.

Deep geothermal potentials were analysed with the advanced GIS models of long-term heat consumption in residential buildings, heat network structures and latest GeotIS data from 2014 which distinguish the temperature zones of the hydrothermal reservoirs. Only direct thermal utilization of hydrothermal reservoirs (hydrogeothermia) is taken into consideration. It is seen as a medium-term relevant technical option using a temperature of more than 60 °C in heating networks (Bracke, 2014).

The estimation of the technical and economic potential of deep hydrogeothermal energy in the heat sector requires a spatial comparison of the long-term energy sources from the reservoirs and the long-term development of heat sinks in the building sector in the regions concerned. In particular, technical and economic feasibility for heat networks must be taken into account. By the exploitation of deep hydrothermal reservoirs with duplex deep drilling, heat outputs of up to 40 MW are available on a point-by-point basis. The average output in the southern German Molasse Basin, where several plants have already been installed is 12 MW. Whether the resulting energy quantities can actually be used depends on the spatial distribution by a corresponding heat sink.

To derive a quantitative potential of deep geothermal heat supply, again a multistep procedure was applied:

- Filter all areas with less than 60 °C in the ground
- Calculate the achievable volume flows in the three main areas
- Derive heat production costs from temperatures and volume flows
- Heat network analysis with specific heat production costs
- Existing heat networks can be supplemented with deep geothermal energy. To this end, heat consumption in the heat network areas is compared to the achievable geothermal heat quantity

At present, it would therefore be technically possible to exploit 5.8 TWh per year for the feed-in into existing district heating networks. This amount decreases to 4.4 TWh in the ambitious renovation scenario until 2050.

Apart from feeding into existing district heating networks in densely populated regions, additional potentials for the use of deep geothermal energy in new local heating systems are emerging. The technical distribution potential is determined analogously to the analyses of the district heating zones by comparing heat consumption as a function of the energetic renovation path and technical extraction potential at the level of local heat clusters. In new local heating systems, 26.3 TWh could be developed. This volume will be significantly reduced to 13.3 TWh in the ambitious renovation scenario of the residential building stock by 2050.

Overall, the technical deep geothermal energy potential in district heating and local heating networks in 2011 amounts to 32.1 TWh or 7 % of the useful energy consumption for space heating and hot water. In the ambitious energetic renovation scenario, the technically achievable potential falls to 17.7 TWh. This corresponds to a slightly increased share of 9.5 % of the heat consumption in residential buildings.

BRINE/WATER-HEAT PUMPS

To obtain the amount of buildings that could be supplied with (efficient) brine/water heat pumps, the totality of all building blocks in Germany was derived from the building data of the real estate cadastre. These include information such as type and number of building types, year of construction, the proportion of the built-up area, and more. The building blocks were divided into seven density classes depending on the ratio of built-up area to undeveloped area. In a random procedure, two building blocks per density class were selected as a sample for each federal state. For these building blocks, the maximum number of possible deep drillings was counted. A numerical relationship between the maximum possible number of drillings and other known properties of the building blocks was derived from the sample. This numerical description was applied to all building blocks in Germany and thus the maximum number of deep drillings in Germany was calculated in a first approximation.

Water protection areas were calculated in defined proportions. The legally maximum possible drilling depth is stipulated in the German water legislation. The technically achievable drill depth was taken into account by a survey of drilling companies. In addition, other barriers of deep drilling were researched by telephone interviews with 21 drilling companies in order to collect practical barriers in deep drilling. For instance, the mandatory minimum distances between drill holes and buildings or property lines can be obstacles for brine/water heat pumps.

The local heat extraction rates of the soil were integrated by using geological data from the federal states. For the spatial distribution of the drillings within the building blocks and the resulting under-supply of individual buildings, a discount factor was derived.

The maximum extraction power from deep drillings determined in this way was converted into the maximum available heat utilization of the heat pump by adding the heat generation of the compressor as a function of the HSPF.

The potential of brine-to-water heat pumps with deep drillings to cover the useful heat consumption in Germany ranges between 145 and 186 TWh for the year 2050. In the scenario with very ambitious energy renovation, it is 116 to 124 TWh.

HEAT PUMPS IN GENERAL

The potential for the use of heat pumps is fundamentally restricted from two sides: from restrictions on the side of heat demand and from restrictions on the side of heat sources. Theoretical supply potential of heat pumps corresponds to the total heat quantity which can be extracted in a usable temperature spectrum. The actual potential is thus limited by the availability of the heat sources in reasonable spatial proximity to a building to be supplied. Furthermore, the required heat extraction must not prevent the regeneration capacity of the sources.

The required electricity can cause further restrictions. They can arise both from the load on distribution networks and from the availability of green electricity.

Considering the demand restrictions, the theoretical potential corresponds to the total useful heat demand of the buildings. Technical and economic potentials are, however, limited by the efficiency of heat pumps. This can be seen clearly as the efficiency of heat pumps decreases with increasing system temperatures in heating systems. Flow temperatures above 60 °C in the radiators are usually an exclusion criterion for the use of heat pumps at common source temperatures. Particularly the type of heat transfer into rooms represents a hard restriction for heat pumps. Unlike in new buildings, which offer the freedom to adapt to the heat pump application, in existing buildings must be assumed that heat distribution, and therefore also the existing radiators are hardly replaced. In cases of complete refurbishments it would certainly be possible to replace the radiators, but the common standard is the further use of the existing radiators.

In approximately 96 % of the buildings erected before 1978, heat is transferred by radiators (IWU 2010). Usually, heaters were designed for temperature spreads of 70/55/20 (flow/return flow/room temperature), in older buildings even for 90/70/20. System temperatures should be reduced as far as possible in order to suit a heat pump. The lower the temperatures are, the higher the heating seasonal performance factor (HSPF) rises. If flow temperature is reduced to 55 °C, the radiator's maximum heat output decreases about 35 %, so that eventually, the building can no longer be heated sufficiently. Larger radiators would then be required.

However, since radiators are not subject to any restoration cycles, the costs for their replacement must be fully taken into account for the energy related additional costs. This has an unfavorable effect on the cost efficiency of the heat pumps. In total, operating heat pumps with radiators is technically possible to a certain degree, but there are economic and energy-balance restrictions.

An alternative could be the use of underfloor heating, because of the larger heat emitting surface area, although in combination with lower operation temperatures. Therefore, underfloor heating cannot transmit more than 70–80 W/m² floor. This performance is not sufficient for unrefurbished old buildings, which require about 100 W/m². Furthermore, retrofitting old buildings with floor heating would lead to considerable and presumably unacceptable structural expenses.

Since heat pump potential, in particular in the case of air heat pumps, depends on the respective building conditions, the task is to identify the buildings whose heating load is low enough for the use of heat pumps. The GEMOD model can filter the heat demand of all buildings whose specific heat demand is below a certain limit. Thus, it can be shown that with increasing insulation measures, an increasing number of buildings fall below this upper heat demand limit.

From a technical point of view the upper heat demand limit for heating pumps is about 120 kWh/m²a. In order to determine the economically and ecologically reasonable upper heat demand limit, a relationship between the specific heat demand and the resulting HSPF was determined. For this purpose, information on the relationship between flow temperature and HSPF was used from existing monitoring programs (FhG, ISE 2010). Using the so-called radiator equation, which describes the dependence of the heat output of radiators on flow temperature, an expectation corridor for the average HSPF can be presented as a function of the heat demand.

For the final determination of the heat pump potential, there has to be an individual assessment of the desired minimum HSPF. If this is judged from the ecological point of view, it should be based on the current primary energy factor for electricity which currently amounts to 1,8 and will continue to decline as a result of increasing renewable shares in the electricity mix. From an economic point of view, the HSPF should range from 2.5–3.0, even if the investment costs of the heat pump are neglected, because electricity is roughly 3 times more expensive than other energy sources. Considering additionally the relatively high investment costs of heat pumps compared to other heat generators the minimum HSPF should increase even further. In total, the upper heat demand limit for heating pumps is about 90 kWh/m²a. Today 23 % of the heat demand is consumed in buildings that are under this limit. In a business as usual scenario their share rises to 78 % – in more ambitious scenarios even higher.

Under the assumption that the identified potentials are fully utilized, the analyses show a resulting maximum electricity demand of 80 TWh/a. This is a share of 12 % of the present total generation of electricity in Germany. The corresponding electric power, however, is required on the coldest winter day when all heat pumps work simultaneously. This asks for high demands to the electric generators and the supply network.

SOLAR THERMAL HEAT ON INDIVIDUAL BUILDINGS

The potential of solar heat systems in single family buildings was derived by Roger Corradini in his dissertation (Corradini 2013).Three exemplary solar heat systems with varying size were analysed with a simulation software to derive the solar coverage rate and the main influencing factors. First, the orientation of the roof was analyzed for the extrapolation of the simulation results. The orientations of single family houses were analyzed with data from open-street-map. The results showed that many roofs are oriented towards south. The so-called practical potential, i.e. the amount which solar heat can substitute is 35–48 TWh final energy per year (Corradini 2013).

The potentials calculated by Corradini refer to the final energy consumption in 2012. However, with ongoing refurbishment this amount will decrease. Heating demand however, influences the solar yield. Therefore the potential calculated by Corradini cannot be perpetuated in future. Corradini calculated the coverage rates and solar yields for ten classes of single-family buildings according to the age of these buildings. These coverage rates and solar yields according to Corradini's calculations were transferred to the building types in GEMOD. Likewise, the typical solar coverage was also transferred to GEMOD. Yet, for very efficient buildings the solar coverage rate was limited to 50 %, because the extrapolation of the trend lines would lead to unrealistically high rates. In GEMOD the useful heat demand was perpetuated for all building classes. Thereby, the solar yield of single-family buildings with a varying heat demand over time was calculated. Additionally, the trend of the potential is presented for a scenario with an ambitious reduction of heating demand. Initially, the solar potential increases with progressing refurbishment of the buildings, but decreases later. This decrease occurs when the gradient of the demand reduction is larger than the gradient of the coverage rate. The solar heat potential for multifamily buildings in 2050 is 38 TWh in the trend scenario and 30 TWh in a scenario with ambitious renovation. The solar heat potential of non-residential buildings depends heavily on its utilization. If there is no or only a little demand for hot water, solar thermal systems are generally not economic viable. According to the utilization profiles of DIN V 18599-10 hot water demand is sufficient only in accommodation buildings, sport buildings and hospitals.

For these building types the calculation followed the approach of the maximum credible solar coverage rate, as it was used for multi-family-buildings. For the year 2050 the potential amounts to 1.1 TWh in the ambitious renovation scenario and 1.5 TWh in the trend scenario.

SOLAR DISTRICT HEATING

Solar district heating denotes the usage of solar heat that is generated in central solar collectors and distributed to consumers via heating network. These systems usually comprise a central heat storage and a respective distribution system, comparable to other heating networks. Consumers are generally single multi-apartment house, a whole neighborhood or a district. A differentiation can be made between such systems that comprise a seasonal heat storage and those without.

Systems with seasonal heat storage can store the heat generated in summer months. It is feasible to achieve comparatively high solar coverage rates of 30–50 %. Without a seasonal storage, the coverage rates amount to 15–20 % (solar district heating 2011).

At present, solar district heat can be provided without subsidies for €60–€80/MWh in Germany (determined at the feed-in point of the district heat (Solar district heating 2011)). Thus, it is not competitive against other heat sources. Under these market conditions, the economic potential for solar district heating approaches zero. On the other hand, Denmark achieved to lower the price for solar district heat down to €40/MWh. In case the Danish model could be adopted in Germany, the solar district heating potential would be limited by the district heating potential on the one hand and the solar coverage rate on the other hand.

In Germany, district heating potential amounts to 39.4 TWh for the year 2050. In present heating systems in Denmark, the solar coverage rate amounts up to 20 % (Schulz 2016). If this coverage rate and a future increase of up to 30 % could be achieved in Germany, the economic potential in the trend scenario would be roughly about 15.8 TWh. In the ambitious scenario, the heating network potential decreases to 6.1 TWh. In this case the potential of solar district heating is about 2.84 TWh (solar district heating 2011).

BIOMASS

Biomass has specific advantages over other kinds of renewable energy in all three relevant sectors of heating, electricity and transport. This is why the three sectors compete for biomass utilization. The most important criteria for the allocation of potentials to the respective sector are:

- generation costs compared to the alternatives in the same sector,
- generation costs compared to the costs of biomass utilization and alternatives in other sectors,
- the amount of alternative renewable energies in a sector,
- the present amount and resulting persistence.

At present, in the heating and transport sector the GHG abatement costs of biomass are lower compared to other renewable energy sources. In the electricity sector biomass can contribute to balance the volatility of PV and wind and thus reduces the demand for electricity storage. For the assumptions of future allocation of biomass to the respective sectors several factors need to be taken into account:

- The potential of the different biomass primary energy sources (energy plants, wood, etc).
- The development of the conversion cost into the respective final energy carrier (burning of firewood is significantly more economical compared to the gasification for the use in CNG-vehicles).
- The differences in the willingness to pay for biomass in the respective sectors, which depends on the costs of the substituted energy carrier, the costs and availability of alternative GHG abatement options and the policy framework (e.g. the directive on a biofuel quota).

Biomass (inclusive of the biogenic share in waste) accounts for 120–125 TWh of the high and low temperature heating demand in Germany in the last year (AGEE Stat, 2015). 65 TWh of final energy consumption was from solid biomass use for low temperature heating demand in households and district heating networks. It is expected that additionally, solid biomass is used in the industry and service sector for low temperature heat demand. Hence, it is estimated that current low temperature heat demand covered by solid biomass amount to 90 TWh of final energy. With regard to the drivers and barriers described above, we assume that there is no room for a further increase in the use of biomass in the sector of heating and hot water supply.

Resulting boundaries for renewable heat supply

With the individual estimations of individual RES potentials at hand, we can now quantify a possible contribution of RES to the overall heat supply – bearing in mind, that these estimations are only a rough estimate and depend on the various definitions and the selected parametrization.

The potential is represented in the form of the minimum achievable average system expenditure. The system expenditure includes the losses for storage, distribution and transfer of heat as well as the generation effort and the primary energy factor. It is the quotient of primary energy and useful energy. Thus the system expenditure is always greater than one when no RES are used. A heating system without any losses would be quoted with a system expenditure equal to one. The value gets smaller than one only in heating systems with RES, where the primary energy factor decreases. In order to derive the minimum system expenditure, the conceptual approach is to use the most

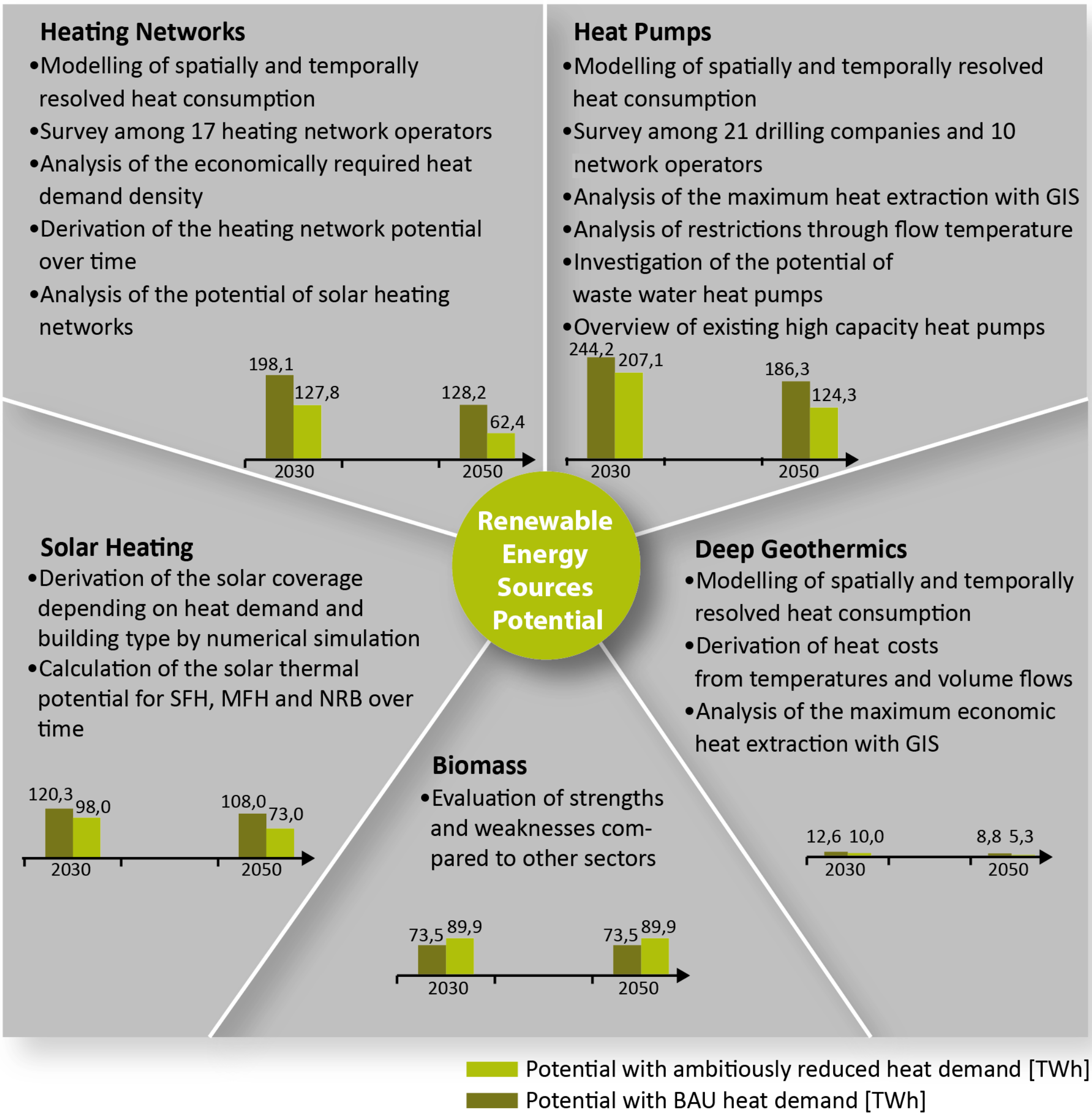

Figure 2. Overview of specific evaluation methods and RES potentials.

efficient generation technology to its full potential. This is followed by the second efficient technology to its potential limit and so on until the heat demand is covered. With this best possible heat generator mix, total primary energy consumption is calculated and then divided by total useful heat consumption. Since most renewable potentials are dependent on useful heat consumption, the minimum system expenditure is calculated for several useful heat consumptions and the resulting function is interpolated from the points.

The sum of the individual potentials of renewable energies, as calculated above, is generally higher than useful heat consumption. However, this should not be interpreted as an actual overlap. Many renewable energy sources are mutually exclusive. As a result, the sum of the RES potentials is smaller than heat demand no matter how far the demand is lowered. There is no feasible way to cover 100 % of heat demand of the German buildings stock with RES. The system expenditure cannot be lowered by 100 % at reasonable costs.

In order to show the range of the minimum system expenditure, it was calculated twice: firstly with a focus on solar thermal energy, biomass and heating networks and secondly with a focus on heat from electricity.

The minimum system expenditure is determined as a function of the useful energy savings. The reduction of the system expenditure is stated in percent in relation to the reference value (average system expenditure in 2008). Figure 3 shows the course of both potential limits compared to the target achievement curves (80 % and 95 % primary energy savings). A strong focus on heat from electricity (pointed line) leads to a smaller potential than a broad mixture of RES. If the useful energy demand of the building stock is not reduced any further (at 0 % on the X axes), the system expenditure can be lowered by 61 % (down to 0,84). In order to achieve the 80 % target, at least a 20 % reduction of the useful energy demand is required. Towards this end, the system expenditure must be reduced by 70 % (to 0.33). The 95 % target can only be achieved with a 53 % reduction of the demand and a simultaneous reduction of the system expenditure by 88 %.

The minimum system expenditure cannot be lowered to the same level when the strategy focusses on heat from electric-

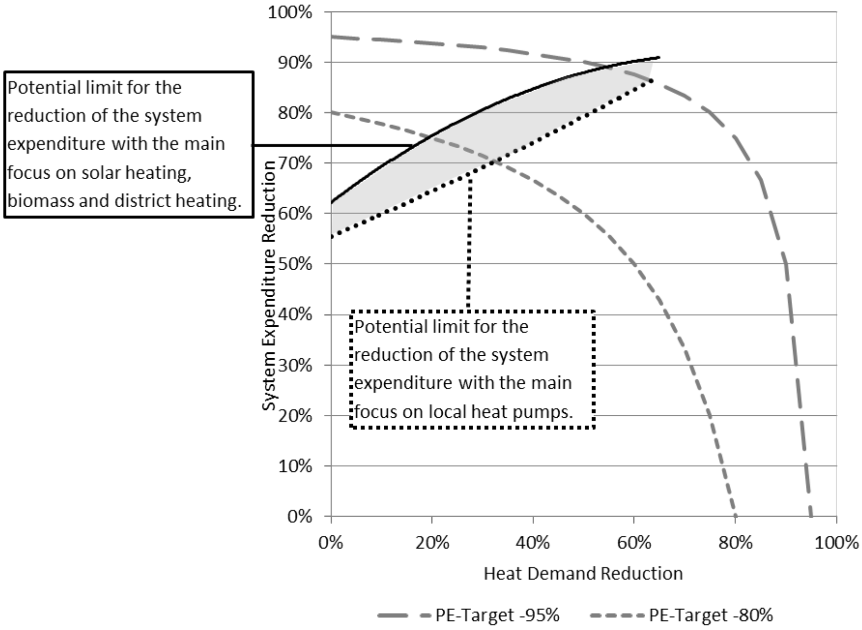

Figure 3. Field of action for the German building stock with limits for the reduction of system expenditure for different RES focuses.

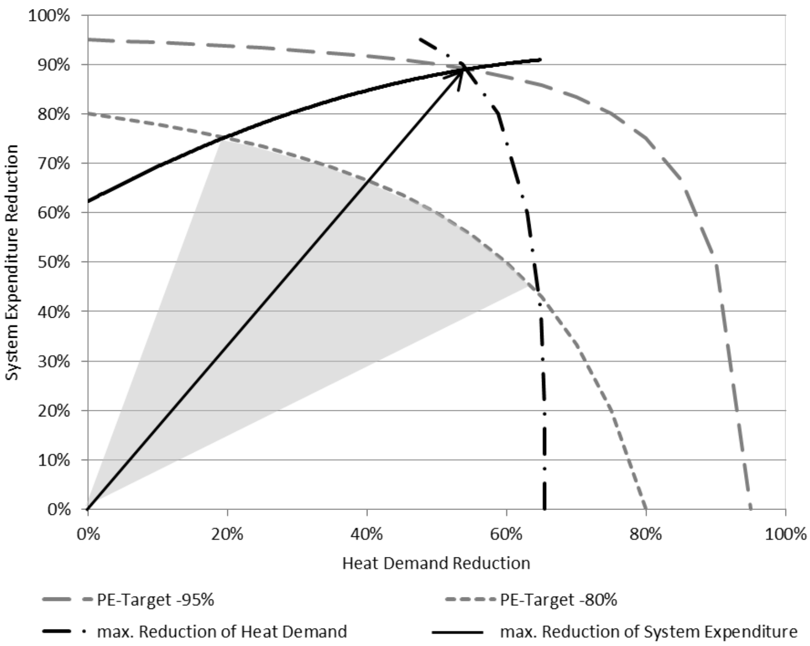

Figure 4. Remaining field of action to achieve the targets restricted by limits on either side.

ity. The primary pronounciation on decentralized heat pumps restricts the field of action. The reason is that a higher share of fossil fuels is needed because the potentials of heating networks and network-bound renewable heat generation cannot be utilized. However, the total final energy demand – without solar and environmental heat – is the same or slightly lower than that with a focus on solar thermal energy, biomass and heating networks. Excessive concentration on electric heat pumps unnecessarily limits the field of action. Only a mix of available RES leads to a high savings potential.

Conclusion

In order to achieve the target of an 80 % reduction the heat demand needs to be reduced by 20–60 %. Simultaneously the system expenditure has to be lowered by 75 % (upper left intersection point in Figure 4) respective 46 % (lower right). The percentage scale, however, can be misleading as it is not linear when translated to the absolute amount of heat: when the heat demand is reduced by 60 % 130 TWh RES are needed (lower right corner). In the upper left corner 423 TWh RES are needed to achieve the target.

Scenarios can be shown in the diagram as lines. They start from zero and approach the target lines on individual paths. Different directions to the target lines provide specific risks: the further horizontally a scenario goes (to more efficiency) the higher the investment costs will rise. Going vertically (focus on RES) holds the risk of getting locked in to a state of too poor efficiency. Detailed economic evaluation of the different paths will be calculated by ifeu.

As a result the following guidelines can be stated.

- The savings targets for buildings cannot be achieved only with RES.
- There is no feasible way to supply the whole building stock only with RES at reasonable costs.
- A broad mixture of RES instead of focusing on one single source mobilizes further potentials and facilitates the progress to the target.
- In order to achieve the targets, a much higher ambition level is needed.
- The field for action is limited from two sides and the limits intersect close to the target of 95 % reduction.
- Reducing energy demand is a robust path (efficiency first)
  - as it is a prerequisite for the use of renewable energies;
  - to avoid lock-in effects, e. g. if it turns out necessary to achieve not only a -80 %, but a full decarbonisation trajectory;
  - ambitious insulation thicknesses lead to overall savings during their life cycle even though high shares of RES are used.

The model results show that assuming the foreseeable technology evolution, the mandatory decarbonisation target can hardly be achieved only with EE and RES. The remaining corridor is extremely narrow and the degree of ambition that is needed to follow the path is far from what could be experienced in reality. To reach the target nonetheless, the field of action should be given a third dimension. From a sustainability point of view, lowering heat consumption represents efficiency, lowering system expenditure represents consistency. The third pillar of sustainability – sufficiency – is still missing in the current debate. It should be added as a third dimension where higher savings might be achieved with less effort.

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