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Research Report FO-2020/06

Grey Energy and Grey Emissions of Insulation Materials in Comparison to the Savings Potential

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1. Abstract

The building sector plays a crucial role in the implementation of the energy transition: Primary energy demand and greenhouse gas emissions must be minimised in all existing building types and for all building age classes.

A significant step towards this goal is the insulation of the building envelope to optimally reduce heat losses. For a holistic evaluation of such measures, the efforts over the entire lifecycle of the insulation materials - from production to deconstruction - should be considered.

For such a life cycle assessment, all relevant environmental impacts that occur during the lifecycle of an insulation material are determined. Typically, the determination and evaluation of the primary energy to be used as well as the resulting greenhouse gas emissions as environmental indicators are conducted. For this study, the total primary energy demand and the primary energy demand from non-renewable resources, the so-called grey energy (non-renewable), were evaluated. In the generation of grey energy, greenhouse gas emissions are released - the so-called grey emissions. These are also included in the life cycle assessment.

Based on the life cycle assessments conducted, the respective ratio of energy expenditure for the production and deconstruction of exemplary insulation measures to the achievable heating energy savings can be shown.

In the following Figure 1, this ratio is illustrated for common insulation materials such as mineral wool, EPS, XPS, and polyurethane.

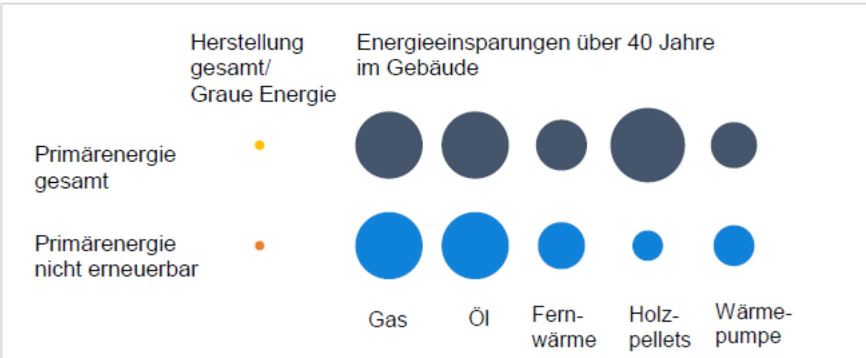

Figure 1: Ratio of energy expenditure for insulation production to the savings in primary energy achievable over a usage period of 40 years for various energy sources based on an example calculation with a U-value improvement from 0.8 to 0.24 W/(m²·K)

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It is shown that the primary energy demand, both total and related to the non-renewable primary energy expenditures, is very low compared to the savings that can be achieved by using insulation to reduce building energy consumption. The same applies to the consideration of grey emissions (Figure 2).

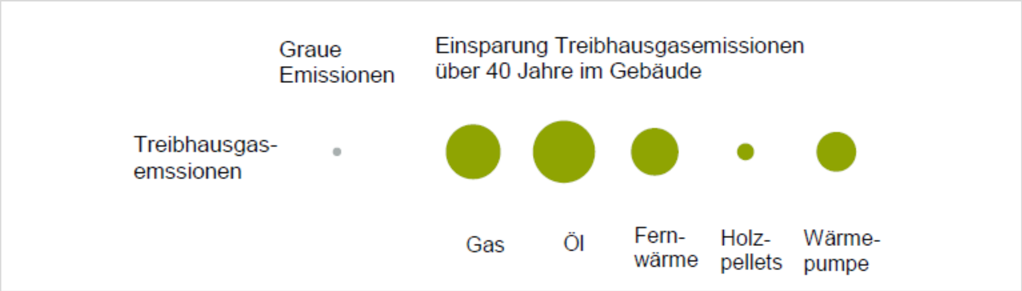

Figure 2: Ratio of greenhouse gas emissions for insulation production to the savings achievable over a usage period of 40 years for various energy sources based on an example calculation with a U-value improvement from 0.8 to 0.24 W/(m²·K)

This ratio is also clearly evident when considering the energy payback time, i.e., the time period until the expenditure for insulation production is compensated by the savings achieved. Figure 3 shows the point of payback for each environmental indicator over the life of insulation.

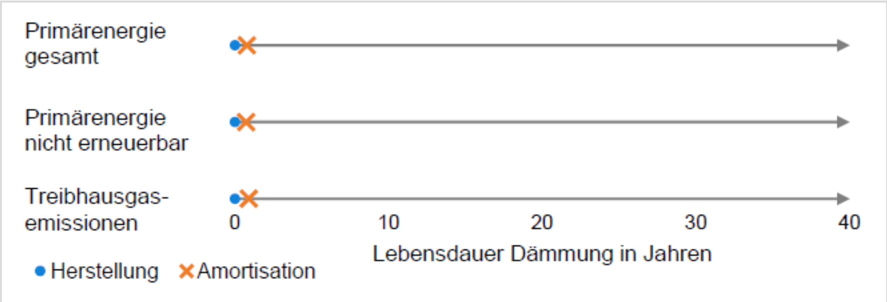

Figure 3: Presentation of the payback time compared to the lifespan (40 years) of an insulation measure for the three considered environmental indicators based on an example calculation with a U-value improvement from 0.8 to 0.24 W/(m²·K); energy source: gas

From these results, it can generally be derived that the primary energy expenditure (total and non-renewable) as well as the greenhouse gas emissions for the production of insulation materials play a minor role compared to the savings achievable through them. This ratio depends on the energetic state of the component before and after the insulation measure as well as the energy source. However, the benefit of insulation always outweighs the effort.

Insulation measures in general, regardless of the choice of insulation material, the chosen insulation thickness, and the initial energetic state of the component, are always a gain from a sustainable and overall energy perspective.

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2. Grey Energy and Greenhouse Gas Emissions for Insulation Measures

To validly assess the expenditures for the total primary energy demand and the primary energy demand from non-renewable resources, the so-called grey energy (non-renewable), as well as the resulting greenhouse gas emissions (GHG) for the production and deconstruction of insulations, environmental product declarations (EPD for Environmental Product Declaration) of various insulation products were used. This allowed the environmental impacts of each product over its entire lifecycle to be evaluated using different indicators. Figure 4 shows the values of important data sources (Ökobaudat, manufacturers, associations) for the production and deconstruction (lifecycle phases A1 - A3, C3, and C4) for the primary energies and greenhouse gas emissions (grey emissions) for established insulation materials from EPS, PUR, XPS, and mineral wool. The data was normalised to an insulation value R of 1 (m²·K)/W for better comparability. Detailed information on the underlying datasets is summarised in Appendix 7.1.

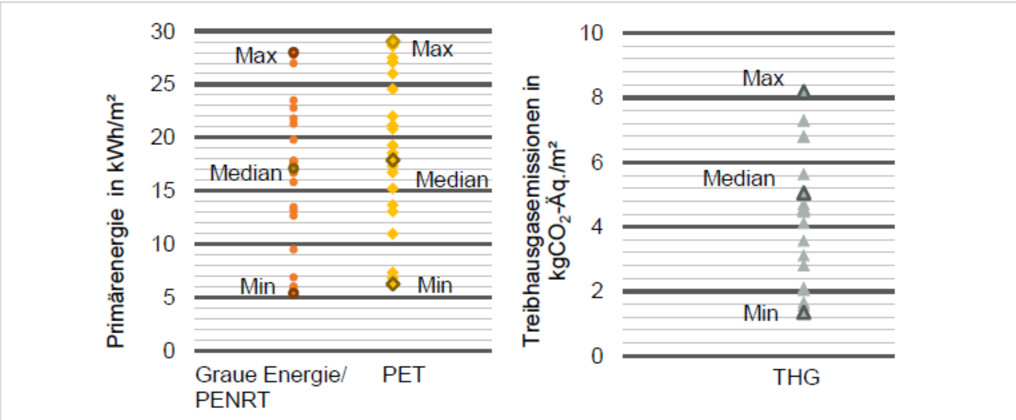

Figure 4: Life cycle assessment data for grey energy (PENRT) and total primary energy (PET), left, and greenhouse gas emissions (GHG, right) for the production and deconstruction of insulation measures with the same insulation effect per m²

With these evaluations, a typical range for the three environmental indicators considered can be defined. To reflect this range in the following calculations, the minimum, maximum, and median EPD dataset was selected for each indicator.

In addition to the environmental impacts of the insulation materials, the thermal properties of a component before and after the insulation measure must be defined to determine the required insulation thickness. This again depends on the thermal conductivity of the insulation material. Figure 5 shows the relationship between the required insulation thickness depending on the desired U-value after the insulation measure and the thermal conductivity of the insulation material in W/(m²·K) for a component with a U-value of 0.8 W/(m²·K). This corresponds to an unsanitary construction with a construction year between 1987 and 1995.

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Explanation of terms

Grey energy is the cumulative non-renewable primary energy required for the extraction of raw materials, manufacture, transport, storage and disposal of a product. The greenhouse gas emissions released during these processes are referred to as grey emissions. However, these terms are neither standardised nor otherwise defined in Germany.

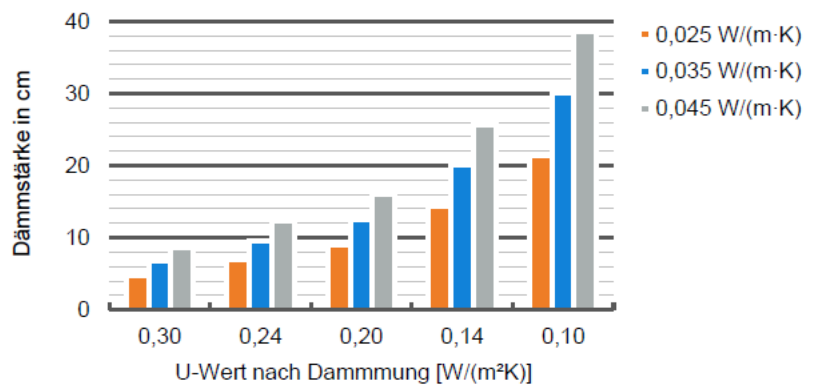

Figure 5: Required insulation thicknesses for an existing U-value of 0.8 W/(m²·K) depending on the thermal conductivity of the insulation material

For the required insulation thickness, the environmental impacts of grey energy and greenhouse gas emissions can be calculated. The chosen minimum, maximum, and median values for an insulation measure with an existing U-value of 0.8 W/(m²·K) are shown in Figure 6 depending on the chosen target U-value after refurbishment. A thermal conductivity of the insulation material of 0.035 W/(m·K) was assumed.

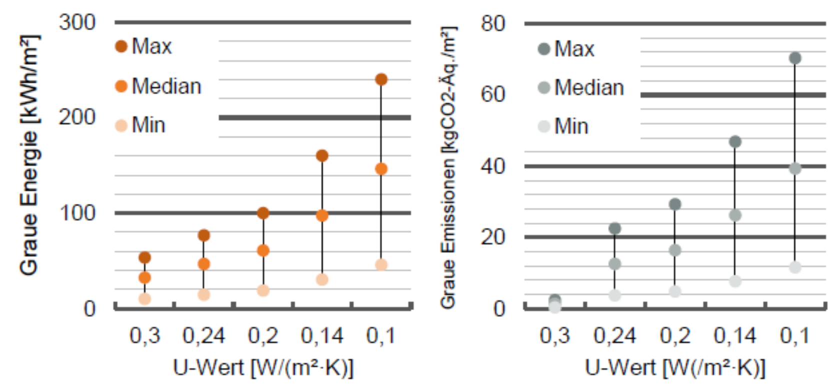

Abbildung 6: Bandbreite von Grauer Energie und Grauen Emissionen in Abhängigkeit des erzielten U-Wertes nach Dämmmaßnahme bei einem Bestands-U-Wert von 0,8 W/(m²·K)

Figure 6: Range of grey energy and grey emissions depending on the achieved U-value after the insulation measure for an existing U-value of 0.8 W/(m²·K)

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3. Savings Through Insulation Measures

For the calculation of heating energy savings through an insulation measure and to determine the resulting savings in primary energy and greenhouse gas emissions, a simplified approach considering only transmission heat losses is used. Ventilation heat losses as well as internal and solar gains are not considered. With the following formula, heating energy savings per m² of component can be calculated.

$$Q = U1 \times FGT,1 - U2 \times FGT,2$$

where

U1 = U-value before the insulation measure in W/(m²·K)

U2 = U-value after the insulation measure in W/(m²·K)

FGT,1 = degree day factor 84 kKh/a

FGT,2 = degree day factor 66 kKh/a

By applying different degree day factors FGT, the fact that room temperature and heating limit temperature typically increase and the heating period is shortened through an insulation measure is taken into account.

Figure 7 shows the heating energy savings per m² of component calculated using this formula depending on the U-values before and after the insulation measure.

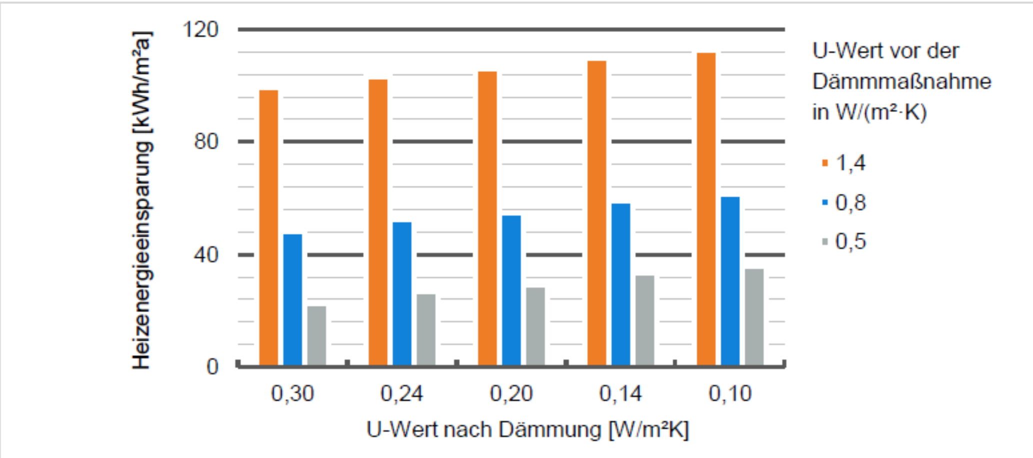

Figure 7: Possible heating energy savings per m² of component depending on the U-values before and after the insulation measure

To convert these savings into total and non-renewable primary energy as well as greenhouse gas emissions, the energy source for heating must be considered. For this purpose, the heating energy

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savings are multiplied by the corresponding factors from Table 1. The efficiency of the heating system or the seasonal performance factor of the heat pump must also be taken into account.

Tabelle 1: Primärenergiefaktoren (f_P) gesamt und nicht erneuerbar sowie Kennwerte für die Berechnung der Treibhausgasemissionen für verschiedene Energieträger

Energie-träger	Wirkungsgrad Anlage[1] η[-]	f_P gesamt[2] [-]	f_P nicht erneuer-bar[3] [-]	Treibhausgas-emissionen[2] [g/kWh]
Gas	0,9	1,1	1,1	240
Öl	0,9	1,1	1,1	310
Fernwärme	1,0	0,7	0,6	200
Pellets	0,8	1,2	0,2	20
Wärmepumpe (Strom)	4,0	2,3	1,8	560

Table 1: Primary energy factors (fP) total and non-renewable as well as parameters for the calculation of greenhouse gas emissions for various energy sources

Sources:

1. Own Assumption

2. BMWi (2020): Analysis of Specific Decarbonisation Options to Achieve the Energy and Climate Targets 2030 and 2050 for Different Residential and Non-Residential Building Typologies

3. Building Energy Act (GEG)

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4. Evaluation of Effort to Savings for Various Existing Conditions

Through the described approach, the expenditures for the total primary energy demand and the primary energy demand from non-renewable resources (grey energy) as well as the resulting greenhouse gas emissions (GHG) for the insulation layer can be determined depending on the insulation quality of the component before and after the refurbishment and the savings achievable depending on the energy source. Three different existing conditions and a refurbishment target to the Building Energy Act (GEG) level with a U-value of 0.24 W/(m²·K) are considered. The assumed U-values for the existing conditions and an assignment to the respective construction age class are summarised below:

- U = 1.4 W/(m²·K): Construction year before 1978
- U = 0.8 W/(m²·K): Construction year between 1978 and 1995
- U = 0.5 W/(m²·K): Construction year from 2002

Figure 8 summarises the results for total primary energy (PET) and grey energy (PENRT)

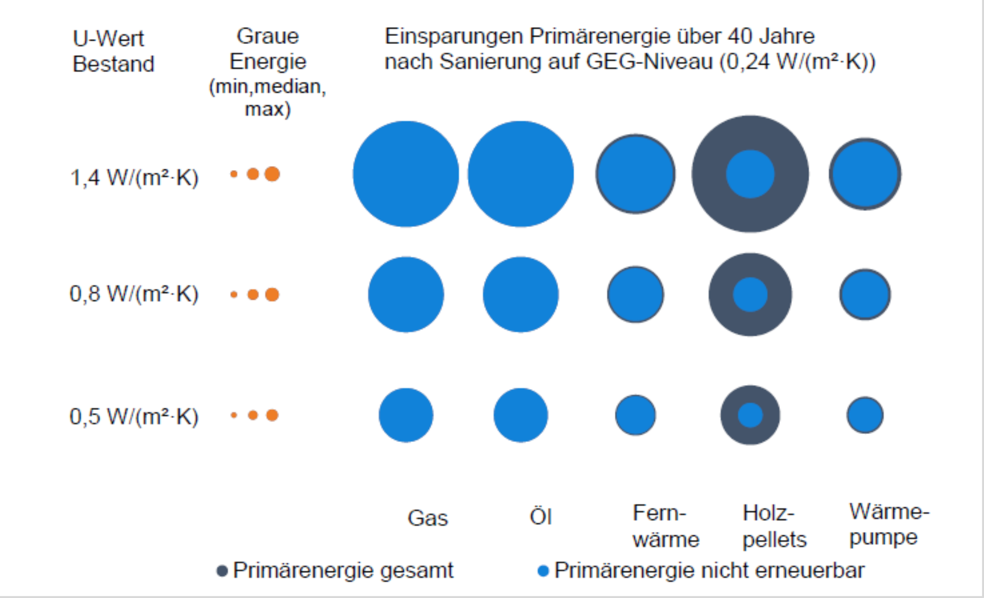

Figure 8: Comparison of effort to achievable savings in total and non-renewable primary energy over 40 years for refurbishment to a U-value of 0.24 W/(m²·K) for various existing conditions

The results PET and PENRT are overlaid for each variant. The expenditures for the creation of the insulation layer are each specified with a minimum, median, and maximum value. This way, the range of different insulation materials available on the market can be represented (see Figure 4). Due to the proportions within this representation, the differences between PET and PENRT in the expenditures for insulation are not recognisable. In contrast, the achievable savings over a usage period of 40 years for different energy sources are shown. In general, it can be read that higher insulation thicknesses and thus higher expenditures are required with poorer initial conditions. At the same time, however, greater savings can be achieved. For all considered existing variants, the savings for all energy sources

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for PET and PENRT are significantly greater than the expenditures required for the creation of the insulation layer.

The energy sources gas and oil are 100% non-renewable, therefore the results for total and non-renewable primary energy are equal. The differences are greatest for the regenerative energy source wood pellets.

Figure 9 shows the results for greenhouse gas emissions. The relationships and ratios are generally comparable to the primary energy representations. Significant deviations exist for the regenerative wood pellets. Due to the significantly lower greenhouse gas emissions per kWh heating energy savings, the emission savings for this energy source are significantly lower in comparison. However, here too the savings significantly outweigh the expenditures.

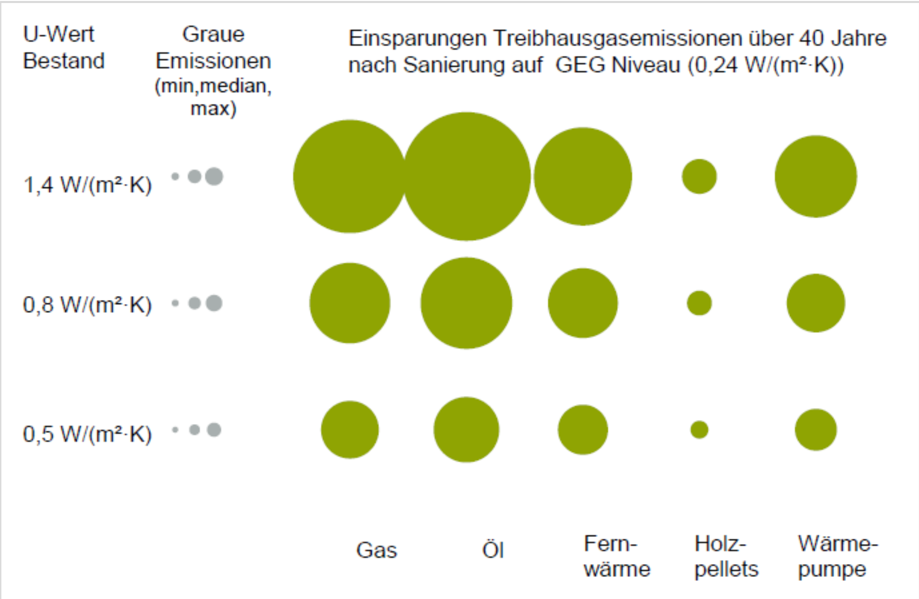

Figure 9: Comparison of effort to achievable savings in GHG over 40 years for refurbishment to a U-value of 0.24 W/(m²·K) for various existing conditions

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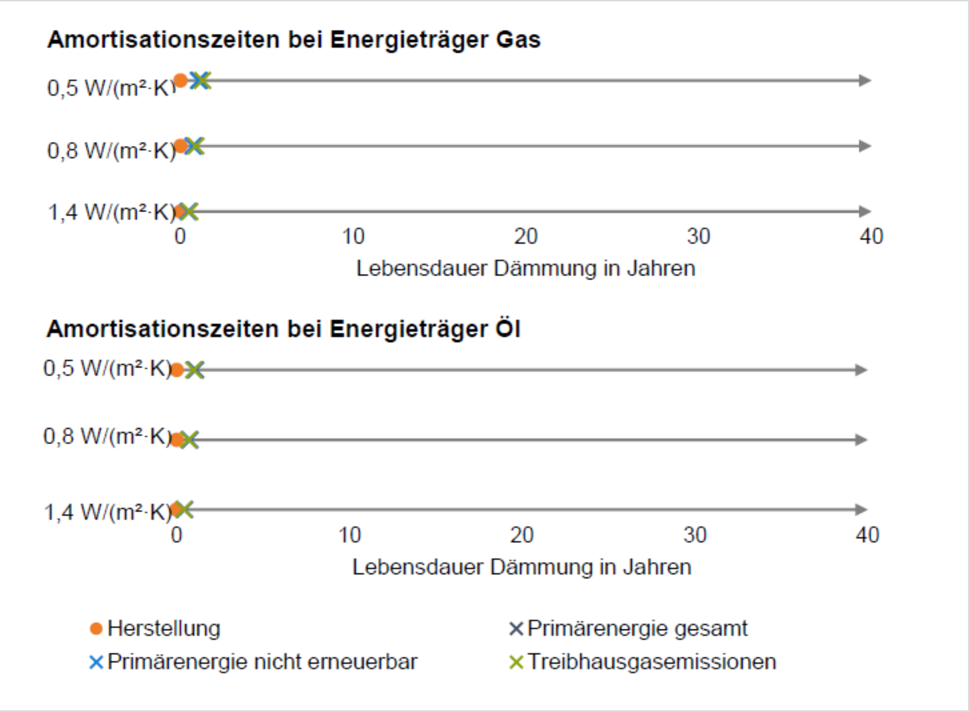
5. Payback Periods

Based on the previously presented results, the energy payback time can be calculated. This is the time span until the primary energy used for the creation of the insulation layer is balanced by the savings achieved. Similarly, a payback period for the greenhouse gas emissions can be calculated. These are presented in the following figures in relation to a usage period of 40 years. The median values of the insulation materials were used for the expenditures.

In principle, the payback periods become slightly longer with increasing energetic quality of the existing condition. The calculated payback periods vary little for the three environmental indicators for the respective energy source. An exception here is the wood pellets. For regenerative energy sources with comparatively low non-renewable content and greenhouse gas emissions, longer time spans are needed for the payback of the insulation measure. In this exemplary consideration, the longest payback periods were determined for wood pellets and an existing U-value of 0.5 W/(m²·K). However, even for this unfavourable scenario, the energy payback periods are very short compared to the lifespan of an insulation of 40 years and more.



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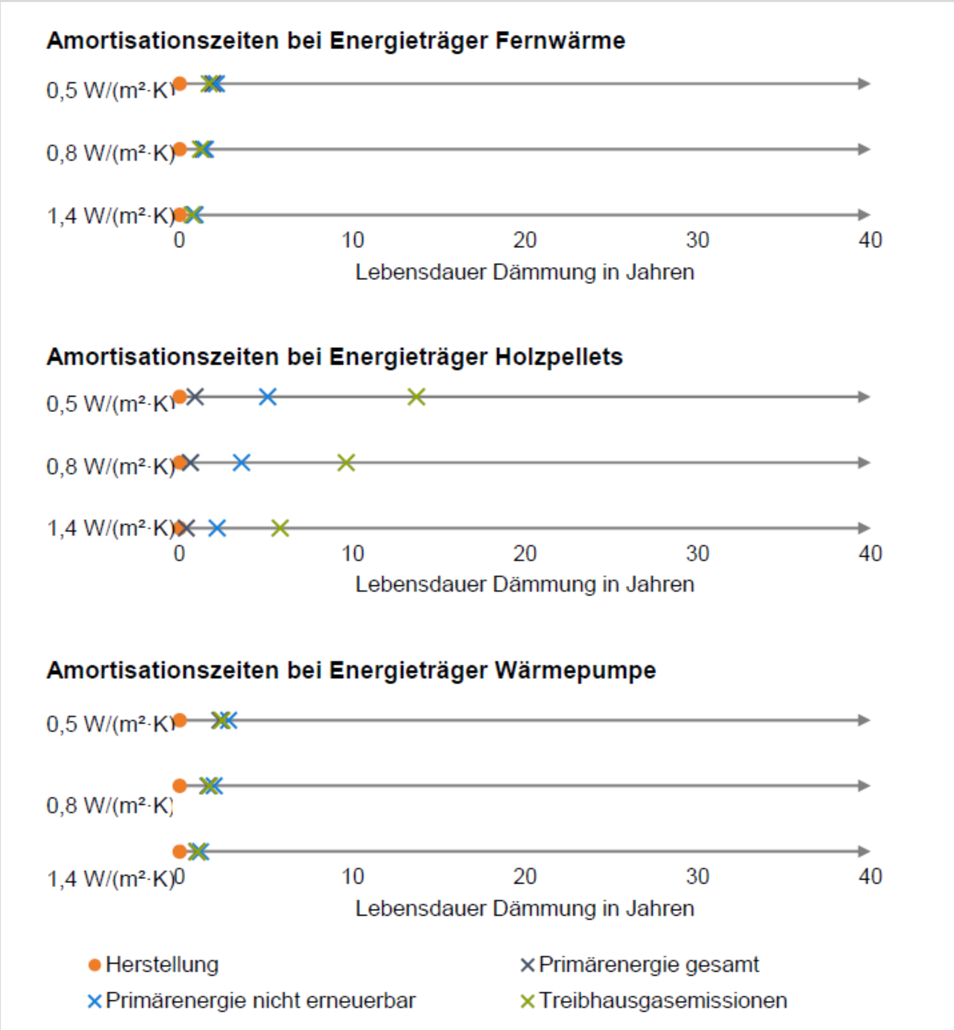

Figure 10: Payback times for total primary energy, non-renewable primary energy, and greenhouse gas emissions for various existing conditions and energy sources for refurbishment to GEG level (U-value = 0.24 W/(m²·K))

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6. Summary and Outlook

The exemplary calculations within this study prove: Insulation measures are always a gain from a sustainable and overall energy perspective. This statement is independent of the energetic state of the component before and after the insulation measure as well as the energy source used for heating. Over a typical lifespan of an insulation measure of 40 years and more, the achievable savings are always greater than the expenditures necessary for the production of the insulation material. This applies to all established insulation materials considered in this study.

With the amendment to the Climate Protection Act decided at the end of June 2021, Germany aims to become greenhouse gas neutral by 2045. By 2030, emissions are to be reduced by 65% compared to 1990. To achieve this ambitious goal, the CO2 reduction targets previously applicable to the building sector and other sectors have been adjusted.

In addition to increasing efficiency and saving energy, switching to mainly renewable energy sources is also an important step towards achieving the goal. This will not only save primary energy consumption and the resulting greenhouse gas emissions for, for example, heating buildings. This development towards the decarbonisation of energy supply will also positively impact the life cycle assessment of building products such as insulation.

With the increased use of regenerative energy sources in production, grey energy and grey emissions for the production of insulation will be reduced.

Therefore, it can be expected that in the future, the savings achieved through insulation measures will continue to be greater than the expenditures for the production (grey energy and grey emissions) of the insulation material.

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7. Appendix: Detailed Results & Further Information

Below, the data bases of the life cycle assessment and the detailed results and figures of the calculations are summarised.

7.1 Life Cycle Assessment Data Used

Table 2 below summarises the environmental product declarations (EPD) of the various insulation materials considered in the calculations. Both generic datasets from Ökobaudat and product-specific life cycle assessment data from manufacturers and associations were considered. The minimal, median, and maximum datasets selected according to the approach described in Chapter 4 for the indicators total primary energy (PET), non-renewable primary energy (PENRT), and global warming potential (GWP) are indicated in the table.

Name / Produkt	Quelle	Deklarationsnummer
Mineralwolle (Boden-Dämmung)	Ökobaudat	-
Mineralwolle (Flachdach-Dämmung)	Ökobaudat	-
Mineralwolle (Schrägdach-Dämmung)	Ökobaudat	-
Mineralwolle (Fassaden-Dämmung)	Ökobaudat	-
Mineralwolle (Innenausbau-Dämmung)	Ökobaudat	-
ROCKWOOL Steinwolle-Dämmstoff im hohen Rohdichtebereich	Rockwool	EPD-DRW-20180119-IBC1-DE
ROCKWOOL Steinwolle-Dämmstoff im niedrigen Rohdichtebereich	Rockwool	EPD-DRW-20180065-IBC1-DE
ROCKWOOL Steinwolle-Dämmstoff im mittleren Rohdichtebereich	Rockwool	EPD-DRW-20180118-IBC1-DE
Mineralwolle-Dämmstoff im niedrigen Rohdichtebereich	FMI	EPD-FMI-20210020IBG1DE
Mineralwolle-Dämmstoff im hohen Rohdichtebereich	FMI	EPD-FMI-20210021-IBG1-DE
Mineralwolle-Dämmstoff im mittleren Rohdichtebereich	FMI	EPD-FMI-20210019IBG1DE
EPS-Hartschaum (grau) mit Wärmestrahlungsabsorber	IVH	EPD-IVH-20140137-IBB2-DE
Dämmplatte mit Neopor® Plus	BASF	EPD-BAS-20180142-IBA1-DE
Dämmplatte mit Neopor® Plus BMB	BASF	EPD-BAS-20190059-IBA1-DE
EPS-Hartschaum (Styropor ®) für Wände und Dächer W/D-040	IVH	EPD-IVH-20140140-IBB2-DE
EPS-Hartschaum (Styropor ®) für Wände und Dächer W/D-035	IVH	EPD-IVH-20140138-IBB2-DE
EPS-Hartschaum (Styropor ®) für Decken/Böden und als Perimeterdämmung B/P-040	IVH	EPD-IVH-20140141-IBB2-DE
EPS-Hartschaum (Styropor ®) für Decken/Böden und als Perimeterdämmung B/P-035	IVH	EPD-IVH-20140139-IBB2-DE
Styrodur®	BASF	EPD-BAS-20190113-IBA1-DE
XPS-Dämmstoff	Ökobaudat	-
XPS mit halogenfreien Treibmitteln	FPX	EPD-FPX-20190111-IBE1-DE
PU-Dämmplatten aus Blockschaumstoff	IVPU	EPD-IVP-20160147-IBE1-DE
PU-Dämmplatten mit 50 µm Aluminium-Deckschicht	IVPU	EPD-IVP-20140207-IBE1-DE
PU-Dämmplatten mit Aluminium-Mehrlagen-Deckschicht	IVPU	EPD-IVP-20140208-IBE1-DE
PU-Dämmplatten mit Mineralvlies-Deckschicht	IVPU	EPD-IVP-20140206-IBE1-DE

Table 2: Compilation of the EPDs of various insulation materials considered in the calculations with indication of the minimal, median, and maximum datasets for the three environmental indicators PENRT, PET, and GWP

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7.2 Results of Life Cycle Assessment Insulation

Table 3: Summary of the results per m² component for the life cycle assessment of an insulation layer to achieve a U-value of 0.24 W/(m²·K) depending on the existing U-value for the three environmental indicators PENRT, PET, and GWP

Tabelle 3: **Zusammenfassung der Ergebnisse pro m² Bauteil für die Ökobilanzierung einer Dämmschicht zu Erreichung eines U-Wertes von 0,24 W/(m²·K) in Abhängigkeit des Bestands-U-Wertes für die drei Umweltindikatoren PENRT, PET und GWP**

U-Wert Bestand [W/(m²·K)]	PENRT [kWh/m²] Min	Median	Max	PET [kWh/m²] Min	Median	Max	GWP [$kgCO_2$-Äq./m²] Min	Median	Max
1,4	17,58	56,08	91,90	20,29	59,25	95,33	4,44	15,06	26,90
0,8	14,71	46,92	76,90	16,97	49,58	79,77	3,71	12,60	22,51
0,5	10,69	34,11	55,90	12,34	36,04	57,99	2,70	9,16	16,36

7.3 Results Achievable Savings by Energy Source

Table 4: Summary of the results for the savings per m² component over 40 years for U-value improvement to 0.24 W/(m²·K) depending on the existing U-value for the three environmental indicators PENRT, PET, and GWP

Energieträger	U- Wert Bestand [W/(m²·K)]	PENRT [kWh/m²]	PET [kWh/m²]	GWP [$kgCO_2$-Äq./m²]
Gas	1,4	5.050,50	5.050,50	1.101,93
	0,8	2.554,11	2.554,11	557,26
	0,5	1.305,92	1.305,92	284,93
Öl	1,4	5.050,50	5.050,50	1.423,32
	0,8	2.554,11	2.554,11	719,80
	0,5	1.305,92	1.305,92	368,03
Fernwärme	1,4	2.479,33	2.892,56	826,44
	0,8	1.253,84	1.462,81	417,95
	0,5	641,09	747,94	213,70
Holzpellets	1,4	1.033,06	6.198,34	103,31
	0,8	522,43	3.134,59	52,24
	0,5	267,12	1.602,72	26,71
Wärmepumpe	1,4	1.859,50	2.376,03	578,51
	0,8	940,38	1.201,59	292,56
	0,5	480,82	614,38	149,59

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7.4 Results Energy Payback Times

Table 5: Summary of the results for the energy payback time of an insulation measure to achieve a U-value of 0.24 W/(m²·K) depending on the existing U-value and the energy source

Energieträger	U- Wert Bestand [W/(m²·K)]	PENRT [a]	PET [a]	GWP [a]
Gas	1,4	0,44	0,47	0,55
	0,8	0,73	0,78	0,90
	0,5	1,04	1,10	1,29
Öl	1,4	0,44	0,47	0,42
	0,8	0,73	0,78	0,70
	0,5	1,04	1,10	1,00
Fernwärme	1,4	0,90	0,82	0,73
	0,8	1,50	1,36	1,21
	0,5	2,13	1,93	1,71
Holzpellets	1,4	2,17	0,38	5,83
	0,8	3,59	0,63	9,65
	0,5	5,11	0,90	13,72
Wärmepumpe	1,4	1,21	1,00	1,04
	0,8	2,00	1,65	1,72
	0,5	2,84	2,35	2,45

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8. List of Tables

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9. List of Figures

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