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Reaching the climate protection targets for the heat supply of the German residential building stock: How and how fast?

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ABSTRACT

Scenario analysis of energy consumption in the German residential building stock for heating and hot water supply was carried out. It focused on how national long-term climate protection targets – a reduction of CO_2 emissions by 80%–95% until 2050 – can be reached. Available technologies of energy saving and efficient and renewable energy supply were examined. Special attention was paid to the necessary dynamics, assuming that improving insulation and heat supply of the complete building stock will be a difficult step-by-step process, taking a long period of time.

The results show that within the next 10 years (until 2025) continuous progress should be made to achieve a doubling of the annual rates of thermal building modernisation and a completely different structure of newly installed heating systems (moving away from boilers to heat pumps, cogeneration systems and solar systems). In addition, a long-term change of the structure of district heating and electric power generation (used for heat supply) towards a high share of renewable energy by 2050 will play an important role to meet the climate protection targets.

1. Introduction

1.1. Subject and basic assumptions

Germany's long-term climate protection target is defined as a reduction of greenhouse gas emissions by 80%–95% until 2050 compared to the year 1990 [1]. This target is analysed in this study from the perspective of heat supply (heating and domestic hot water) of residential buildings. It is obvious that such an ambitious level of emission reduction can only be achieved by far-reaching measures. From a technical point of view, building insulation and heat supply technologies are affected – the latter incorporating building systems themselves and the higher-level energy supply sector (e.g. electric heat pumps as well as related electricity production).

The first question to be answered is: How can the 2050 target be reached at all, that means: Which level of insulation and which structure of heat supply will be necessary in the German residential building sector? Much would be possible if fast development of new technologies was envisaged. But from a more precautious point of view, it appears plausible to look first at what one can achieve with measures which are already well known in practice. Hence, analysis is restricted to those technologies of building insulation and heat supply which are already more or less established in the market. This means that available building insulation measures (also high-level with more than average insulation layers or better than average window types) and common heat supply systems like gas, oil or biomass boilers, electric heat pumps, cogeneration systems (via district heating or small systems in the buildings) as well as accompanying solar systems with short-term storage are considered. In contrast technologies like deep geothermal energy or the long-term (seasonal) storage of thermal or electric energy (enabling high fractions of fluctuating solar and wind energy) are not envisaged. Those systems are in a very early stage of market development [2–4]. Accordingly, there are a lot of uncertainties about future potentials and costs.

Getting into greater detail, one will soon find that maintaining the long-term climate protection targets with available technologies is not an easy task because there are a number of restrictions which limit the range of all single measures: Even though there are certainly high energy saving potentials in the German residential building stock, it will not be realistic to assume that all buildings could be refurbished to a passive house standard. Forward-looking energy generation systems like heat pumps and cogeneration systems (combined heat and power: CHP) may be introduced, but for practical and economic reasons they often cannot stand alone but have to be accompanied by boilers which cover the peak load.

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Moreover, they can improve the efficiency of fossil fuel use to a certain extent but they are not CO_2-free (e.g. because electricity from fossil fuel plants is used in electric heat pumps). Biomass as a renewable energy source is an alternative to fossil fuels, but its potential in Germany is very much limited. Solar energy (solar thermal or photovoltaics) and wind energy might fill that gap to a certain degree, but these are fluctuating energy sources, and without long-term storage they can only partly contribute to building heat supply (solar thermal systems directly, photovoltaics and wind energy mainly via electric heat pumps).

Against that background, one major intention of this paper is to have a general look at the existing options and restrictions. The scope for reaching the climate protection targets in 2050 with available technologies will be described to provide better orientation for developing climate protection strategies.

The year 2050 is still more than three decades away, but in view of the required far-reaching transformation process this period of time appears rather short. So the second basic question to be answered is: How fast must insulation and heat supply be upgraded? How must the existing dynamics be accelerated before it might be too late to reach the targets?

Again, a cautious perspective is taken: It is assumed that reaching the ambitious targets will need long-term continuous development. Progress will not be made instantly, but through a step-by-step acceleration of building insulation and introduction of better energy supply technologies. Even if there are examples of very fast structural changes which affect the whole society (e.g. today's information technologies) it is very questionable whether such dynamics can be achieved for the energy saving and climate protection measures in the building sector: Investment costs of building insulation and new heating systems are relatively high compared to other goods. Investment decisions have to be taken by a large number of building owners with very different financial powers and economic benefits. This is often linked to the question whether energy saving measures can be combined with necessary renovation measures at a distinct building. Past experiences suggest that climate protection in the residential building stock is a tough and slow-moving process: While the challenge of climate protection and necessary measures have been widely discussed at least since 1990 [5,6], the progress which has been achieved to date, as can be examined in a 2010 survey [7], does not reflect the state of knowledge of the requirements.

The general question of climate protection measures and strategies is of course still very complex and not all relevant aspects can be addressed in this article. In reality, many barriers would have to be overcome to implement measures in practice. Costs and economic viability surely would play a predominant role, but also a lot of other technical, social or political obstacles would occur (e.g. conflicts around sharing burden of climate protection costs between landlords and tenants). These aspects cannot be discussed in this paper. However, by restricting the considerations to already available measures and neglecting technologies which have not yet entered the market, an economic point of view is at least implicitly included.

Furthermore, it has to be noted that the issue of greenhouse gas emissions caused by the heat supply of residential buildings is only a part of the problem. There are interrelations with other sectors (non-residential buildings, traffic, industry) which can also not be discussed in detail. Also assessing the global warming potentials of the fuels applied is a complex problem in principle, raising detailed questions (e.g. see [8] for the biomass case) which cannot be discussed in this article. The results here are mainly based on direct CO_2 emissions. Upstream emissions of supplying the fuels (including biomass) are also considered on the basis of current values; that means not taking into account possible future changes.

A further simplification is made by looking at the energy use of buildings for heat supply only; that means at the utilisation phase of the building and its components and systems, not considering the energy input and the emissions caused by the construction and deconstruction of building materials and heat supply systems. However, it is worth noting that to include those contributions in a broader view of life cycle analysis would on the one hand probably make target achievement more difficult or delay it (because better insulation and more complex energy supply systems increase material input). But on the other hand embodied energy and related emissions are not generally undermining the benefits of typical measures of energy efficiency or renewable energy supply. This is shown by several studies, e.g. the following for thermal insulation materials [9], energy saving building concepts [10,11] and renewable energy supply systems [12,13].

Altogether it can be stated that against the background of a high complex problem simplifying the research approach is necessary and not all questions of interest can be answered. But this does not affect the actual scope of this article which seeks to provide a general idea of how the ambitious climate protection targets can be reached at all with available technologies and measures.

1.2. Complementing previous scenario studies

The investigation in this paper is mainly built upon model development and analysis which was carried out in three consecutive European and national projects [14–17]. In these studies more detailed information of the applied modelling approach can be found.

There are also several recent studies dealing with scenario analysis of energy saving and climate protection in Germany with reference to the perspective by 2050 which are also considering or focused on the building stock. Studies about the German energy sector as a whole [18–24] also include models for estimating the development of energy demand of buildings, usually without going very much into detail. In contrast, studies which are focused on the building sector [4,25–28] mostly do not explicitly consider the energy sector but describe it with general figures (e.g. development of CO_2 emissions per kilowatt-hour of electricity produced). The paper available here can be counted towards the second type, with an explicit (but still simple) consideration of the energy sector.

As a common result of the studies available it can roughly be stated that with different weighting all postulate the necessity of both increased effort in building insulation as well as a far-reaching change of the heat supply technologies applied (accompanied by a restructuring of the energy sector). This will also be the outcome of the analysis described below and in the face of ambitious climate protection targets this is on the one hand not surprising. On the other hand, when looking at the details, the problem is very complex and it is not easy to obtain a clear picture of the existing options, restrictions and requirements according to many assumptions and influencing factors even in a single scenario study. Against that background it is intended to complement the existing work by exploring two key aspects in this paper:

- Analysis of the year 2050 is a systematic approach introducing a new scheme to discuss the options and restrictions of the different measures and technologies of CO_2 reduction ("how?"). It aims at simplification to get – at the same time – a rough but complete and illustrative picture of the existing scope.
- Analysis of the time period until 2050, exemplified through three target-oriented scenarios, aims at deriving conclusions for actions necessary in the near future by asking when the postulated transition progress must start and how it must develop without losing sight of the targets ("how fast?").

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