Towards a climate-compatible building stock

Updated version with analysis of the Coalition Agreement of 2021

Jürgen Schnieders, Wolfgang Feist, Benjamin Krick, Jan Steiger, Witta Ebel, March 2022

Contact person:

Jan Steiger
Passive House Institute
jan.steiger@passiv.de

outphit – Deep retrofits made faster, cheaper and more reliable

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Overview

The existing building stock plays a key role in the achievement of climate objectives. Above all, this area depends on storable energy sources (still predominantly fossil fuels) which leads to quite significant supply uncertainty, fluctuating costs and political dependence. Climate protection needs lead to the same requirements and the same measures as potential supply shortages to consistently and sustainably reduce the energy demand in the building stock.

Over half of the natural gas utilized in Germany is used solely for space heating. As a storable energy source, in particular, it offers many advantages because the seasonal energy demand arises in winter when the availability of renewable energy is low. Continued use of natural gas as a bridging technology seems appealing, but this is a risk factor that should not be underestimated. Relying on fossil energy cannot ensure with certainty that elementary basic needs such as sufficiently warm rooms will be met, and this constitutes a substantial cost factor in addition. If we wish to make our building stock resilient then this means reducing consumption; with consistent energy efficiency measures, this can be achieved in a sustainable and cost-effective way.

With the present provisions of the German building energy act GEG, it is neither possible to achieve adequate supply security, nor is it necessary for the climate neutrality of the building stock in Germany. The current political coalition has responded to this issue by formulating significantly more ambitious measures and coals in its coalition agreement.

However, this still won't be enough, especially if the efficiency measures (as we have observed so far) are not implemented to the intended extent and quality, or if the proposed expansion of renewable energy use is further delayed. As our study shows, the energy transition in the building sector will succeed if the focus is more consistently placed on the energy efficiency of the buildings themselves: this unneeded energy will no longer have to be obtained and neither will it have to be replaced with renewable energy. This will lead to the independence of politics and consumers and will make buildings resilient. Heating energy is particularly affected because it accounts for a major share of the energy demand in buildings and requires an energy source that is storable, or renewable energy that is shifted from the summer into the winter via storage facilities. Availability in the cold period would also be too low in the case of a renewable energy supply and a high level of efficiency. Additional losses and especially costs will be incurred due to the seasonal storage. Natural gas as a bridging technology is becoming increasingly uncertain, even with the option of switching to renewable gas later on.

In our study we will show that above all, it is a matter of using upcoming measures in the building for carrying out energy retrofits at the same time ("coupling principle"), and at a consistently high quality ("if you have to do it at all, do it right"). The additional investment will then be small, and it will be compensated for by the saved energy costs – that's climate protection not only at zero cost but also with additional profit. This opportunity can be used to undertake measures in addition, which can be implemented quickly as other "low hanging fruits", which will already accommodate dependencies and energy costs in the next winter.

Measures for increasing the energy efficiency of buildings using the Passive House and EnerPHit quality standards are most appropriate for reliably achieving climate goals as well as for supply security for containing costs. The expertise, experience, suitable products and procedures for this are already available. What counts now is good and comprehensible communication, competence/capacity of the trades, widespread acceptance and, where necessary, the right incentives – and especially the avoidance of false incentives. We will provide suggestions for optimisation of these measures in the short term. Mitigation of the social impact of rising energy costs has already been considered in the coalition agreement. Such measures must aim for a reduction in the energy demand instead of further subsidising energy consumption.

1 Introduction

The consequences of climate change can no longer be ignored [IPCC 2022]. Given the importance of this task, in the Paris Agreement countries across the world have already pledged to limit global warming to well under 2 °C and to aim for 1.5 °C. In order to reach this goal, net emission of greenhouse gases must be rapidly and drastically reduced. With unchanged emissions, the remaining budget for the goal of 1.5 °C would already be used up in the next 10 years – calculated from 2020 onwards (see [IPCC 2018]). Consistent with this, Fig. 1 shows that emissions must drop to zero in 20 to 30 years.

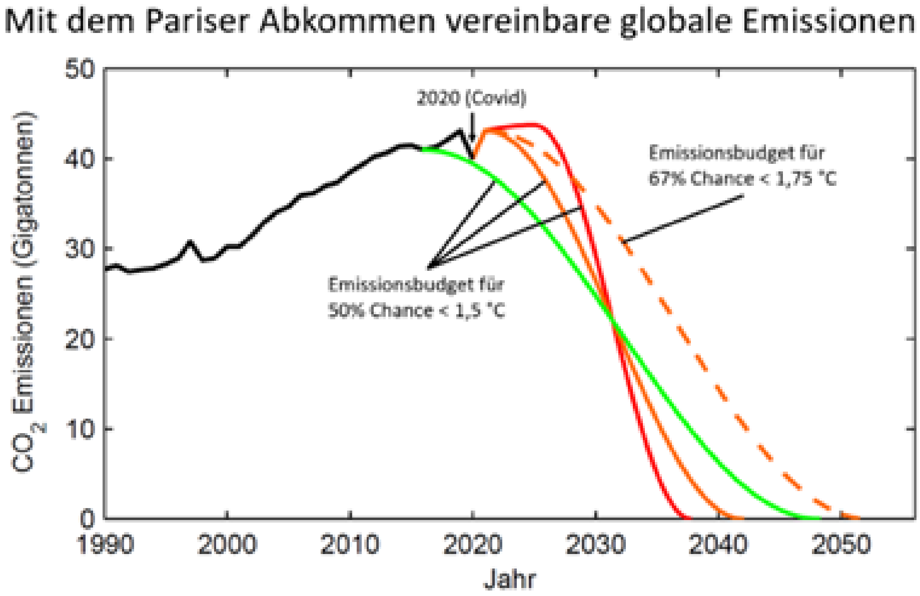


Fig. 1: In order to achieve the climate objectives of the Paris Agreement, CO_2 emissions must drop to zero by around 2040. Diagram from [Rahmstorf 2020].
Mit dem …. =Global emissions agreed in the Paris Agreement

Establishing a new energy supply system cannot happen overnight. If fast action is desired, it will be necessary to make changes on the demand side, in addition to suitable efficiency measures, to make fast action possible. Done properly, these will support the transformation to climate neutrality in the mid-term. With regard to the utilization of the huge potential, however, the building stock is a very slow-moving system, because many of the substantive changes are costly and time-consuming. At present, there are not enough specialists to renew the existing building stock within the space of a few years. It is already clear here that the goal mentioned above can only be achieved if climate protection as well as independence from the fossil energy supply are given the highest priority immediately.

In [Schnieders 2021], it was demonstrated that the German building energy act (GEG), which only came into effect in November 2020, is completely inadequate in this respect. It was also determined here that it is still possible to achieve this goal provided that resolute action is undertaken, and it will even be economically attractive.

The German federal government recently elected in Autumn 2021 has now promised in its coalition agreement [Koalition 2021] that there will be significant changes in the generation of renewable energy and the specification for energy efficiency of buildings. The following analysis shows that the measures adopted in the coalition agreement constitute a substantial improvement compared to the existing GEG and would in theory make it possible to supply the building stock in a climate-neutral way – but only under the condition of full implementation of the optimistic interpretation of the coalition agreement as used here. The climate protection objectives of the Paris Agreement can be achieved more reliably with a significant increase in energy efficiency. That would simultaneously be more economical and sustainable in the long term.

2 The coupling principle and quality of measures

Building stock is not a static parameter: non-functional or old windows are constantly being replaced (at a rate of approximately 2.7%/a), roof coverings are being replaced (approximately 1.5%/a), façades are re-plastered or re-painted (more than 2%/a). Each of these (and other) measures can be combined with an energy retrofit of the relevant building component – because at that time scaffolding for the construction site will already be needed anyway for example; exposure of the building component which will be necessary for the energy efficiency measure, and renewal of the respective weather protection cover will also be necessary in any case. Ever since the 1980s, in heat insulation ordinances, later on in the energy saving regulations, and today's building energy act, such occasions have been regarded as triggers for so-called "conditional measures". Corresponding thermally relevant improvement is then called for – in such a case, this will be exceptionally cost-effective [Kah 2008]. Of course, non-coupled measures are also acceptable, particularly if there is no reason for the coupling of measures. Above all, willingness and competence are needed here; especially short-term successes may then also be achieved here. In each case, particularly also for the legally formulated causes, it is very important that *deep retrofits are carried out to a highly efficient thermal quality,* as otherwise another retrofit in the same place usually wouldn't be realistic for many decades, and from the economic perspective its performance would be significantly less favorable. The result would be a lock-in effect which would block the energy transition, and make the achievement of the climate objectives impossible.

3 Climate-neutral building stock in Germany: Boundary conditions for the analysis

In order to identify how the climate objectives of the Paris Agreement can be achieved for the building sector, the building stock in Germany was modeled using the [districtPH 2021] tool. First, the selected boundary conditions will be explained in this section.

Different construction year categories, building sizes, and building uses as well as partial heating aspects are considered. In this model, total emissions to the amount of 214 Mt/a CO_2 result for heating and hot water in the year 2021.

When the carbon budget is applied to the building stock in Germany in accordance with Fig. 1, in order to achieve the target of 1.5 °C this sector may emit around 2,000 Mt of CO_2 in total from 2020 onwards. For the target of 2 °C, roughly 3,000 Mt of CO_2 would be permissible.

3.1 Energy costs

The electricity generation costs of renewable energy are now of a level similar to those of conventional power plants. Fig. 2 depicts this for various electricity generators in detail. While conventional power plants have electricity generation costs of around 12 cents/kWh, wind and PV are already somewhat cheaper. However, because intermediate storage of some of the renewable electricity will be necessary in the future assuming corresponding (market) penetration, this electricity will be just as expensive as conventional electricity at the time it is consumed. In the coming years, the demand for storage will increase, and the number of storage cycles will decrease, resulting in an increase in this cost addition.

Gas turbine power plants ("Gas") are indicated with significantly higher costs in Fig. 2. The reason for this is that these power plants are used for short-term, flexible application with an assumed operation duration of only 500 to 3,000 full load hours per year.

Of course, for the end-user, only a part of the electricity price comprises of the electricity generation costs, added to these are the costs for distribution, regulation in the power grid, marketing, charging and last but not least, also taxes. Although this does not play any significant role in the comparison between electricity generation variants, it does have an important role to play in the comparison of alternative options for end-users, such as district heating or solar collectors. If these parts are considered, on the whole it will be reasonable to apply largely stable electricity prices in the future for this study, regardless of the percentage of renewable energy.

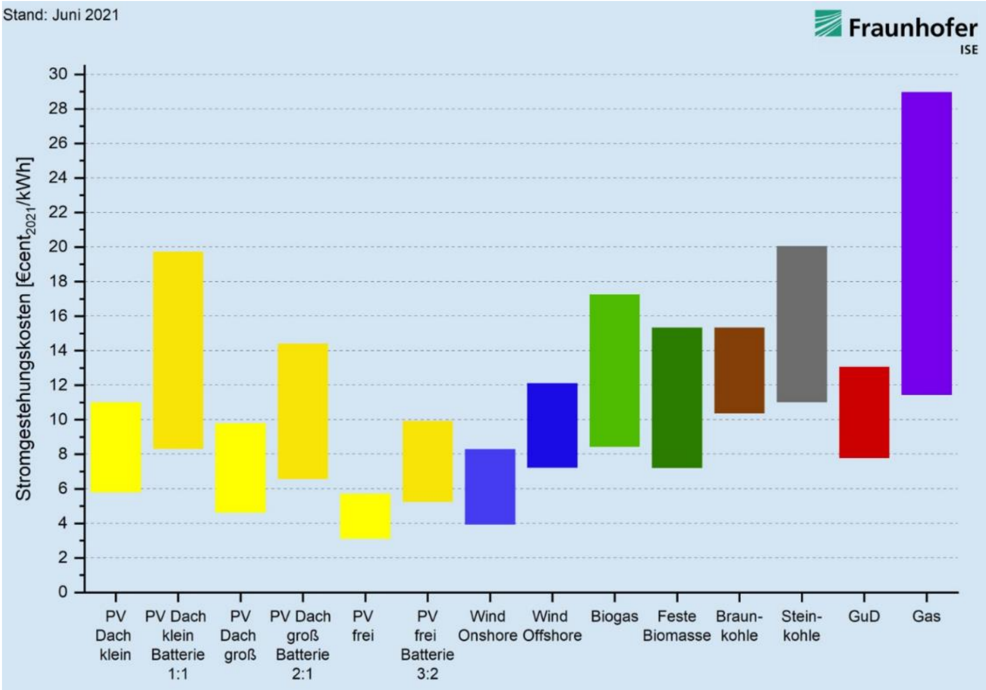
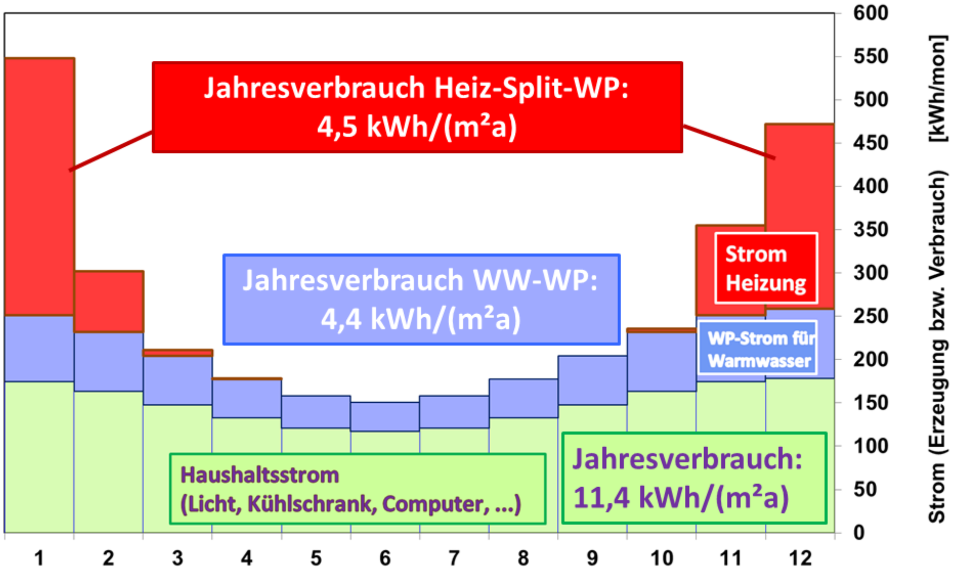


Fig. 2: Electricity generation costs in Germany in the middle of the year 2021. Chart taken from [Kost 2021].

In the model used here, the energy prices for the end-user in the future are influenced by the investments in peak-load power plants like the gas turbines and storage technologies mentioned above. These investments are necessary, especially in order to be able to cover the peak loads in winter for electricity consumption which is primarily caused by space heating, despite the low PV availability during this season (see Fig. 3). Accordingly, we will assume slightly higher electricity prices in winter: a kilowatt hour of electricity from the seasonal storage, assessed optimistically, costs 10 cents more. This naturally impacts the costs of heating electricity in particular (see Fig. 4).



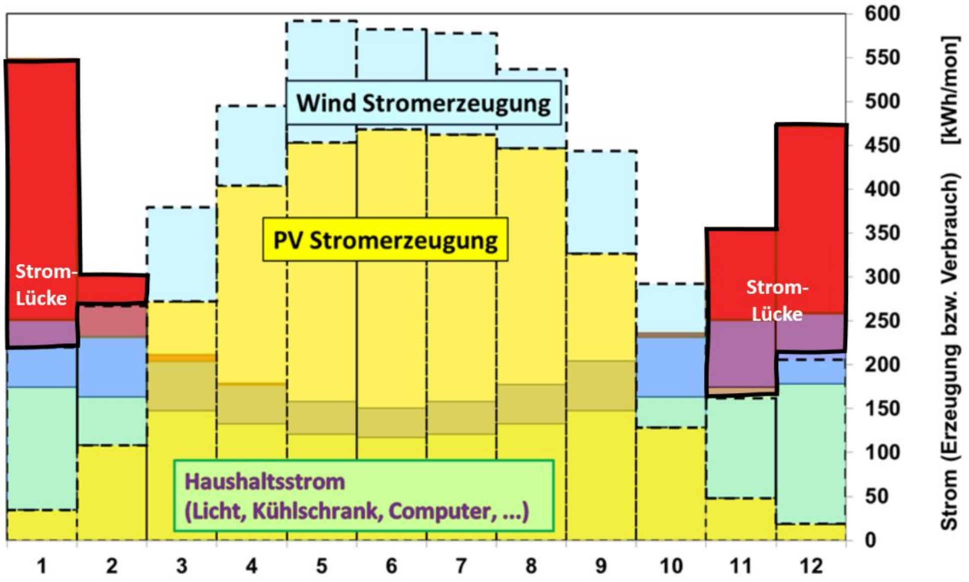


Fig. 3: Annual consumption of electricity for all energy applications in the Passive House in Darmstadt-Kranichstein (top) and potential coverage via PV and wind power (bottom). Even with this extremely efficient building, there is a gap between the availability and consumption in the winter; with poorer standards this gap is much larger. This can be closed by means of seasonal storage for surpluses in summer, but this generates storage losses and increased costs. Chart taken from [Feist 2021].

Strom (Erzeugung bzw. Verbrauch)=Electricity (generation and consumption), Strom lücke= gap in electricity generation, Strom Erzeugung=electricity generation, Haushaltsstrom…=domestic electricity (lighting, fridge, computer..), Jahresverbrauch=annual consumption. Heiz-split-WP=heating split HP

The average private consumer price for heating oil over the past 10 years was 7.08 cents/kWh, while that for gas was 6.91 cents/kWh (final energy). These prices are assumed to be constant as a base amount for the future fuel energy price. On top of this, there is initially only a gradual increase due to carbon pricing.

With the change to the Fuel Emissions Trading Act of November 2020 ([Bundesregierung 2020]), a carbon tax was introduced which set the CO_2 price to 25 €/t in January 2021. This price will be progressively raised to 55 €/t in 2025. In 2026 the CO_2 price will be between 55 and 65 €/t. According to [UBA 2018], the cost of environmental impacts of CO_2 emissions is 180 €/t, whereby newer analyses even mention significantly higher costs, particularly if the impacts on the welfare of future generations are equally considered ([UBA 2020]). 180 €/t should also roughly correspond to the future costs for CO_2 removal from the atmosphere ([IEA 2021]). Below it will be assumed for the development of the oil and gas prices that with a gradual increase, the CO_2 price of 180 €/t will be achieved in the year 2050.

According to [GEMIS 4.95], the CO_2 factor for heating oil is 319 g CO_{2eq}/kWh final energy and 250 g CO_{2eq}/kWh final energy for natural gas. Costs of environmental impacts of 5.75 cents/kWh for oil and 4.5 cents/kWh for gas will result if the mentioned price of 180 €/t is assumed. This results in a moderate further increase in fuel prices after 2026. Gradually decarbonized district heating and also biomass are similarly applied to the price development here ("applicable prices": in the future, to some extent, the district heating supply will need additional investment in heat sources with lower CO_2 emissions; to what extent these will be financially feasible here also depends on the "applicable price").

For the substitution of energy sources such as gas and oil with renewables (e.g. imported power-to-gas, power-to-liquid) the costs must be set even higher according to [Agora 2018], [Dena 2018], [ESYS 2017] and [ISE 2020] (see Table 1). We will omit that in this study. With the approaches applied here, buildings that are supplied with gas or oil, whatever the origin, are thus assessed rather favorably below in economic terms.

Table 1: Estimation of costs (cents/kWh) for the import of synthetic power-to-gas or power-to-liquid in the year 2050

Cents/kWh	Gas 2020	PtG 2050	PtL 2050	Remarks
[ISE 2020]	6	20	24	gross
[Agora 2018]	2.2	10		at the border
[Dena 2018]	1.9	9	12	without transport
[ESYS 2017]		10	10	with transport

Fig. 4 shows the chosen economic boundary conditions.

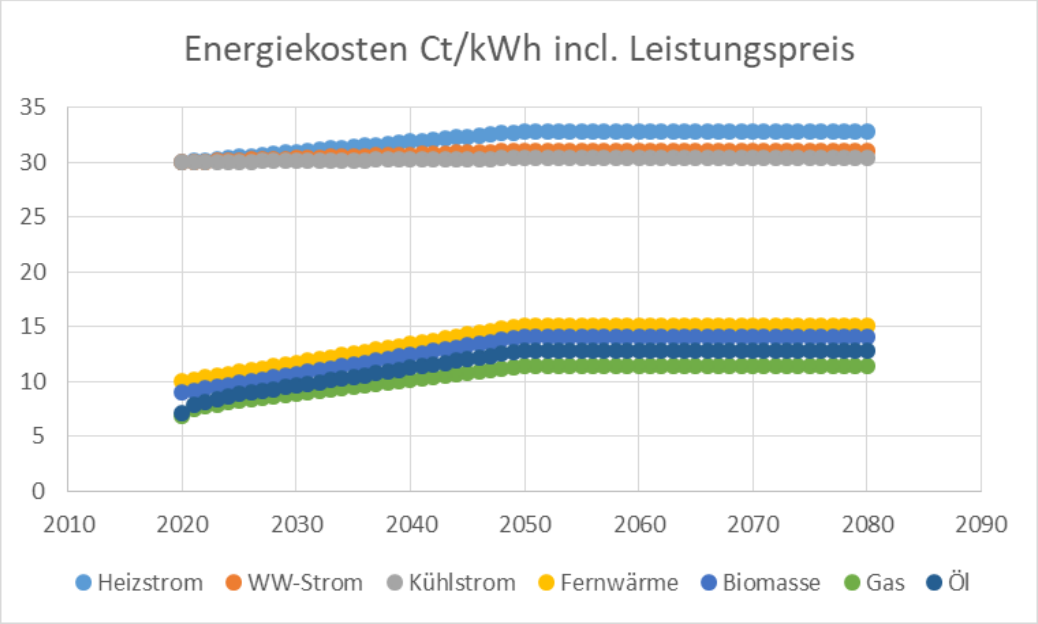


Fig. 4: Scenarios with the underlying progression of energy costs for end-users

Energiekosten incl. Leistungspreis…=energy costs .. including service price

3.2 Investment costs

For the arising construction costs, it must be considered that the costs for a specific measure usually consist of two components: business-as-usual costs/costs incurred anyway, which always arise in every case, e.g. when a roof has to be renewed or a window has to be replaced, and the additional costs for increased efficiency, for instance, an additional centimeter of thermal insulation, or the third glass pane in thermal insulating glazing.

In the calculations, only those costs are shown which might differ potentially between the scenarios, therefore these are not the total costs incurred for construction activity, especially in the case of new builds.

The following values were used for the building envelope components (not all intermediate values are stated):

	Business-as-usual costs/ costs incurred anyway	**Additional costs for efficiency**
Wall	250 €/m²$_{CA}$	1.80 €/m² per cm insulation, λ=0.035 W/(mK)
Roof	253 €/m² $_{CA}$	1.50 €/m² per cm insulation, λ=0.035 W/(mK)
Basement ceiling / floor slab	70 €/m² $_{CA}$	1.25 €/m² per cm insulation, λ=0.035 W/(mK)
Window	336 €/m² $_{CA}$	0 €/m² for U-value 1.2 W/(m²K) 81 €/m² for U- value 0.75 W/(m²K)
Entrance door	387 €/m² $_{CA}$	0 €/m² for U- value 2 W/(m²K) 49 €/m² for U- value 1 W/(m²K) 213 €/m² for U- value 0.5 W/(m²K)
Airtightness	26 €/m²$_{TFA}$	0 €/m² for n_{50} = 3 h^{-1} 4 €/m² for n_{50} = 1 h^{-1} 6 €/m² for n_{50} = 0.6 h^{-1}
Ventilation system	28 €/m²$_{TFA}$	0 €/m² for exhaust air system 30 €/m² for ventilation with 80% HRV

CA: component area; TFA: treated floor area, corresponds roughly to the living/useful area within the heated building envelope

The heat supply variants may possibly differ in the following costs:

	Per building	Per m² TFA	Per home	Service life
Gas boiler	9000	23		40
District heating connection	8500	12		50
Heat interface units for district heating			1200	30
Heat pump including geothermal probes etc.	10500	54		20
Heating distribution Radiators	2500	58		40
Heating distribution Underfloor heating	3000	72		50
Hot water system	1725	16		40

3.3 Renewable energy

Fig. 5 shows the planned expansion of all renewable energy generation in Germany per the 2021 coalition agreement.

According to this coalition agreement, the expansion of PV to 200 GW by 2030 is foreseen. It is assumed that the pace of expansion will be maintained initially in the coming decades. It is difficult to exactly quantify the PV potential in Germany, we have assumed 500 TWh/a here (see also [Wirth 2021]).

The following is planned for the expansion of offshore wind energy: 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045. 120 GW by 2030 is planned for onshore wind energy (see [Andreae 2021]). Altogether, 80% of the predicted electricity consumption of 680-750 TWh/a annually will be met through renewables by 2030. That would equate to electricity production of approximately 560 TWh/a, which roughly matches the mentioned expansion targets. The total wind energy potential is assessed with 681 TWh/a here (see [AEE 2021] for this).

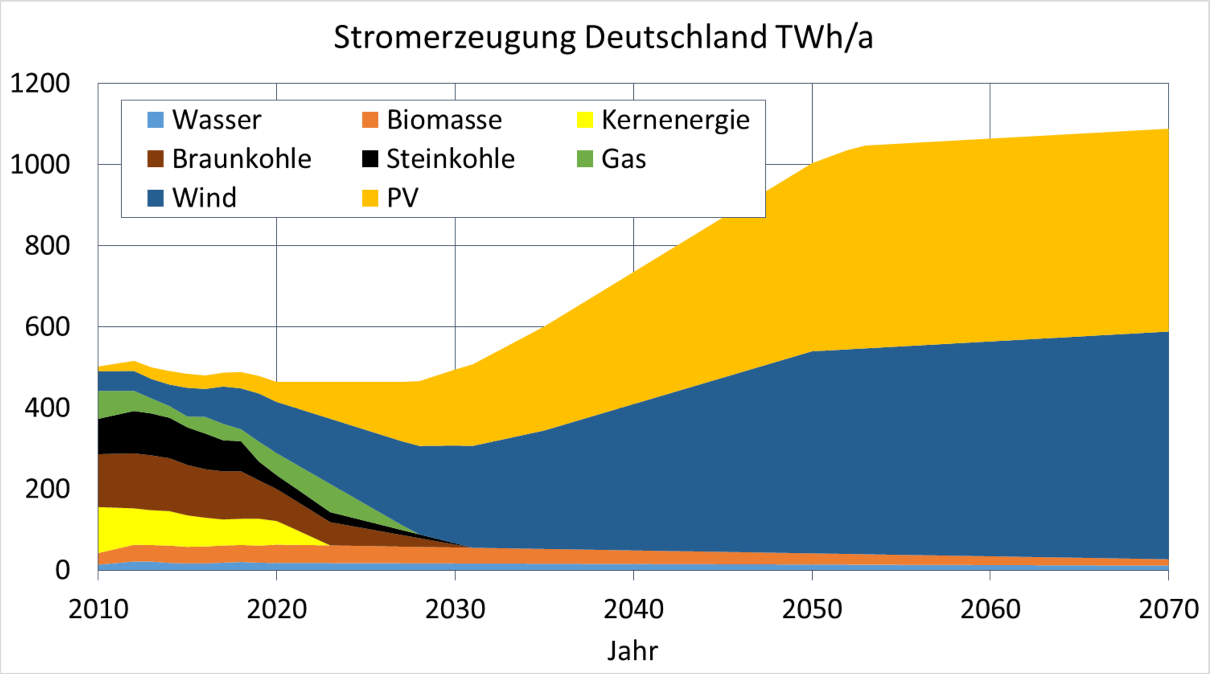


Fig. 5: Share of energy sources for electricity generation in Germany. Historically up to June 2021, then projection on the basis of expansion targets of the German government in accordance with the coalition agreement of 2021. The potential for all domestic renewable electricity generation is estimated to be approximately 1000 TWh/a.

Only part of this is available for heating and hot water generation. Based on the current situation, in which a third of the final energy consumption is used for low-temperature heat ([ISE 2020]), we assume that one-third of the renewable electricity generation shown here is available for heating and hot water. In the year 2070, this will be approximately 360 TWh/a of renewables for heating and hot water in the building sector.

In the model, renewable electricity is always used where the most CO_2 can be saved. This can be ascertained by employing CO_2 and PER factors (see Section 5.3 for evaluation using PER, Primary Energy Renewable). For example, if natural gas is replaced with renewable gas obtained through renewable energy (Power-to-Gas, synthetic methane), then 250 g CO_2 will be saved per kilowatt hour of natural gas and 1.75 kWh SNG will be required. This results in the following prioritization:

a) cooling
b) electrical generation of hot water (possibly with a heat pump)
c) electrical space heating (generally with a heat pump)
d) generation of district heat
e) generation of renewable gas and substitution of natural gas from fossil sources
f) generation of renewable fuel oil and substitution of fossil-based fuel oil
g) substitute for bioenergy

Consumed electricity which cannot be generated renewably continues to be provided from non-CO_2 sources in this model: initially with a power mix (including the current proportion of coal) with 692 g_{CO2}/kWh, reducing to 450 g_{CO2}/kWh for electricity from combined cycle power plants/CCPP by the end of the coal phase-out in 2030.

If more renewable electricity is available than is required, then 250 g_{CO2}/kWh will be credited for this in this paper, which corresponds to use as power-to-heat in place of a gas-fired boiler, e.g. an electrode boiler. Such applications require very low investment costs and are therefore suitable as a standard of comparison. Numerous other applications for saving CO_2 – or using the energy for the removal of CO_2 from the atmosphere – are conceivable with higher or lower CO_2 factors, so the credited amount can only serve as a guide.

3.4 Evaluation standards

Initially, CO_2 emissions are of relevance for a comparative evaluation of scenarios. These are calculated based on the depicted trajectory. With progressing decarbonization of the energy supply, a comparison based on this alone is no longer meaningful. The PER demand would then be a productive criterion for the compatibility and utilization of resources in a sustainable supply based on renewable energy. ([Grove-Smith 2021], [Passipedia 2021]). This indicates how much renewable energy has to be generated to meet the heat demand of the building, including the losses due to storage where seasonal storage is considered. As a third criterion, the costs incurred in each case are of importance for the feasibility and acceptance of the variants.

4 Scenarios for future performance

Several scenarios will be discussed below. These are not forecasts in the sense of predictions of the actual occurrences; instead, these scenarios show how actions taken today have an impact on future outcomes. This allows informed decisions to be made – without implying this from the outset. First, some simplifications can be made for this.

For example, in all of the scenarios presented here the impact of lowered requirements for buildings listed as historic monuments was not deducted (approximately 5% of residential buildings are classified as historical monuments, in whole or in part; it is still possible to achieve savings here also [Loga 2015]). Differences between the various courses of action are not influenced by this.

4.1 GEG scenario

In this scenario, which meanwhile has already become obsolete, we will determine the outcomes that can be expected under the regulations of the German building energy act GEG 2020. The main contribution to the emissions is made not by new builds but by the existing building stock with the present deep energy retrofit equivalent of about 1% per year. Although the actual renovation rate of exterior building components is in the range of 3%/a (see also above), retrofits are not always associated with thermally relevant improvements [Hörner 2021]. In this scenario, we will take this existing implementation deficit and update it: in 40% of the component retrofits, which inevitably take place at the end of the service life, the energy standard of the building component is not improved, while in the remaining cases renovation takes place to the statutory minimum standard ($U_{wall/roof}$ = 0.24 W/(m²K), U_{window} = 1.3 W/(m²K), no ventilation heat recovery, n_{50} = 3 h^{-1} etc.)

On account of the long periods under consideration, demolition (assumed: 0.5% of the respective stock) and new construction are considered. The number of building approvals in 2019 will be updated in the process.

For the heating technology, corresponding to newer empirical data for the building services (see [Hörner 2021]), oil-fired boilers are hardly installed anymore, while gas-fired boilers, biomass boilers, and electrical heat supply (after a renovation this is always a heat pump) are largely retained. District heating is currently converted to gas boilers by approximately 40%, this percentage is also updated in the scenario.

4.2 Scenarios for the 2021 coalition agreement

In the German coalition agreement of November 2021 key points were specified for future regulations relating to the building sector. This resulted in the following boundary conditions:

a) From 2025, only newly installed heat generators which can be operated with 65% renewable energy will be permissible. The concrete definition is still pending, we will assume that new generators in the ratio of 65% heat pump, 15% district heating, 20% biomass will be installed at the end of the service life of an oil or gas-fired boiler. In retrofits, the three last-mentioned energy sources will be retained in each case.[1]

b) Components corresponding with (efficiency class) EH 70 will be stipulated from 2024 onwards. For the EH 70, it is necessary that H'_T amounts to 85% of the value for reference buildings according to GEG, Appendix 1. This will result in the following average effective U-values:
    a. Exterior walls 0.24 W/(m²K)
    b. Roofs 0.17 W/(m²K)
    c. Building assemblies against the ground 0.3 W/(m²K)
    d. Windows (without thermal bridges) 1.1 W/(m²K)

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[1] Here we therefore assume that oil or gas fired boilers generally cannot meet the 65% renewables condition. In particular, this means that precisely heating with gas is not labelled as sustainable – the EU taxonomy does not actually provide for this either. However, the corresponding clarification of this fact on the part of the German coalition is still pending. If the coalition does continue to accept gas-fired boilers as a sustainable, permissible option in practice, then the boundary conditions chosen for the scenario here will no longer be applicable.

   e. Exterior doors 1.5 W/(m²K)
   f. Thermal bridge supplement/addition 0.0425 W/(m²K)

   Installation of ventilation systems with heat recovery does not take place, a n_{50} value of 3 h^{-1} is achieved in the long term.

c) First, we will examine a situation in which the same implementation deficit exists as in the scenario for GEG ("**KV (coalition agreement) 2021, 60% implementation**"). In contrast, in the scenario "**CA 2021, full implementation**" it is assumed that there are corresponding improvements of all components which need to be renovated in any case.

d) In the area of new constructions, EH 40 will become the standard, i.e. a H'_T value of 55% of the reference building will be achieved. A ventilation system with HRV is *not* stipulated (stipulated only for EH 40 Plus). We will therefore also stick with the n_{50} requirement of 3 h^{-1}.

e) The fact that building standards must only be improved from 2024/2025 onwards according to the coalition agreement will be disregarded here. Because of the long-time scales, the influence is small and a transitional period would be necessary even for alternative standards. However, this approach is also optimistic.

f) The heating systems in new builds will be selected in the same ratio of 65:15:20 electricity: district heating: biomass as after a retrofit.

For an improvement to result in comparison to the GEG scenario, it is of crucial importance that the requirement for H'_T remains in place. With the "renewable" heat generators already stipulated in the coalition agreement, the PE requirement alone would often already be met with the GEG 2020 standard (or close to this).

For new builds, a requirement for the area-specific heating energy demand is more effective than the H'_T requirement. This will have the advantage that favorable orientations and cubatures which reduce the energy demand have a positive impact on the verification, and costs and use of grey energy will be reduced as a result.

4.3 Scenario for EnerPHit/Passive House standards

EnerPHit is short for "**ener**gy retrofits using **P**assive **H**ouse components **i**n exis**t**ing buildings". This can also be carried out in a staged process where necessary in case of replacement or repair of building assemblies. More details on this can be found in [Passipedia 2021a].

In this scenario, the focus is on Passive House quality whenever a component needs to be renewed anyway. In terms of implementation speed, this variant, therefore, corresponds to the scenario for the 2021 coalition agreement, an implementation deficit is not assumed here. For this scenario, new construction takes place to the Passive House Standard. These measures are already cost-effective in themselves (see [AK 55]).

The good quality of the building envelope facilitates the transition to electric heat pumps as the heating system, both in the individual case (smaller heating load, lower necessary forward flow temperature, and therefore lower investment) as well as in regard to the network and generation capacities. For this reason, heat pumps have a higher share in heating system renewal here: when a heating system based on gas, oil, or biomass is renewed, heat pumps are used in 90% of the cases, while district heating connection is used in 10% of the cases. As a consequence, in the year 2070, almost two-thirds of heat generation (concerning the final energy demand) will rely on electric heat pumps, with district heating accounting for the rest.

As a further improvement compared to the coalition agreement scenario, it is necessary to mention the more efficient hot water generation that is foreseen here. With a heat pump-based supply system, decentral heat pumps will be used, while heat interface units will reduce the distribution losses of a district heating-based supply system.

4.4 Scenario CA 2021, accelerated

Here, the renewal rate for all components which do not have the necessary level of efficiency will be accelerated over the coming 10 years in such a way that they are already improved after half of their service life rather than at the end of their service life. In this way, a complete deep retrofit of the existing building stock will already be achieved by 2050.

4.5 Scenario CA 2021, only HP/DH

For the reference case of the 2021 coalition agreement, heat supply will take place with bioenergy in part. However, bioenergy is particularly suitable for closing the gap between generation and demand on account of its natural storage capacity. At the same time, its availability is limited to an even greater extent than PV or wind power for example. Valuable bioenergy can be used most efficiently in CHP plants, particularly at times when electricity from renewables or short-term storage is not available.

Similarly, to the scenario for the EnerPHit/Passive House standards, it will therefore be examined what effects the boundary conditions of the coalition agreement will have if heat supply takes place with *direct* utilization of bioenergy (see [UBA 2022]).

4.6 Scenarios with slower expansion of renewable energies

It is not guaranteed at all that the ambitious trajectory for renewable energies can be implemented as planned in the coalition agreement or that the assumed percentage of renewables will be available for space heating and hot water generation. The two scenarios **CA 2021, full implementation, 50% RE** and **EnerPHit/Passive House, 50% RE** were therefore calculated as a sensitivity study, in which only half the renewable energy is available in each case.

5 Comparison of results

5.1 Heating energy demand

As Fig. 6 shows, in the EnerPHit case, the heating energy demand declines slowly but in a sustained manner. Up to 2045, the value is halved, from 2070 a saturation of the initial value is reached at approximately 25% if no further technical progress is achieved. In the past, there has always been such progress, and it is also already foreseeable for the future. We will therefore remain significantly on the safe side here, particularly for the time after approximately 2035. In other words: in this case, the future looks even more favorable in reality. Nevertheless, it is also clear that unless importance is attached to improved efficiency specifically, such progress cannot be achieved on a large scale.

In the GEG scenario in comparison, a completely insufficient reduction is recognizable. By contrast, the scenarios for the coalition agreement already represent a considerable improvement; here the heating energy demand also goes down, although not as strongly as in the EnerPHit-scenario. The reason for this lies mainly in the clearly too-weak EH 70 standards for existing buildings. The new builds in accordance with EH 40 are also less efficient than in the EnerPHit/Passive House case, due mostly to a lack of mechanical ventilation with heat recovery and the poorer level of air tightness.

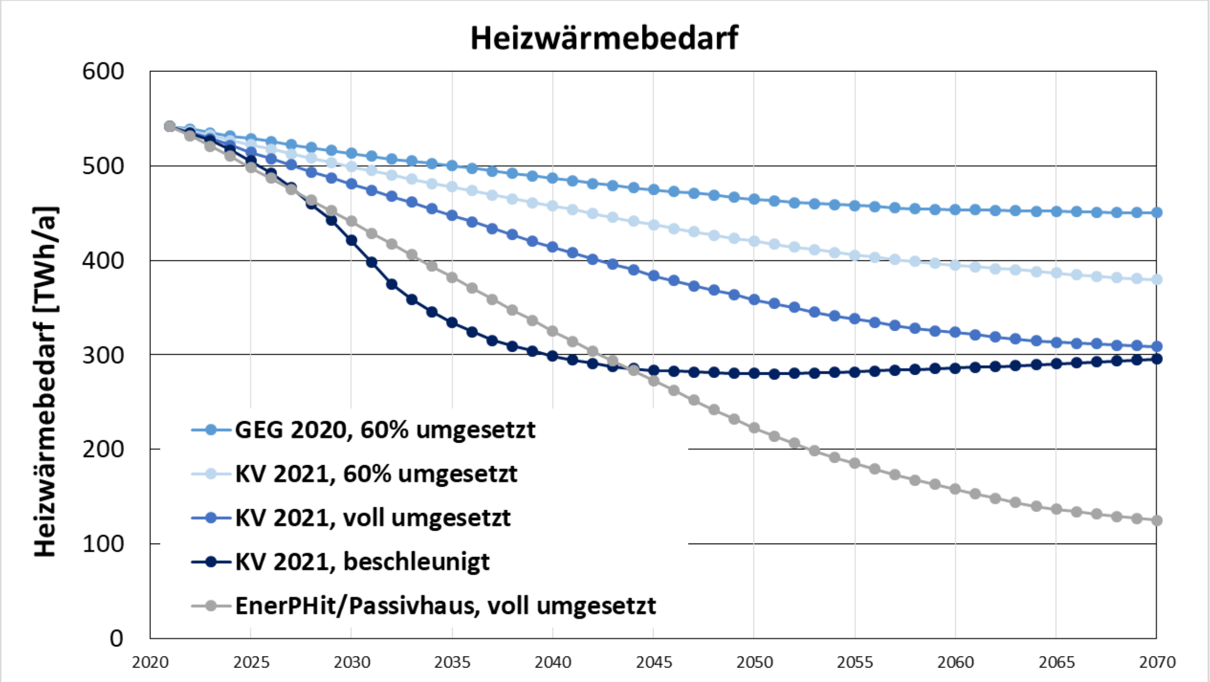


Fig. 6: Heating energy demand in the scenarios studied. With the EnerPHit/Passive House scenario, a 75% reduction of the demand is possible by 2070 The targets decided in the coalition agreement lead to a smaller reduction, whereby the implementation speeds differ considerably depending on the scenario. KV=CA, umgesetzt=implementation, beschleunigt=accelerated, voll umgesetzt=full implementation, Passsivhaus=Passive House, Heizwärmebedarf=heating energy demand

At this point it must be noted that all results inevitably have certain accuracy limits; these can be estimated to be around ±50 TWh/a here, whereby the differences between the scenarios are only around half of this since they are determined under otherwise constant boundary conditions (ceteris paribus).

5.2 CO_2 emissions

The significantly accelerated expansion of renewable energies compared to earlier strategies leads to an almost climate-neutral building stock being achieved from approximately 2050 onwards (Fig. 7) in all examined cases except for the GEG scenario. In combination with Fig. 8, it is apparent that:

a) Compared to previous statutory requirements, improvements are foreseen with which the envisaged objectives can be achieved in theory (compare **GEG 2020** with the other variants).

b) The consistent implementation of improvements with every renovation that is carried out is crucial to reducing greenhouse gas emissions (compare **CA 2021, 60% implementation** with **Ca 2021, full implementation**).

c) The small CO_2 factor of biomass (20 g/kWh) contributes to this result to some extent; however, even in relation to the entire energy system, this does not acknowledge the fact that biomass is a scarce resource with many other fields of application, see also Section 5.3. Replacing the fuel consumed in the biomass boiler with other renewable energies is very inefficient; an electricity surplus will result and negative CO_2 emissions will become possible only if bioenergy is not used in the base load (compare **CA 2021, full implementation** with **CA 2021, only HP/DH**).

d) The **EnerPHit/Passive House** variant reaches climate neutrality a few years earlier. After that, less energy will be consumed in the building sector than the amount of renewable energy available for this purpose. The emissions become negative: CO_2 can be retrieved from the atmosphere using surplus energy.

e) Due to shortened renovation cycles in the **CA 2021, accelerated** variant, emissions can be reduced faster in theory, however, the practicability of this is highly debatable (see below).

f) It is not unlikely that in 2050 and later, less renewable energies will be available for low-temperature heat in the building sector than previously estimated, e.g. because the expansion of renewables could not be implemented to the desired extent and larger percentages are consumed in other sectors. For this reason, the maximum possible efficiency must already be achieved today at every opportunity. With 50% renewables available, climate neutrality will only be reached with the EnerPHit/Passive House variant.

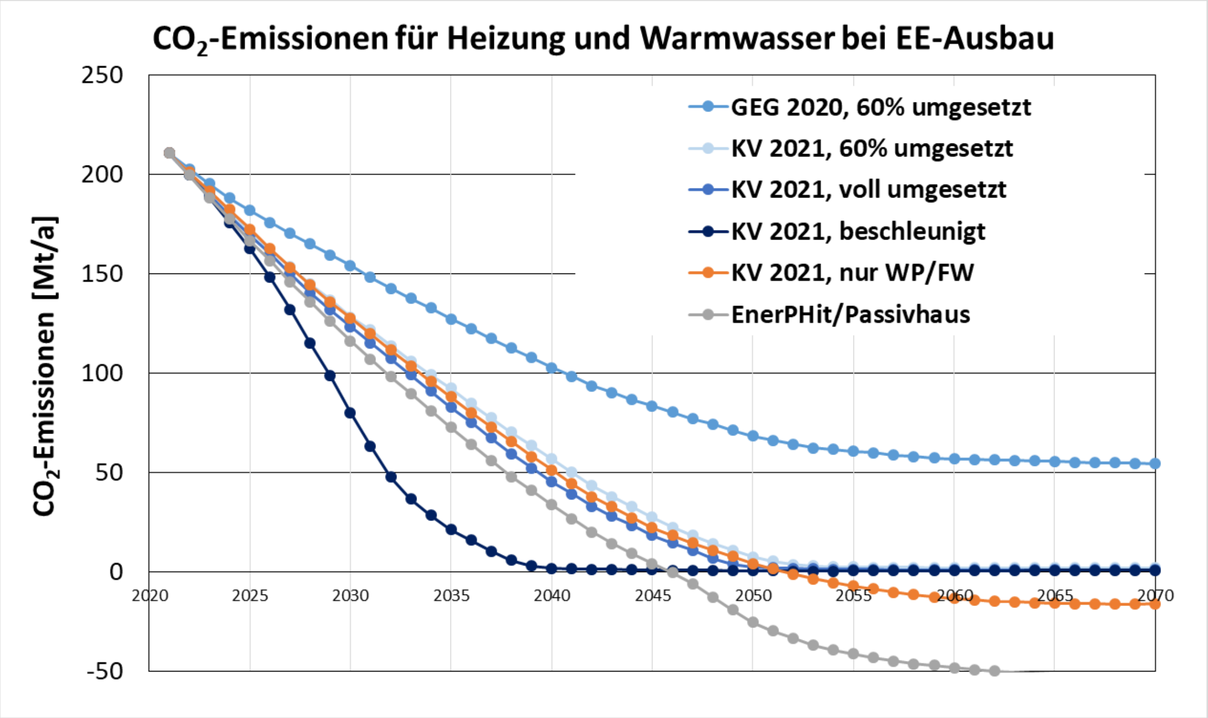


Fig. 7: Development of CO_2 emissions in the studied scenarios
CO_2-Emissionen für Heizung…= CO_2 emissions for heating and hot water with the expansion of RE, nur WP/FW=only HP/DH

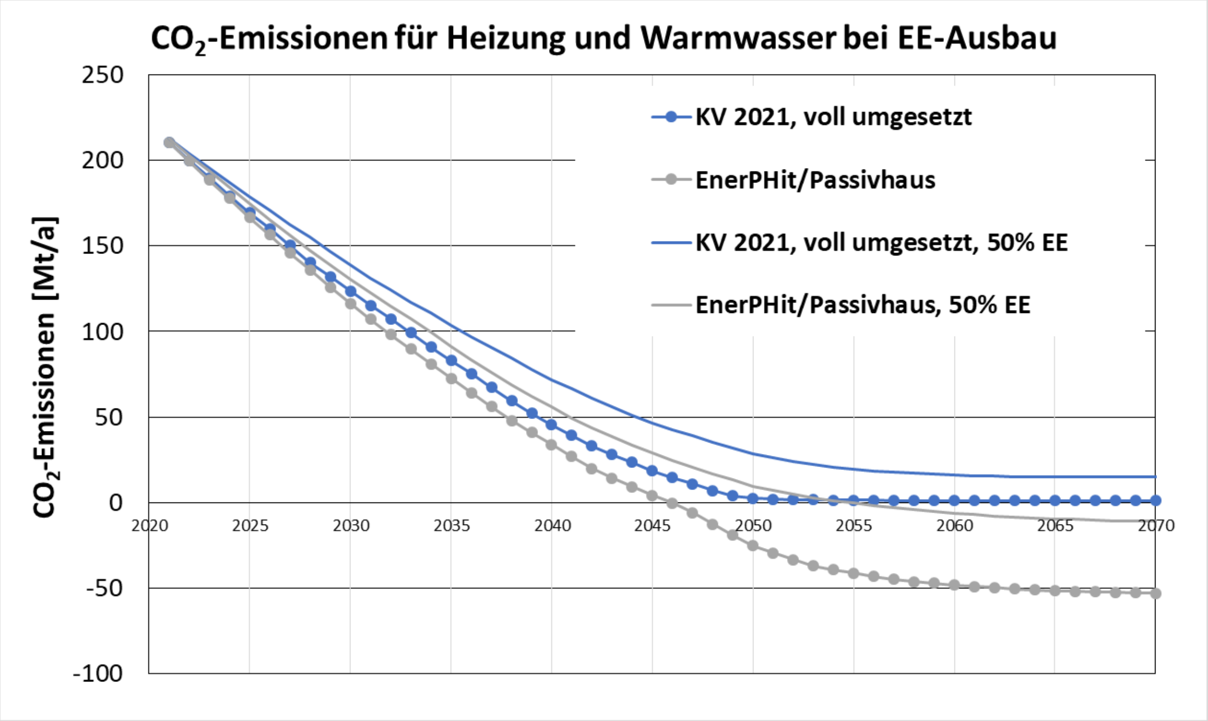


Fig. 8: Development of CO_2 emissions in the studied scenarios with 50% renewable energy availability

The cumulated CO_2 emissions for heating and hot water over the next 50 years convey the same message (Fig. 9). The target of 1.5 °C will only be achieved in two of the scenarios (**EnerPHit/Passive House** and **CA 2021, accelerated**). However, if rapid expansion of renewable energy succeeds, the results (except for the case of **GEG 2020, 60% implementation**) will still be compatible with the 2 °C targets for maximum global warming of the Paris Agreement.

In the long term, measures will likely have to be undertaken for reducing the excessive CO_2 content in the atmosphere. In the EnerPHit scenario, there is scope for this from approximately 2050 onwards due to renewable energy surpluses that will become available due to this.

A high level of efficiency at the Passive House level demonstrates its advantages here. Except for the unrealistic "accelerated" scenario, the lowest emissions over the next 50 years can be achieved with this. Even if the expansion of renewable energies were to progress more slowly, an acceptable outcome will still be achieved with this.

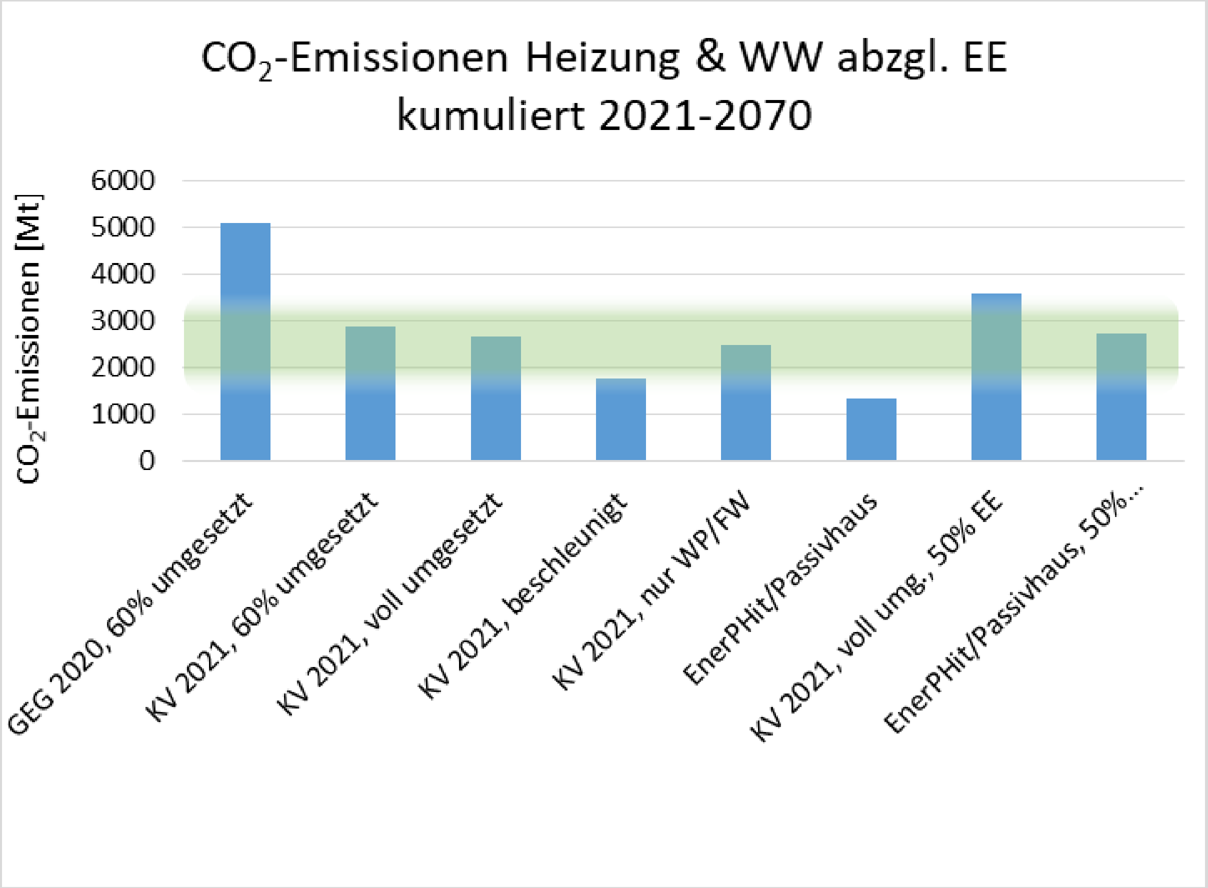


Fig. 9: Total CO_2 emissions from 2021 till 2070. The green band indicates the greenhouse gas budget that is still available (1.5° to 2° global warming).

Fig. 10 and Fig. 11 show how CO_2 emissions are allocated to different energy sources. A large proportion of gas heating remains with the GEG variant, which will still have to be covered almost completely through fossil sources in 2070 – despite the massive expansion of renewable energies. Incidentally, the same would still apply if natural gas heating was classified as "sustainable" (contrary to physical facts) by politics. The EnerPHit variant at the other end of the scale in contrast would still release relevant reserves in around 2050, which can be used for other purposes – for example for the likely case that 100% implementation is not achieved.

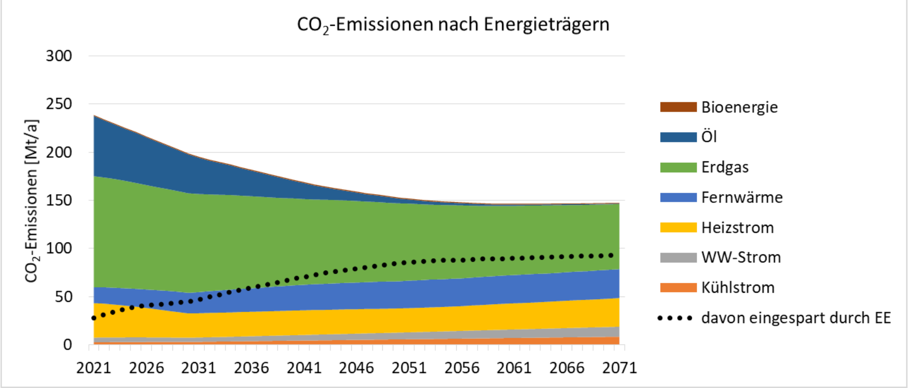
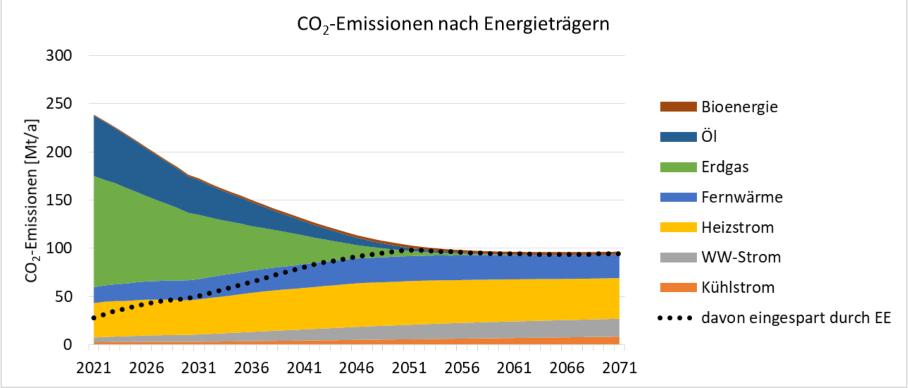
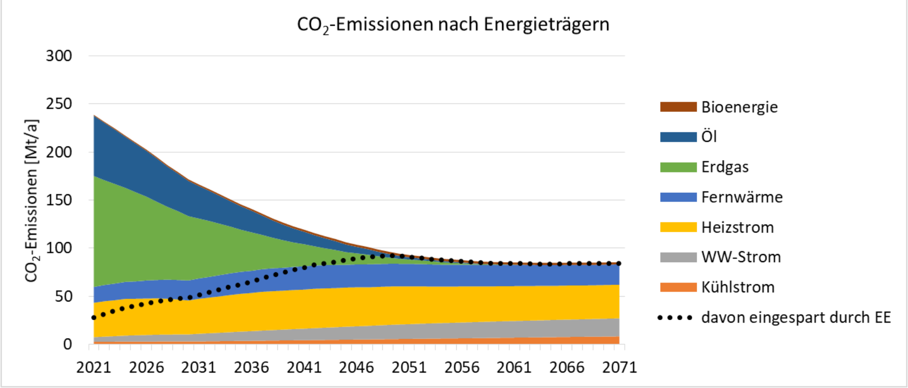
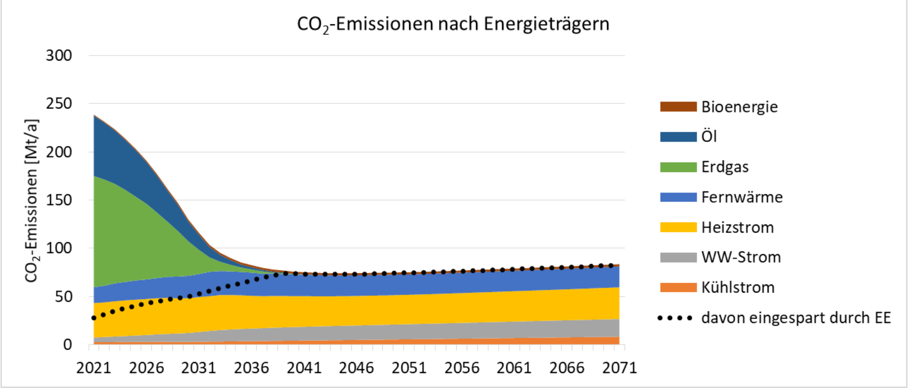
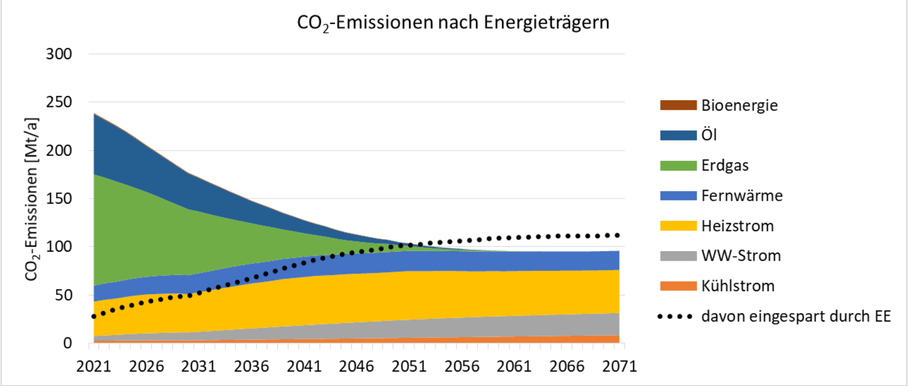
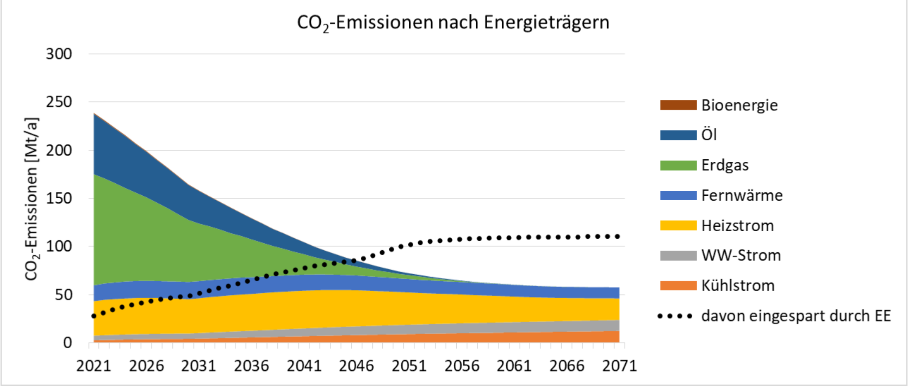
	GEG 2020, 60% implementation
	CA 2021, 60% implementation
	CA 2021, full implementation
	CA 2021, accelerated

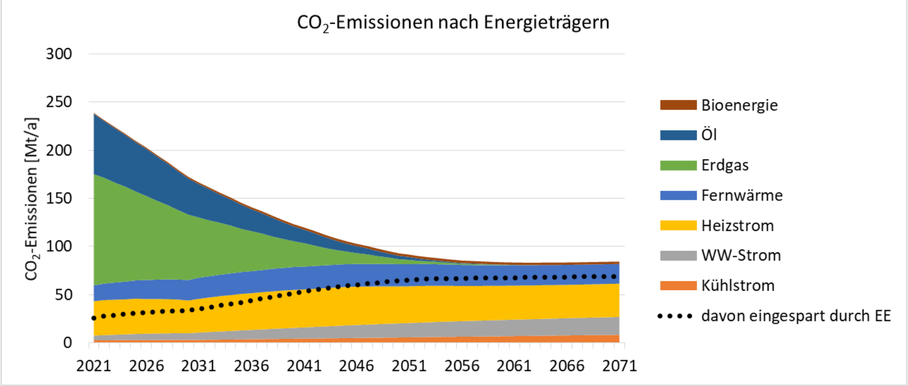
Fig. 10: Make-up of CO_2 emissions for the first four cases



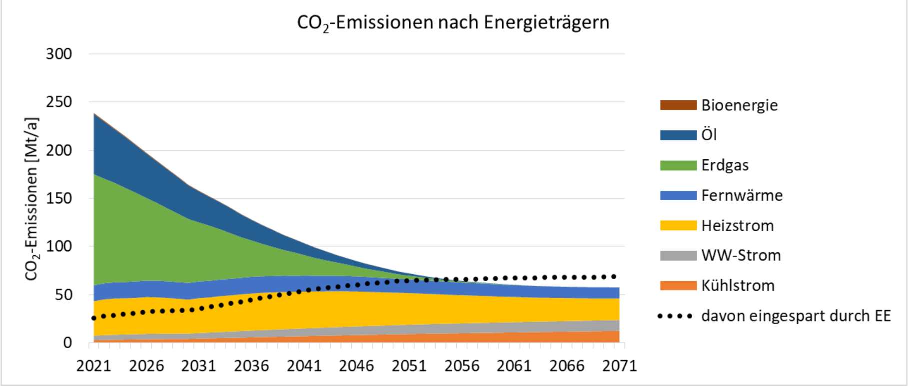
CA 2021,
only HP/DH



EnerPHit /
Passive House



CA 2021,
full
implementation,
50% RE



EnerPHit / Passive
House,
50% RE

Fig. 11: Make-up of CO_2 emissions for the last four cases

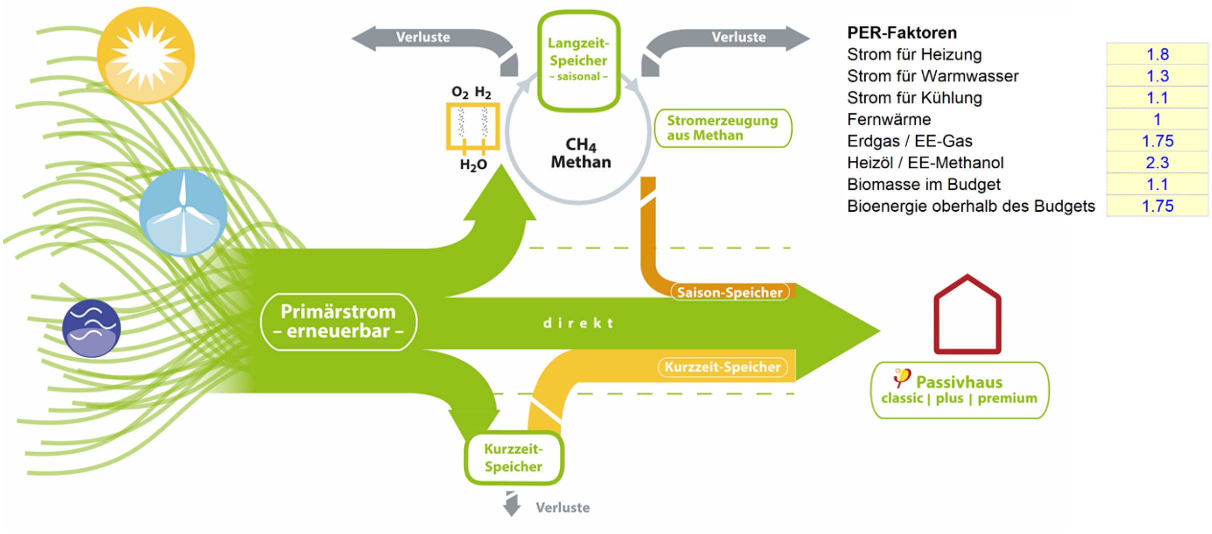
5.3 PER demand

Primary **E**nergy **R**enewable (PER) is a measure of the expenditure for renewable energy which is needed for a specific energy application. Renewable energy is mostly available in the form of electrical current, but not in the amount in which it is required. As illustrated in Fig. 12, only a part of the renewable energy electricity from solar, wind, or hydropower can be directly consumed. A part must be stored over a few days for example; this may be done utilizing batteries or pumped storage plants. These storage facilities have an efficiency of around 70%. Besides this, it is necessary (see also Fig. 3) to store a part of the electricity generated in the summer for use in the winter. This is possible through the generation of hydrogen or methane from renewable electricity; however, the efficiency here is only 28%. Accordingly, an especially high amount of renewable primary energy must be generated for heating electricity in the winter.

Other energy sources can likewise be generated from electricity. In the case of gas, electrolysis and mechanization are necessary for this. One kilowatt hour of gas requires 1.75 kWh of primary energy.

Bioenergy as a renewable energy source is assessed with a PER factor of 1.1. However, limited availability must be considered; above the budget of 20 kWh/(m²a) "bio" energy in reality is generated via PtG with a PER factor of 1.75.

District heating may use a variety of heat sources depending on availability, some of which have very low PER expenditure. With appropriate efforts, a PER factor of around 1 is achievable.



PER-Faktoren	
Strom für Heizung	1.8
Strom für Warmwasser	1.3
Strom für Kühlung	1.1
Fernwärme	1
Erdgas / EE-Gas	1.75
Heizöl / EE-Methanol	2.3
Biomasse im Budget	1.1
Bioenergie oberhalb des Budgets	1.75

Fig. 12: Basic concept of the PER system: electricity must be stored over different time periods, which gives rise to losses and costs. The table on the right shows the PER factors applicable in Germany.

Fig. 13 shows the PER demand of the different scenarios at the end of the period under consideration, in the year 2070. There are drastic differences between the variants. The scenarios with a high percentage of biomass but moderate efficiency (**CA 2021, 60% implementation**; **CA 2021, full implementation**; **CA 2021, accelerated**), perform less well here. The bioenergy budget of 20 kWh/(m²a) in the year 2070 corresponds to a total of 145 TWh/a. The calculated biomass demand in the case of **CA 2021, full implementation** is 115 TWh/a and is still within the scope of such a budget. Nevertheless, PER demand results are significantly higher than in the variants in which HP/DH prevail – appropriately because bioenergy is now missing for effective use in the generation of electricity and district heating in the winter. The EnerPHit/Passive House variants perform particularly well as they require less seasonal storage and therefore incur fewer losses due to the smaller heating energy demand.

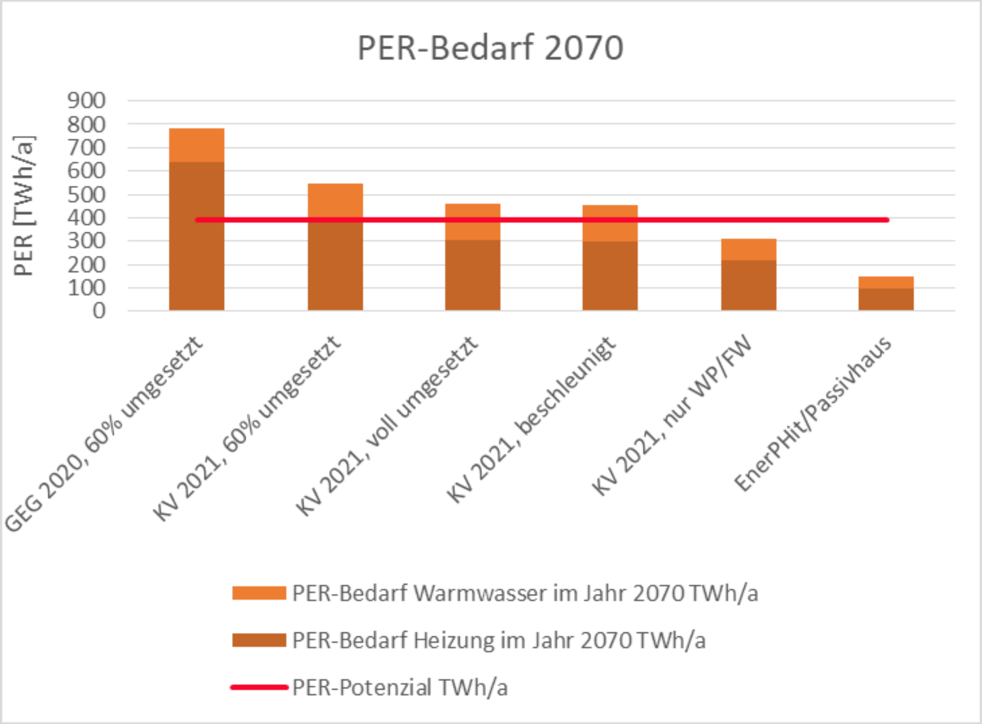


Fig. 13: Annual PER demand at the end of the period under consideration.

5.4 Costs

The total costs for the energy demand plus energy-relevant measures (Fig. 14) are higher in the case of **CA 2021, full implementation** than in the EnerPHit variant; the overall higher energy demand is noticeable here. In the EnerPHit scenario, moderately higher investment costs are necessary, but these are more than compensated by the saved energy. The difference in the total costs (present value) in both cases is 610 billion euros. As already explained, the costs mentioned here relate exclusively to the energy-relevant portions of the measures.

High overall costs are incurred if the efficiency is not significantly improved as in the first two variants. The accelerated scenario is particularly costly, with 1500 billion euros more than the EnerPHit variant: in this, residual values are destroyed to a considerable extent due to the relatively rapid renewal of building components that are still functional. This also means an increase in the manufacturing energy demand and the CO_2 emissions associated with this. We have not included these here because they play a role only in this specific scenario and otherwise remain below the accuracy margin of the model calculation. In the other scenarios, replacement measures are largely only undertaken in the normal renewal cycle, in which case the differences in the manufacturing energy are small (e.g. replacing a gas boiler with an electric heat pump). The situation is different if the boiler is to be replaced ahead of time – then its full manufacturing expenditure will be incurred before energy production has switched to sustainable energy sources to a large extent. The earlier a measure is applied, the more harmful the use of manufacturing energy will be to the climate.

Fig. 15 shows when the additional costs are incurred in the accelerated scenario. Huge sums would have to be invested in the existing building stock within the space of a few years. For comparison: Germany's total public budget for 2020, including social insurance was 1700 billion euros, and the gross domestic product was 3300 billion euros.

The practicability of accelerated deep retrofits stands in opposition to the capacity, especially in the construction industry. This employs around 2 million people in Germany, with a turnover of approximately 400 billion euros annually. The trajectory sketched in Fig. 15 would increase the share of energy-related costs recorded here by approximately 120 billion euros, that is about 30% of the total volume in the building sector within the space of a few years; about 600,000 construction workers plus the necessary specialists for the complex field of existing building retrofitting would have to be available at short notice. It must also be kept in mind that in line with the investments, the big wave of modernization may lead to mass layoffs in the construction industry from the start of the 2030s because after the premature retrofits there will be a significantly reduced demand over a few decades. Such a scenario would be suboptimal both in terms of the national economy and social policy. However, at present precisely these boundary conditions are changing: dependency on fossil fuel natural gas as a "bridging solution" may turn out to be an illusion not only concerning the achievement of the climate goals but also in geopolitical terms. Of course, to a certain extent, the energy demand of the existing building stock can be reduced in the short term using financial means, and at a quicker pace than would be possible through the expansion of the renewable energy supply. To this end, it is necessary to identify measures that can be rapidly and cost-effectively implemented with a greater impact on the reduction of the heating energy demand.

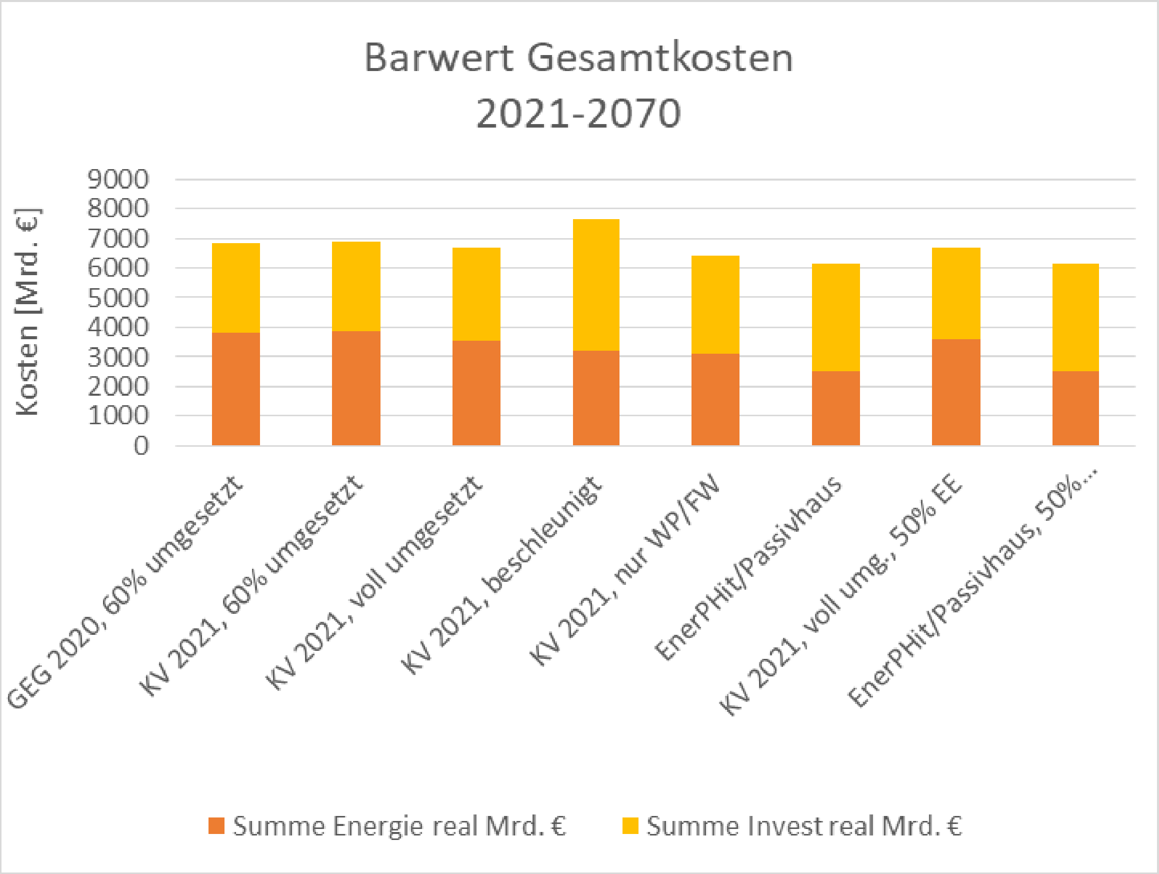


Fig. 14: Energy and investment costs for energy-relevant measures in the studied scenarios.

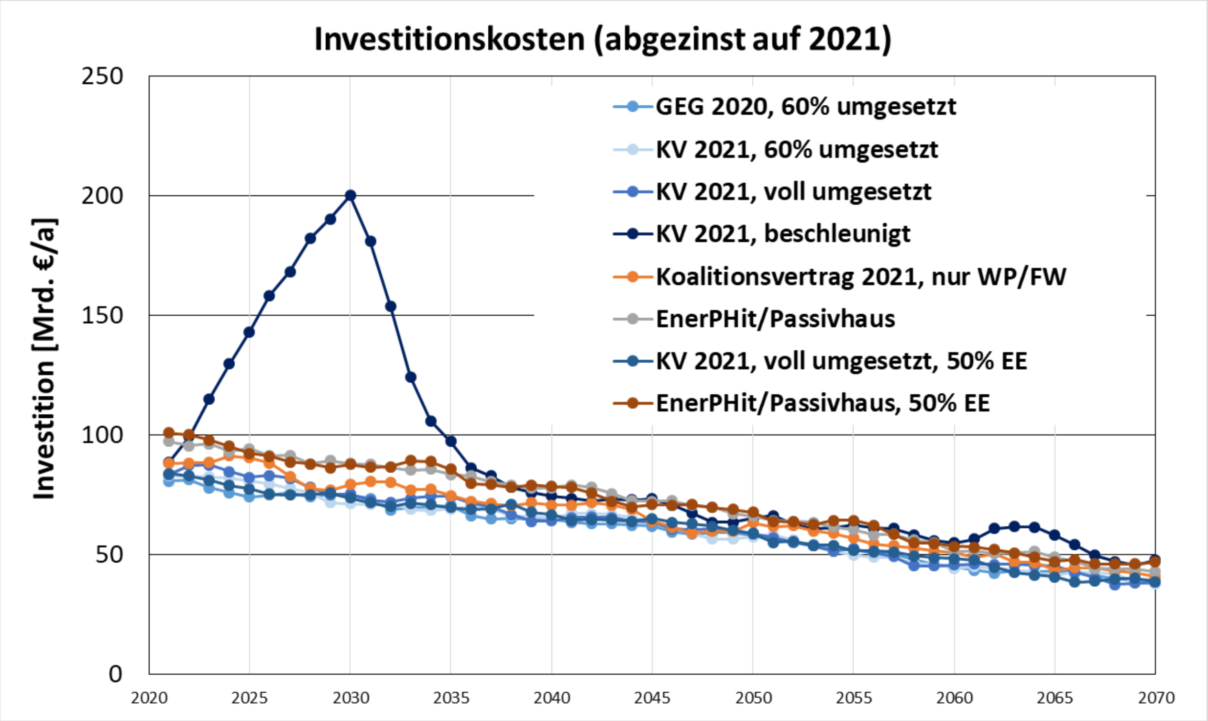


Fig. 15: Investment costs for energy-relevant measures in the studied scenarios over time

6 Evaluation

Under the very optimistic assumptions hypothesized in this study, the decisions made in the 2021 coalition agreement would in theory be suitable for advancing toward the climate protection goals of the Paris Agreement. However, consistent implementation of the EnerPHit standard in existing buildings and the Passive House standard in new constructions will be significantly more advantageous, both in terms of greenhouse gas emissions and economically. Apart from that, this approach offers better resilience and higher flexibility as well as the possibility of compensating for emissions of individual buildings that are difficult to retrofit.

The following will matter in the future:

a) Consistent application of the coupling principle. If a component is to be renewed, the opportunity must always also be taken to improve efficiency to a sustainable level. Exceptions to the rule for conditional measures should be reduced.

b) Furthermore, requirements must be laid down regarding the quality of the building envelope, e.g. by specifying U-values or maximum values for H'_T in the case of the existing building stock. In new constructions, it is better to do this with a heating energy demand based on the living area/useable area. In this way, a reliable basis for a low energy demand will be created in the first place. A requirement relating solely to primary energy or CO_2 is by no means sufficient.

c) A higher quality must be implemented – with each retrofit, regardless of the reason for it. Quality assurance similar to that for Passive House certification, supplemented with individual on-site visits/appointments would be helpful here. Adequate CO_2 prices which are equally borne by tenants and landlords may have a supportive effect. The coalition agreement has already foreseen cushioning of the social effects of high energy prices. This will be successful, in a sustainable way, especially if the measures are aimed at improving energy efficiency, i.e. if energy consumption is reduced. Subsidizing a high demand and thus continuing to support the fossil energy system with all its implications would be counterproductive.

d) The expansion of renewable energy must be implemented as planned. If this does not succeed, then a higher level of efficiency will be even more crucial. Regardless of exactly how future developments proceed, highly efficient buildings will allow deadlocks to be reliably avoided; they will be a "no-regrets" measure. Above all, they will facilitate the situation even when, in the course of restructuring, shortages in the supply of fossil energy occur e.g. due to political reasons!

e) Heat recovery ventilation and improved airtightness are recommended for reducing loads, particularly in winter. The minimization of loads is important, especially with heat pumps, because investments are decreased due to this, and/or less expensive peak-load electricity is needed. In this way, substantial costs can be saved in especially critical periods in which a lot of heating is necessary but there is little sun and hardly any wind. Investments in network expansion can also be shouldered more easily as a result. Heat pumps should always be dimensioned so that they will still function efficiently in the heating load case.

f) Suitable standards are needed for building efficiency. Assessment of CO_2 alone is unsuitable because CO_2 is a flexible goal and would lose all relevance as a benchmark when the energy supply becomes completely renewable. This is not appropriate because every form of energy provision implies an ecological cost (in the most favorable case this means additional land use). The efficiency of the building envelope as the most durable component should be evaluated separately; the specific heating energy demand is particularly suitable for this. The load/burden on the future renewable energy system due to the building as a whole, including the heat supply, can be assessed easily on the basis of the PER system, for example.

In the **EnerPHit/Passive House** scenario described above, just slightly greater renewal rate is sufficient for reducing the heating energy demand of existing building stock within 20 to 30 years by a factor of 2. Due to the coupling principle, this is exceptionally economical – for the most important measures even cheaper than today's heating energy from fossil energy sources. Not only can implementing these measures save energy costs and decrease CO_2 emissions to almost zero, but it can also relieve the financial burden on households. In addition, in place of fossil energy from abroad, regional manpower can be deployed for carrying out construction measures. This will create jobs and increase domestic value creation. Furthermore, such an approach based on the EnerPHit principle will increase public sector revenues – a multiple win-win situations will result.

Nevertheless, this scenario will not run by itself: it requires boundary conditions that must be actively created, which we will detail here once again:

1. Communication: there are many examples of building retrofits to a sustainable level of efficiency. Let's make these better known/let's raise awareness of these! Information initiatives are needed for this; the project documentation available in the Passive House database/portal?? (https://passivehouse-database.org/) and the international Passive House Open Days are a good basis for this. The focus now is on existing building stock!
2. Implementation to a high standard ("if you do it, do it properly") and – even when rapid action is needed – without impeding further subsequent measures. Capacity of the trades is necessary for this, and (easily communicated) basic training on the topic of "Why is energy efficiency necessary in existing building stock, and how this can be achieved effectively and sustainably?"
3. Advanced training: Let us impart the know-how for energy efficient retrofits. The courses offered by the PHI are a good basis for this: https://cms.passivehouse.com/de/training/kurse/.

4. Let's help the industry to quickly adapt their production of building components to energy efficient components. Good examples are available with the certified Passive House components – small and large companies have already successfully mastered this transition; it's not as hard as some people think. The Passive House Institute provides advice to companies in this connection. Passive House suitable components are documented in the component database: www.componentdatabase.org.
5. The financial resources must be made available: for this, what matters above all is the willingness of banks to preferentially finance such retrofit measures as well. Interest rates are low at present, investment projects are actually being sought – these are good prerequisites. However, in many cases banks are often hesitant when it comes to measures that serve climate protection because often, realistic rather than speculative expected returns are stated here – which, when considered from this perspective, is an advantage.
6. Public funding of measures must be directed towards overcoming dependency on fossil energy sources: saving CO_2 as well as ensuring that climate neutrality can be achieved consistently with these forms of assistance. For this reason, systems that continue to rely on fossil energy sources as a "bridging" technology" must not receive funding, and neither should incentives be provided for low quality retrofits such as those without improved ventilation (Corona!), or such as those in which double glazing or uninsulated window frames are again used etc. Instead, based on the results of the scenarios, special incentives should be set for highly energy efficient deep retrofits.

Sustainable building stock will follow almost automatically from a programme which leads to the use of highly efficient components with competent planning and expert implementation.

Anything other than that would not be an adequate contribution to climate protection – on the contrary, it would fix the bad state in place over further decades (lock-in effect).

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