FRAUNHOFER-INSTITUTE FOR SOLAR ENERGY SYSTEMS (ISE)

FRAUNHOFER INSTITUTE FOR ENERGY ECONOMICS AND ENERGY SYSTEM TECHNOLOGY (IEE)

Bottom-up study on possible pathways for an efficient and socially responsible approach to decarbonisation of the heating sector

Short form report

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THE GERMAN NATIONAL HYDROGEN COUNCIL

On 10 June 2020, the German government adopted the National Hydrogen Strategy and appointed the German National Hydrogen Council. The Council consists of 26 high-ranking experts in the fields of economy, science and civil society. These experts are not part of public administration. The members of the German National Hydrogen Council are experts in the fields of production, research and innovation, industrial decarbonisation, transportation and buildings/heating, infrastructure, international partnerships as well as climate and sustainability. The National Hydrogen Council is chaired by former Parliamentary State Secretary Katherina Reiche. The task of the German National Hydrogen Council is to advise and support the State Secretaries' Committee on Hydrogen with proposals and recommendations for action in the implementation and further development of Germany's National Hydrogen Strategy.
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Abstract

Initial situation

Prepared by the Fraunhofer Society on behalf of the German National Hydrogen Council, this study has set itself the task of identifying possible pathways for an efficient (bottom-up) approach to decarbonisation of the heating sector on the basis of the local conditions in four case studies (Burg near Magdeburg, Fellbach, Mainz and Westerstede), while examining the role of hydrogen in a climate-neutral heating supply by 2045. The local infrastructures, the diversity of the building stock, commercial and industrial structures and participating users in the heating sector are key aspects in order to be able to reflect the full range of decision criteria, goals and economic conditions that are relevant for the individual actors and decision-makers and can guide their actions in real-world conditions.

Aim and methodology

As described above, there is a range of estimates on development pathways of costs and prices of different energy sources, as well as a discrepancy between the actual local situation and top-down solution pathways. Due to these factors, the aim of this bottom-up study is to evaluate transformation pathways that can lead to a climate-neutral heating supply in four supply areas, taking into account local infrastructures, geographical location and the existing building stock locally. The study also analyses the dependencies of the transformation pathways on certain local characteristics. A particular focus is placed on investigating the space heating technologies that could provide a cost-optimal supply mix while incorporating refurbishment and infrastructure costs.

The following figure depicts the methodological approach of the bottom-up study:

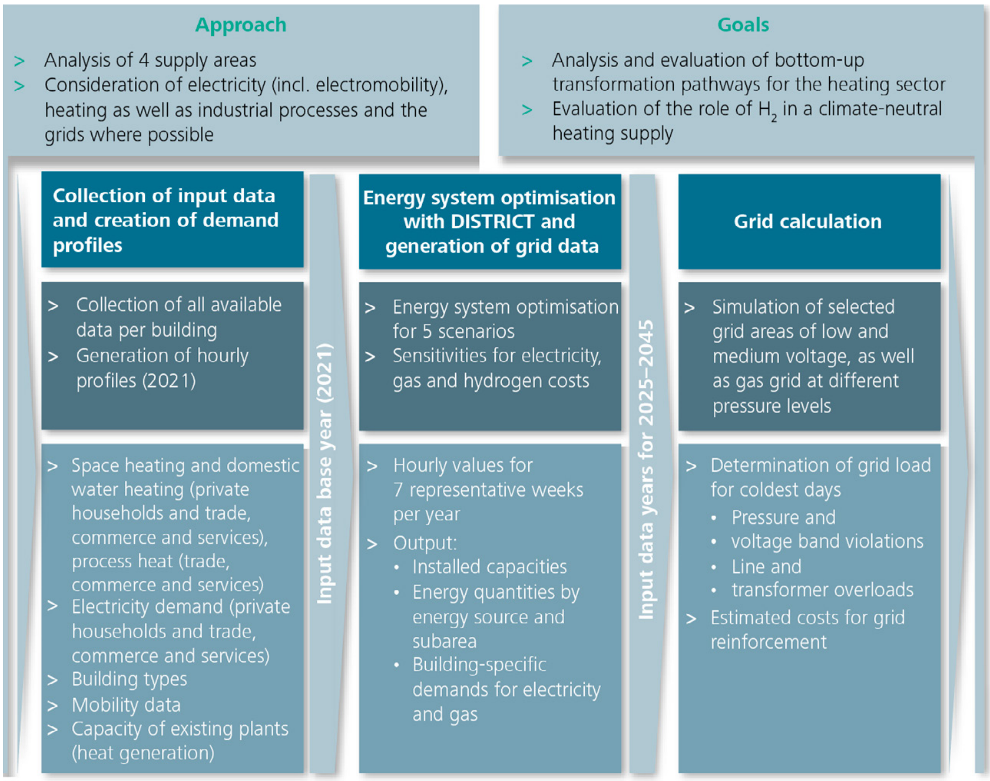

Fig. 1: **Methodological approach of the bottom-up study**

This study was conducted during a period when the circumstances and state of the energy markets are under significant pressure and change due to the Russian war of aggression in Ukraine. The issues regarding the security of the energy supply and import of energy sources have been reassessed. At the same time, new dynamics have developed in the heating sector due to high energy prices, which will visibly accelerate the transformation and have brought the issue of affordability into focus. The assumptions in the study regarding the energy source prices (especially the fossil energy sources) were defined based on pre-crisis levels for a long-term perspective. For the defined scenarios, the study switched between the scenarios in particular in terms of the assumptions for the availability of hydrogen infrastructure and price assumptions for hydrogen (H2) and electricity. It should be noted that these three scenarios assume a high availability of hydrogen imports; however, whether these assumptions come true is still very uncertain. All pathways with high hydrogen use assume low hydrogen prices for consumers, for which a significant reduction in generation costs and a strong market ramp-up are required. The resulting feedback mechanisms in the energy markets are not considered since no feedback between supply and demand of the individual energy sources was performed in the study.

Tab. 1: List of the scenarios' characteristics

	Scenario				
Scope	**1**	**2**	**3**	**3A**	**3B**
Refurbishment rate/depth	1,2% / KfW 70	1,8% / KfW 70	1,8% / KfW 70	1,8% / KfW 70	1,8% / KfW 70
H_2 backbone available	2030	2035	2030	2030	2035
H_2 prices 2035 [ct/kWh] (households/industry)	low 10,8 / 9	high 16,3 / 14,5	low 10,8 / 9	low 10,8 / 9	high 16,3 / 14,5
H_2 availability DE [TWh/a] (2030/2045)	high 200 / 1000	low 0 / 150	high 200 / 1000	high 200 / 1000	low 0 / 150
Electricity prices 2035 [ct/kWh] (households/industry)	medium 21,8 / 11,6	medium 21,8 / 11,6	medium 21,8 / 11,6	high 28,1 / 17,9	low 20,3 / 10,1
Natural gas prices 2035 [ct/kWh] (households/industry)	medium 5,4 / 3,1	high 6,1 /3,8	medium 5,4 / 3,1	medium 5,4 / 3,1	medium 5,4 / 3,1
Availability of electricity from renewable energy sources	high	medium	high	low	high
Heat pump replacement rates	medium	medium	high	high	high
Gas boiler replacement rates	medium	medium	medium	high	high

Key findings of the study

Figure 2 shows heating by energy source in the four supply areas for the scenarios investigated: Mainz, Burg near Magdeburg, Fellbach and Westerstede, Germany.

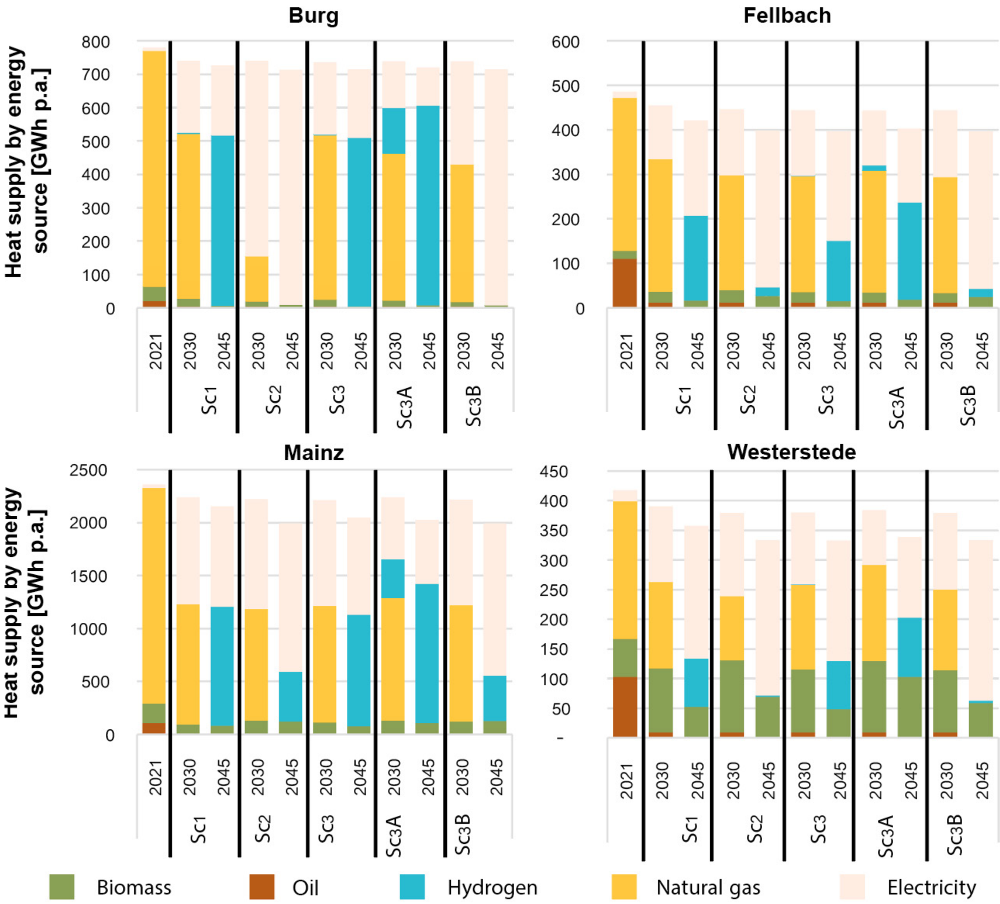

Fig. 2: Overview of heating by energy source in each supply area

Key findings of the study

(1) All potentially climate-neutral energy sources – electricity, district heating, renewables (photovoltaics, wind power, solar thermal, geothermal, biomass) and hydrogen – are needed in the heating supply in order to achieve a climate-neutral energy supply by 2045. The share attributable to each energy source is largely determined by the cost difference between the energy sources and their availability in the scenarios considered. The overall solution of each supply area depends on the share of demand for process heat, population density, building stock and local potentials for environmental heat and for electricity generation from renewable energy sources (RES).

(2) Detailed analysis of the supply areas

Fellbach

In terms of the heating supply, Fellbach, an urban town with little industry, is mainly characterised by a demand for space heating; process heat is only of secondary importance here.

The scenarios with a low availability of hydrogen at high prices (Scenarios 2 and 3B) see space heating being mainly supplied by decentralised heat pumps (79% and 86%, respectively) and supplemented by biogas plants (8% and 7%, respectively). In the scenarios with a high availability of hydrogen at low prices (Scenarios 1, 3 and 3A), the share of hydrogen in the decentralised and central space heating supply is 43%, 30% and 51%, respectively. In Scenarios 1 and 3, the supply with decentralised space heating is mainly distributed between heat pumps (46% and 59%, respectively, of total space heating supply) and hydrogen boilers (39% and 25%, respectively). The share of space heating supplied by local or district heating (central heating supply) in Scenario 3A increases up to 44%, of which the largest share (41% of space heat generation) is hydrogen-based. Decentralised hydrogen boilers play only a minor role in this scenario (10%), with heat pumps accounting for 41%.

Process heat in Fellbach is mainly supplied by direct electrification and hydrogen. Independent of the scenario, the share of hydrogen here is at least 48%, with shares reaching up to 96% depending on the scenario (Scenario 3A); the highest share of electrified process heat plants is 41% (Scenario 2).

Westerstede

Westerstede, a rural town with little industry, sees heat demand arising primarily in the area of space heating, as well. Westerstede has a large, local biomass potential.

The space heating in Scenarios 2 and 3B (66% and 67%, respectively) is supplied by decentralised heat pumps and supplemented by decentralised biomass boilers (8% in each case). The share of central space heating in these scenarios is around 25%, generated by large-scale heat pumps and biomass plants in nearly equal parts. In Scenarios 1, 3 and 3A, the share of decentralised heat pumps is 54%, 52% and 32%, respectively. In addition, decentralised hydrogen boilers provide shares of 23%, 25% and 21%, respectively, for space heating, as well as shares of 6% (Scenarios 1 and 3) and 7% for decentralised biomass boilers. District heating in Scenarios 1, 3 and 3A is supplied by biomass (6%, 5% and 21%, respectively), large-scale heat pumps in combination with power-to-heat (8% and 11%, respectively, in Scenario 3A) and additionally by hydrogen (10%) in Scenario 3A, with shares of 17% (Scenarios 1 and 3) and 39% of the total space heating supply.

The structure of process heat supply is similar in almost all scenarios. Electrification by means of large-scale heat pumps and direct electrification represent shares of 33–42%. Biomass (shares of 50–57%) and hydrogen (shares of 8–11%) are used as a fuel. The share of electrified process heat generation plants is the greatest in Scenario 3B with 73% at low industrial electricity prices.

Mainz

The demand for space and process heat in Mainz, an urban and industrial city, is of a similar magnitude.

The space heating in Scenarios 2 and 3B (89%) is supplied by decentralised heat pumps and supplemented by decentralised biomass boilers (6% and 7%, respectively). In Scenarios 1, 3 and 3A, heat pumps supply shares of 73%, 77% and 45%, respectively, for space heating and are supplemented by decentralised hydrogen boilers with shares of 8%, 5% and 1%, respectively, and central hydrogen-based heat generation of 9% (Scenarios 1 and 3) and 44%, respectively. All three scenarios see around 7% of the demand for space heating in Mainz being supplied by decentralised biomass boilers.

In Mainz, process heat is supplied by large-scale heat pumps in combination with direct electrification and by hydrogen-based district heating and hydrogen-based combined heat and power (CHP) plants. In Scenarios 2 and 3B, the share of electric process heat supply is 48% and 52%, respectively, and supplemented by hydrogen-based process heat generation with shares of 46% and 43%, respectively. In Scenarios 1, 3 and 3A, hydrogen-based district heating (between 76% and 78%) supplies the largest share of process heat and is supplemented by district heating through electricity with shares of around 20%.

Burg near Magdeburg

Burg near Magdeburg, a rural town with industrial activities, sees demand for process heat being mainly determined by a single large industrial consumer, which also dominates the total heat supply.

Space heating in Scenarios 2 and 3B is mainly supplied by decentralised heat pumps (77% and 75%, respectively) and supplemented by district heating (16% and 15%, respectively). In Scenarios 1, 3 and 3A, the share of hydrogen for space heating is 13%, 11% and 23%, respectively. The share of heat pumps here is 66%, 70% and 30%, respectively. In Scenario 3A, the share of district heating for space heating increases to 64%, with renewables accounting for 39% and hydrogen for 23%.

(3) If we assume low H_2 prices of 7 ct/kWh for industrial customers and 9 ct/kWh for residential customers after 2035, an appreciable share (between 5% and 39% depending on the supply area) for space heating and domestic water heating is supplied by H2 boilers in a decentralised supply pathway. All pathways with high H2 use assume a massive expansion of infrastructures in the European and international area as well as low hydrogen prices for consumers. These assumptions, including a hydrogen backbone connection starting in 2030, are used in Scenarios 1, 3 and 3A, respectively. The national hydrogen quantities extrapolated for these scenarios increase to 350–610 TWh in 2035 as well as to 475–645 TWh in 2045 for locally generated heat (decentralised generation) as well as centrally generated heat (CHP and district heating). The demand for hydrogen from the extrapolation exceeds the defined uncertainty range of 140 to 440 TWh in Scenario 3A in 2035. In addition, the results of hydrogen use in space heating react in a very sensitive manner to the price assumptions in general, especially to the price difference between hydrogen and electricity.

(4) The mix of technologies in district and local heating includes the use of local sources by heat pumps, biomass and the use of hydrogen in CHP plants. The share of hydrogen-based generation depends on both local heating sources and the assumed hydrogen price. Even at higher hydrogen prices (Scenarios 2 and 3B), supply shares of up to 40% with hydrogen in district and local heating are cost-optimal if other supply options in district and local heating are limited, such as by a limited availability of heat sources. Another important role is to secure the thermal output by CHP or boilers powered or fired by hydrogen or synthetic derived products. Local renewable energy potentials, such as solar power, geothermal and surface water heat, also promote the use of heat pumps in district and local heating.

(5) The decarbonisation strategy of energy-consuming businesses is critical to the transformation pathway of the supply area when industrial demand for process heat significantly exceeds the demand for space heat. Compared to space heating, the ability to meet demand for process heat is characterised by higher shares of biomass, biogas and, depending on the scenario, direct electrification or hydro-

gen. The optimal supply technologies are highly specific to the process and require a more detailed analysis for implementation than possible in this study, especially with respect to the use of heat pumps for process heat at <200°C. The higher cost sensitivity in industry, and thus in areas with higher shares of process heat, shows that it is necessary to develop a reliable solution for supply options that can be planned over the longer term, especially for meeting demand for process heat, in order to minimise local risks.

(6) Assuming similar energy source and technology costs, the results are generally consistent with those of the major national energy system studies (type of technology, energy source, transformation speed) in Germany. In this context, the bottom-up perspective provides a wide range of additional insights into the characteristics and diversity of the transformation pathways.

(7) The total costs of the scenarios indicate small differences between the transformation pathways in each area and are characterised by the consumption costs. If one of the energy sources is in the high price trajectory or both are in the average one, the total costs increase; for this reason, the highest total costs are observed in Scenarios 2 and 3A. In Scenarios 1 and 3, the low hydrogen price leads to positive effects in total costs. This is further strengthened by lower investments in building refurbishment in Scenario 1.

(8) The differences in infrastructure costs (expansion of the electricity grid, conversion to H_2) between the scenarios are small compared to the total costs (and in turn the costs for the sources of energy, especially electricity and hydrogen).

(9) The path to 2030 is very similar in all scenarios and characterised by a strong ramp-up of photovoltaic and heat pump capacity to achieve the goals of the German Climate Protection Act. The energy source and heating technology transformation with an increase in electricity and heat pumps takes place in all sectors (that is, single-family homes, apartment buildings and applications for trade, commerce and services and district heating) in each scenario. The same applies to the start of the hydrogen ramp-up for industrial applications and central heat generation, which will be initiated by 2030.

Deductions

The bottom-up study shows the complexity of the heating market when viewed locally and the need for on-site analysis

(10) The bottom-up approach shows a complexity due to which sufficient resources for municipal heating planning and climate protection measures will be required. Investigations must be carried out for all supply areas across all existing infrastructures on a region-by-region basis. A one-size-fits-all solution does not exist for the heating market, as the range of possible combinations within the existing infrastructures, the existing renewable energy potentials, the building stock and consumer requirements for their heat supply is rather large.

(11) The high level of congruity in the scenarios in the phase leading up to 2030 should be used exhaustively to make all preparations for the decision regarding the distribution grid infrastructures that will supply the areas during this time. This includes developing municipal heating plans, informing building owners about the available options, establishing a commitment for expansion, conversion or dismantling. This creates space and time for broad acceptance in society, as well as the opportunity for participation in finding local solutions.

(12) Municipal heat planning is a central instrument for addressing local conditions and, in turn, relevant factors influencing the heat market. In the preparation of municipal heating plans, a uniform framework for technical (such as development of annual performance factors, temperature levels and CO_2 emission factors for the various energy sources) and economic conditions (such as development of energy source prices, technology and infrastructure costs) that are included in the calculation of decentralised heat production costs should be set as standards and regularly updated. In this context, it makes sense to consider ranges that reflect uncertainties.

(13) Transformation pathways must include all major technologies – heat pumps based on electricity from renewable energy sources, district heating, geothermal, solar thermal, biomass and non-avoidable waste heat, water/wastewater heat as well as H_2-based electricity and heat generators – as possible solution options. In doing so, the best possible solutions for the locally/regionally very different supply tasks based on local/regional availabilities and grid topologies can be found, taking into account all aspects.

(14) At this stage, when it comes to introducing mandatory municipal heat plans, no technology options should be excluded. In particular, the concerns of industrial and commercial businesses relying on process heat and, in some cases, on process gases should be taken into consideration, especially when considering infrastructure development at an early stage.

(15) The solution space for transforming the heating sector is largely determined by the required temperature levels of heat demand and the availability of local heat sources. Therefore, it is essential that we have accurate information about these conditions, and the appropriate resources (both financial and human) in a municipal heat planning effort should be provided in order to ensure that the necessary data is collected. In addition, we also need a standardised procedure for surveying heat demand, existing plants, potentials for plants using renewable energy sources and waste heat potentials in order to ensure a reliable basis for municipal heat planning.

Bundle of technology options needed for successful heat transition – main solutions: heat pumps, heat grids, heat from renewable sources and hydrogen

(16) The primary decarbonisation strategy in space heating in all supply areas by 2030 is the expansion of heat pumps, but also in the long term by 2045. More consumers need to be connected to district heating in densely populated areas. The development of sufficient planning, installation and production capacities is essential.

(17) The use of hydrogen ensures the achievement of long-term climate targets (after 2030) in industry and power generation (district heating). Low hydrogen prices for consumers will expand the solution space for household decarbonisation, if market development leads to this case. The scenarios show that hydrogen prices for consumers should be no more than half the electricity prices for consumers to enable the economic attractiveness of hydrogen deployment in decentralised space heating. In addition to the ramp-up of the generation market, it is critical to expand and rebuild the necessary infrastructures, while taking a proactive approach.

Integrated supply infrastructures must be further developed and an efficient H_2 backbone with downstream hydrogen infrastructures for the relevant applications must be established

(18) Once municipal heat planning has been successfully carried out, adhering to suitable regulatory requirements, an implementation commitment at the municipal level must be established for a successful heating transition. If this does not occur, conflicts of interest and other legal obligations, such as ensuring security of supply for all consumers, could lead to the municipal heat transition becoming unnecessarily more expensive, slowed down or prevented.

(19) Interaction with the development plans of a national and European hydrogen infrastructure must be established in the development of the regional supply infrastructure for implementation at the municipal level. To this end, a mandatory prerequisite is the development of an efficient H_2 backbone and downstream hydrogen infrastructures for the relevant applications.

(20) In the context of municipal heat planning, the future local supply task of the distribution grids must be adapted or they need to be described. Once this supply task is concluded, the local distribution grid infrastructures should be developed or transformed. In this context, repurposing and decommissioning of existing lines as well as adaptation of the grid topology should be examined in the context of the transformation of the gas distribution grids. A regulatory framework for this still has to be created, in addition to the preparatory measures. The issue of transforming the gas grid and dealing with declining gas volumes has not yet been addressed in regulations. The energy demand of local industrial and commercial businesses needs to be assessed, especially where they have a large share in the local demand for heating. A direct dialogue between suppliers, municipalities and companies is necessary to align the decarbonisation strategies of the businesses with municipal heat planning and the transformation or strengthening of both gas and electricity distribution grids.