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Eco-Efficiency Analysis

Refurbishment of an existing detached house in Germany using an External Thermal Insulation Composite System based on Neopor® or Styropor®

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On behalf of BASF SE

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Results
Gap Assessment & Peer Review

by

DEKRA Consulting GmbH
Sustainability Services

Alles im grünen Bereich.

DEKRA Peer Review Summary *(1/2)*

Subject of this critical review was the Eco-efficiency Analysis of three different alternatives of a single family detached house:

a) Non-insulated house;

b) Refurbished house with insulation at exterior walls (based on Neopor®);

c) Refurbished house with insulation at exterior walls (based on Styropor®).

The Eco-efficiency Analysis is a peer-reviewed and very sophisticated method. Its execution is supported by a professional LCA database and a well-developed software model.

The goal was to compare the environmental and economic performance of an existing detached house without refurbishment with the same house refurbished with an external thermal insulation composite system for the exterior walls in two alternatives, otherwise no changes are considered with regards to any other building components over a 40 year lifetime. The main motivation of the study is to serve as an example case for avoided GHG emissions of a chemical product.

So, the goal is to only demonstrate the contribution of the chemical insulation material as one singular element of a holistic and complex concept of a building refurbishment. Due to the reduced complexity of the subject, the general conclusiveness of the results is limited. The scope is a detached house built in the 1960s – in the base case, the construction and disposal of the house itself is neglected.

The critical review process included data quality checks. An appropriate and sufficient data quality can be stated. The review meeting and the review process as such was performed by BASF SE in an open, competent and very professional manner.

The key results are:

- Compared to the average condition of existing non-insulated houses in Germany, the application of insulation at exterior walls - following the ENEV 2009 and KfW Bankengruppe requirements – has a clear advantage regarding environmental and economic performance;
- The type of insulations materials does not affect the results;
- The use phase dominates the results;
- The choice of scope, whether the construction and disposal phase of the house itself is included or not, does not change the main conclusion of the study.

DEKRA Peer Review Summary *(2/2)*

The abovementioned results and conclusions were plausibly and transparently derived from the data. The underlying life cycle models, assumptions, and calculations are transparent, detailed, well documented and appropriate.

The scenarios chosen helped to identify the high volatility of the results. The results of the scenarios demonstrate the dependency on the definition of the key parameters. For example, the reference case of a non-insulated house can be defined based on actual building and heating system data in a way that the environmental advantage of the insulation is not significant anymore.

One weakness of this Eco-efficiency study is the age and partly inconsistency of the database used for secondary datasets. Although updated datasets are unlikely to change the relative results for the house alternatives analysed, using more up-to-date and consistent background data sets would help to improve the overall accuracy of the LCA results.

Besides, the reviewers found the overall quality of the methodology and its execution to be adequate for the purposes of the study. The study is reported in a comprehensive manner including a transparent documentation of its scope and limitations.

Except where noted in the review with respect to weighting and aggregation, the LCA elements of the Eco-efficiency study were conducted in accordance with ISO 14040/44.

The Eco-efficiency Analysis – including portions beyond the scope of LCA according to ISO 14040/44 – was conducted in accordance with peer-reviewed publications on this methodology.

The involvement of interested parties in the review of the LCA portion of this Eco-efficiency study was beyond the scope of this critical review.

This critical review does not imply an endorsement of the Eco-efficiency method, nor of any comparative assertion based on this Eco-efficiency Analysis and its LCA elements.

Executive Summary *(1/3)*

- This study quantifies the environmental and economic performance of an existing detached house with and without a wall insulation system based on expandable polystyrene (EPS white or grey) over a life time of 40 years. The main focus of the study was to analyze the contribution of chemical insulation products as part of a wall insulation system to GHG emissions reductions. The study serves as the analytical foundation for a case study to be included in the document *Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies*[1].
- This analysis examines and compares the following alternatives for living in an existing, detached house in Germany for 40 years (2011-2051) at an average room temperature of 19°C.
  - Leave the house as it is without any refurbishment and insulation
  - Refurbish the façade with an external thermal insulation composite system (ETICS) based on Styropor® (Expanded Polystyrene (EPS) white, WLG 035) or Neopor® (EPS grey, WLG 032) foam boards

Executive Summary *(2/3)*

- The results of the study clearly demonstrate the environmental and economic benefits of wall insulation by saving energy to heat the house: The Styropor or Neopor insulated house is significantly more eco-efficient than the non-insulated house with lower environmental impacts and lower costs. The type of the insulation material does not affect the outcome of the study.
- The environmental differences are significant and by far more pronounced than the economic differences.
- In all alternatives, the crucial influencing factors are the environmental impacts as well as the costs that are linked to the energy for heating the house.
- The present study analyzes just one of the many aspects in the low-energy modernization of a house and in this context only the impact of a chemical solution. This simplified approach does not (necessarily) reflect the current practice and thus limits the conclusiveness of the study.

Executive Summary *(3/3)*

- The study is based on specific conditions and assumptions that were selected to demonstrate an average situation for Germany. Consequently the study results are less realistic and are not transferable to other conditions that might be present in the real case.

Background & Motivation

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- This eco-efficiency analysis was conducted to provide a case example for the document *Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies*[1], developed by ICCA and the Chemical Sector Group of the WBCSD. The analysis was designed to be in alignment with the requirements of the guidance document.
- The focus of this study as a case example is on chemical products only, since the guidance document has been developed to support chemical companies in their efforts to measure, manage and communicate the avoided GHG emissions of their chemical products. Thus, this study does not consider other non-chemical solutions that may be used for the same user benefit.
- The study builds on a former eco-efficiency analysis performed in 2008 that compared various alternatives for living in a detached house in Germany (building year 1963) for 30 years[2].

Goal of the Eco-Efficiency Analysis

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- The purpose of this eco-efficiency study is to provide the life cycle assessment (LCA) basis to conduct a study on avoided emissions from chemical insulation materials and hence to show and quantify the positive contribution of chemical insulation materials to emissions reductions in the building sector. Therefore, this eco-efficiency analysis can be understood as vehicle for developing a case study on accounting and reporting of avoided GHG emissions from chemical insulation materials. This eco-efficiency study does not intend to assess all technical possibilities to fulfill the defined user benefit (see also scope and limitations of the study) or to conduct a full-fledged analysis including the construction and disposal of the house, which are identical for the studied alternatives.
- Nevertheless, a more general goal of the study is also to understand and quantify the environmental and economic impacts of the production, use and disposal of chemical insulation materials in the context of existing buildings within the limited scope of the study.

Use of the Eco-Efficiency Analysis

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- The study will mainly be used as best practice example for the communication of avoided GHG emissions in conjunction with the *Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies*. The guidance document including a summary of this case example is expected to be published in August 2013.
- A publication of the full study (as download from the WBCSD website besides the guidance document) is envisaged in order to provide more background information to interested parties.
- However, the communication of the results of this study to BASF customers and other stakeholders in the building industry at a later point in time cannot be ruled out.

Audience

- The target audience of this study will be LCA practitioners, sustainability managers, and the interested public.

Introductory Remark on the Scope of the Study *(1/2)*

- The study focuses on a particular aspect to fulfill the defined user benefit that is the insulation of the house walls by using an external thermal insulation composite system (ETICS) based on expanded polystyrene (EPS).
- There are other (technical) solutions that can fulfill the same user benefit such as the use of a different heating system e.g. based on renewable energies or different insulation materials, which have not been considered in accordance with the objective of the study.
- In addition, wall insulation is often just one of the many steps in building refurbishment. In practice, the refurbishment of existing buildings comprises not only wall insulation, but also roof insulation, the replacement of windows or the heating system by more energy-efficient systems.
- Thus the present study is a simplified analysis with reduced complexity that only addresses one aspect in a building refurbishment. All other building components are assumed to remain unchanged and thus have the same impact before and after the refurbishment. This approach was chosen to solely demonstrate the contribution of the chemical insulation material.

Introductory Remark on the Scope of the Study *(2/2)*

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- The construction and disposal phases of the house were not considered in the analysis since these processes are identical for the alternatives and their non-consideration does not change the overall conclusion of the study as shown in Scenario 7.
- However, it is acknowledged that by omitting the construction & disposal phase of the house, the results of the environmental impact assessment do not represent the total but the major impacts.
- The report required for this study is this power point presentation. However, excerpts from this study will be part of the above mentioned Guidance Document[1] as well as part of a background pdf.-report, which will be available as download from the WBCSD website.

Limitations of the Study

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- The present study analyzes just one of the many aspects in the low-energy modernization of a house and in this context only the impact of a chemical solution. This simplified approach does not reflect the current practice and thus limits the conclusiveness of the study.
- Some of the limitations are addressed in the scenario analysis, in which the impact of different heating systems, energy carriers, the life time as well as a best case/worst case is studied.

Methodology

- The study is based on the eco-efficiency methodology, developed by BASF to assess the life cycle of all materials and energy required to fulfill a defined customer benefit (functional unit). A detailed description of the methodology can be found in Appendix C.
- The environmental analysis follows the ISO norms 14040 and 14044 for life cycle assessment. The BASF eco-efficiency methodology goes beyond the norms by including life cycle costs and weighting to derive an environmental fingerprint as well as an overall environmental impact.
- The methodology has been validated by the German TÜV in 2002 and by the US National Sanitation Foundation (NSF) in 2009.
- This methodology was used by the "Öko-Institut" (Institute for Applied Ecology)" in Freiburg, Germany and in different Plastics Europe (formerly APME) studies. Öko-Institut uses a similar methodology with a different weighting system ("Ecograde"). TNO in the Netherlands uses the BASF standard method with a different weighting system. The Wuppertal Institute on the method: "Basically, the large number of indicators used in the eco-efficiency analysis of BASF make relatively reliable statements possible …". The method was initially developed by BASF and Roland Berger Consulting, Munich.

Level in the Value Chain

- The study focuses on a single family, detached house with and without an exterior wall insulation system based on chemical insulation material.
- The level in the value chain is the end-use level in accordance with the Guidance Document[1]. This chosen calculation level is the lowest possible level closest to the chemical solution, which still allows the comparison of the two alternatives living with and without an exterior wall insulation system.

General Information on the Chemical Product

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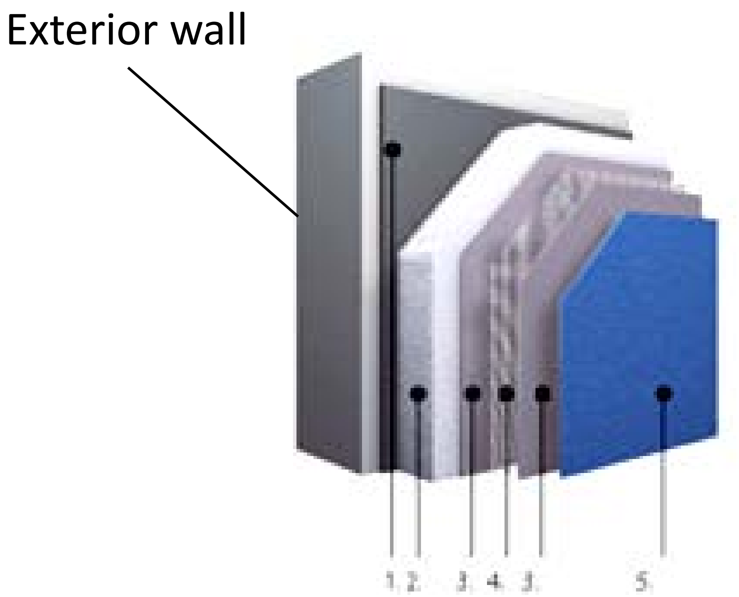
- Over 50 years ago BASF discovered a classic in expandable polystyrene (EPS): Under the trade name Styropor®, EPS is a widely known and used solution for efficient insulation.
- With Neopor®, BASF has taken the classic Styropor a step further. This new material for modern insulating materials is foamed like Styropor and processed into boards. The difference is that Neopor contains graphite which absorbs and reflects heat radiation, thus improving the insulating performance of EPS by up to 20 percent.
- BASF produces, markets and sells Neopor and Styropor beads.
- Neopor and Styropor are available in the German market and have been used for several years in ETICS.

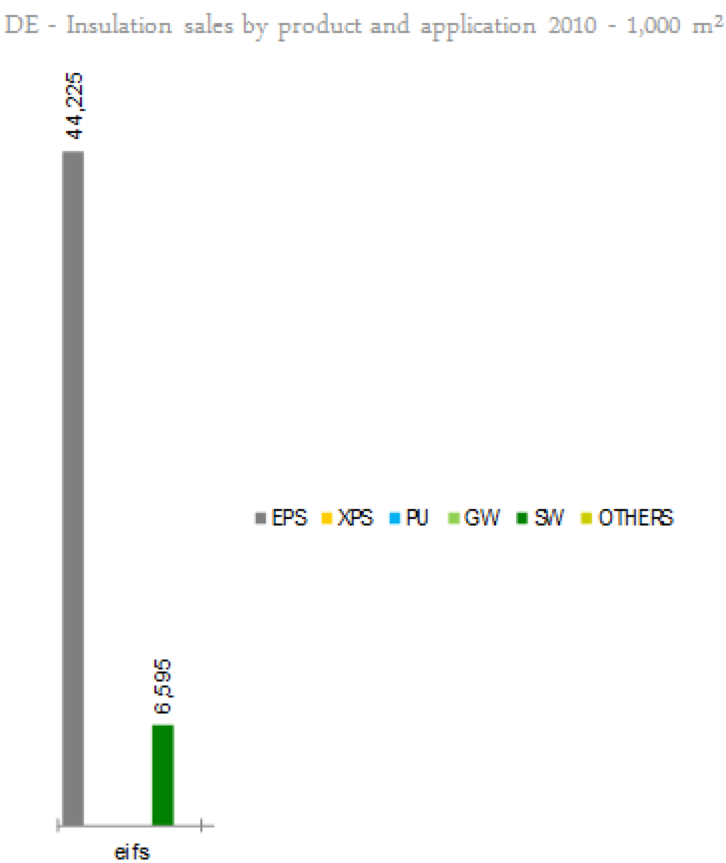
ETIC System Components

- The basic principle of an ETIC System: The system consists of an insulation core like polystyrene and the necessary components for fixing and decoration.



1. Adhesive
2. Insulation board
3. Reinforcement plaster
4. Reinforcement mesh
5. Exterior plaster

Market Information



- According to a German market study conducted by B+L[3] in 2011, the market share of expanded polystyrene in ETIC Systems for wall insulation is about 87% based on sales in 2010. The only other material that is used in ETIC Systems with a considerable market share is stone wool.

User Benefit and Alternatives

<u>User Benefit:</u>
Living in an existing, detached house in Germany at an average room temperature of 19°C for 40 years (2011-2051)

No insulation

Facade refurbishment (ETICS) with Styropor (14 cm, d= 20 kg/m^3, WLG 035)

Facade refurbishment (ETICS) with Neopor (14 cm, d= 15 kg/m^3, WLG 032)

Equivalence of the Alternatives

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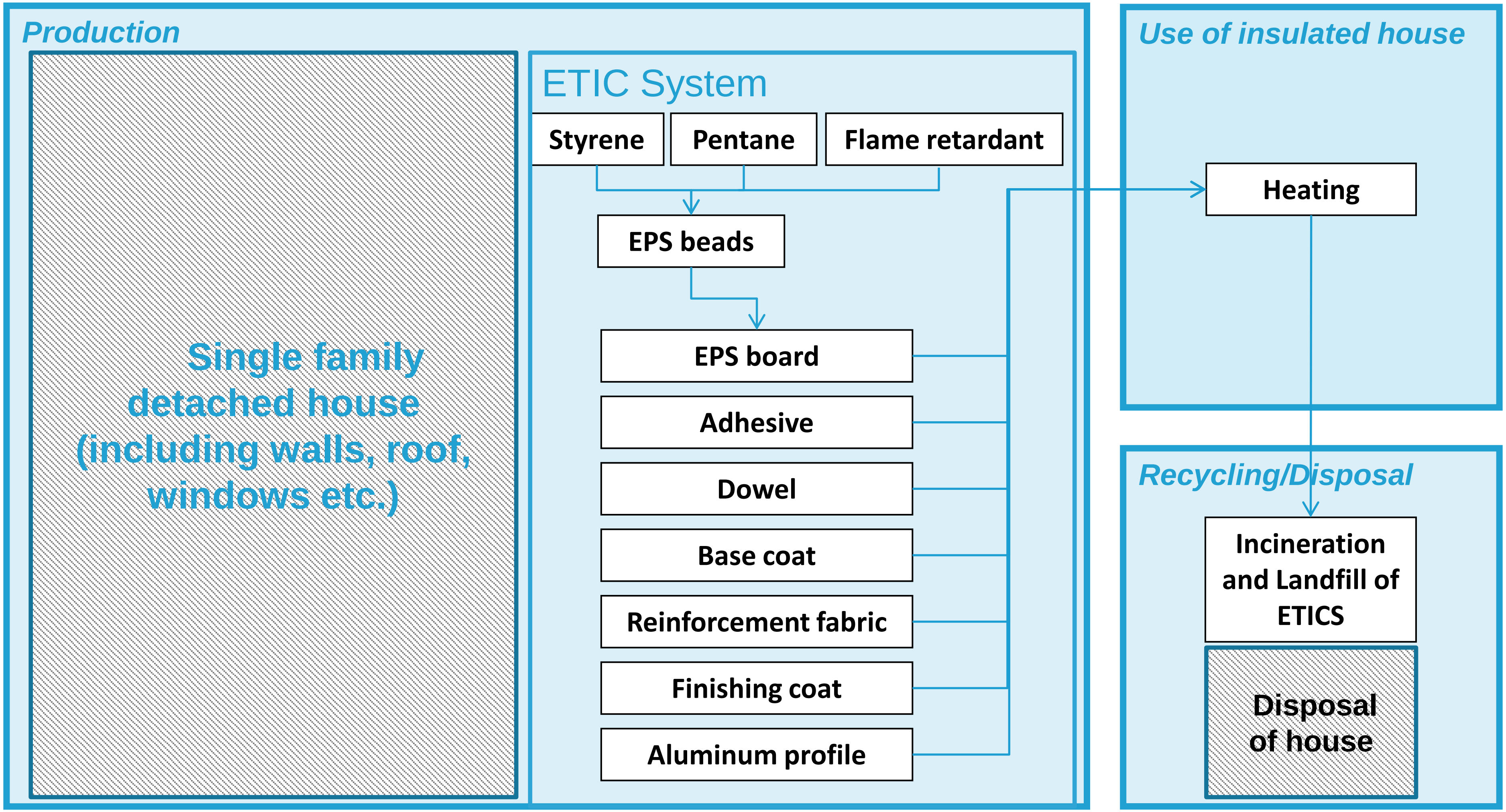
- *Functionality:* The main function of the studied solutions is to maintain an internal temperature of 19°C. This is achieved by means of solely burning fuel to generate heat or by using exterior wall insulation in conjunction with a lower consumption of heating fuel.
- *Technical quality:* The solutions are stable and resistant. The heating systems need to be maintained in all alternatives; the ETIC System does not need any specific maintenance. ETIC Systems are used for more than 40 years. They do not have any underlying shortcomings. With proper care for example painting of the façade, their life time is as long as the life time of the building.
- *Additional services rendered during use and disposal:* Besides repainting, the ETIC System needs to be disposed of at the end of its life, which is considered in the life cycle assessment. A ventilation system to remove moisture in well-insulated buildings is often recommended in particular in passive houses. However, it is not required by law. It was not considered in the analysis.

System Boundaries:
House with ETICS



System Boundaries: House without ETICS

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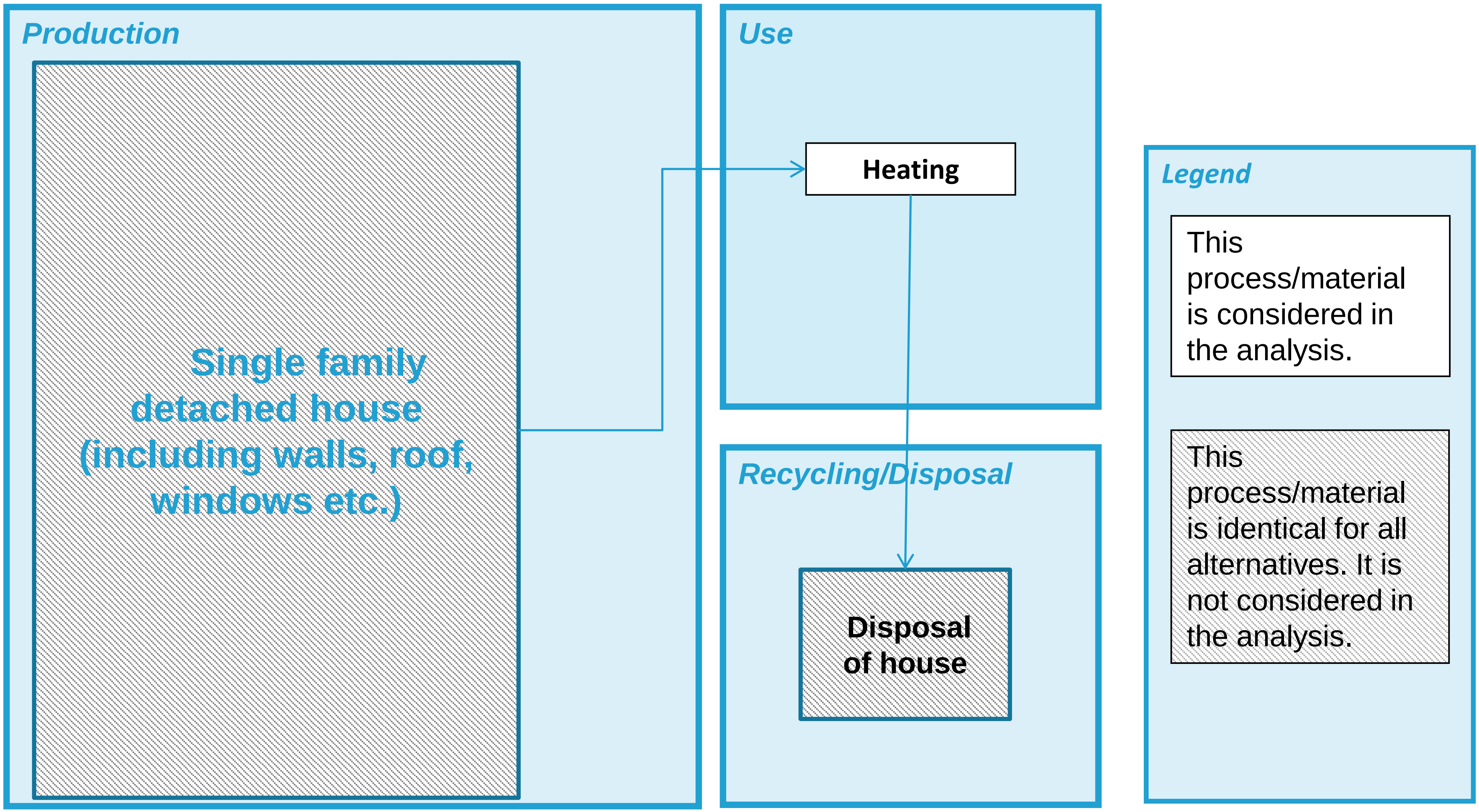

System Description: House with ETICS

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- Production and installation of the ETIC System: The ETIC System consists of an EPS foam board as the main component which is made from EPS beads provided by the chemical industry. EPS is manufactured from styrene, a liquid petrochemical, in the presence of small amounts of pentane (foaming agent) and a flame retardant (HBCD). Converters expand and mold the EPS beads to form boards or blocks by means of steam.* Besides EPS, the ETIC System contains adhesive, dowels, reinforcement plaster, reinforcement mesh and exterior plaster. The ETIC System is assembled at the construction site.
- Use of the house: The house is heated to obtain an average internal temperature of 19°C. The house does not have air conditioning, i.e. no cooling of the house in hot weather occurs.
- Disposal: At the end of the defined service life, the ETIC System is disposed of. 90% of the EPS is incinerated with energy recovery, the remaining components are landfilled.

* For more information on the manufacturing process of the EPS foam boards, please see http://www.eumeps.org/manufacturing_4106.html

System Description: House without ETICS

- Use of the house: The house is heated to obtain an average internal temperature of 19°C. The house does not have air conditioning, i.e. no cooling of the house in hot weather occurs.

Selection of the Alternatives
Preliminary remark

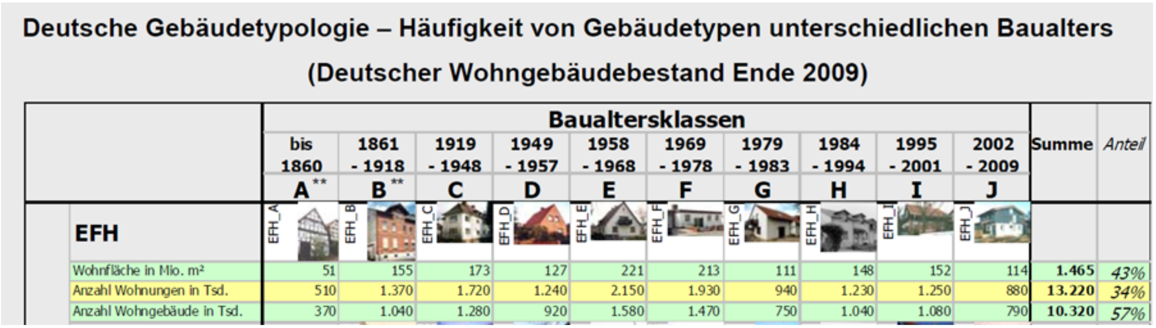
- The current German energy-efficiency regulation for buildings (EnEV 2009) differentiates between the refurbishment of existing buildings and the insulation of new houses with different requirements to the U-values of walls, roofs or windows.
- Consequently, two markets for insulation materials can be defined that form the basis for the selection of the reference case:
  - Insulation of existing buildings: The product of comparison is the implemented technology mix, which is currently 80 % of non-insulated houses and 20% of insulated houses in Germany.
  - Insulation of new buildings: Since it is a requirement to insulate new buildings, the product for comparison is the mix of new houses insulated with different insulation materials.
- According to a study by B+ L[3], about 60% of the insulation material in 2011 goes into the renovation market, 40% in new buildings. The present study addresses only the market of existing buildings.

Selection of the Alternatives

The solutions to compare were selected on the basis of the following facts:

- 83% of all buildings in Germany are detached and semi-detached houses (this corresponds to 43% of the total living area in Germany), thus the chosen building type of the case study represents the largest share of buildings in Germany.[4]
- Only about 20 % of the existing detached and semi-detached house stock in Germany is renovated with wall insulation.[5]
- The existing building stock in Germany has been categorized according to the construction year and type of building by the German Institut Wohnen und Umwelt GmbH (IWU) - institute for housing and environment[6,7]. Thus, for each building category and class, the total living space and the energy performance of the building in terms of the respective U-values for different construction components (such as exterior wall, roof, windows or floor) are known.

Selection of the Alternatives
German building structure



Deutsche Gebäudetypologie – Häufigkeit von Gebäudetypen unterschiedlichen Baualters

(Deutscher Wohngebäudebestand Ende 2009)

	Baualtersklassen										Summe	*Anteil*
	bis 1860	1861 - 1918	1919 - 1948	1949 - 1957	1958 - 1968	1969 - 1978	1979 - 1983	1984 - 1994	1995 - 2001	2002 - 2009		
	A**	B**	C	D	E	F	G	H	I	J		
EFH	EFH_A	EFH_B	EFH_C	EFH_D	EFH_E	EFH_F	EFH_G	EFH_H	EFH_I	EFH_J		
Wohnfläche in Mio. m²	51	155	173	127	221	213	111	148	152	114	**1.465**	*43%*
Anzahl Wohnungen in Tsd.	510	1.370	1.720	1.240	2.150	1.930	940	1.230	1.250	880	**13.220**	*34%*
Anzahl Wohngebäude in Tsd.	370	1.040	1.280	920	1.580	1.470	750	1.040	1.080	790	**10.320**	*57%*

Building type	A	B	C	D	E	F	G	H	I	J	K
Year of construction	up to 1860	1861-1918	1919-1948	1948-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	2002-2009	2010
Living area in million m²	51	155	173	127	221	213	111	148	152	114	14.65
U-value (wall) in W/(m²*K)	1.9	1.7	1.7	0.93	1.44	1.21	0.8	0.68	0.5	0.35	0.24
Share of building type of total living area in %	3.41	10.37	11.58	8.50	14.79	14,.5	7.43	9.90	10.17	7.63	0.98

References: (6) and (7); The living area for the building type K is estimated based on a new construction rate in Germany of about 1% of the existing living space per year (source: IWU Darmstadt).

Selection of the Alternatives Reference case

- Based on this information, an average U-value of 0.96 $W/(m^2*K)$ for an exterior wall of a single family detached house in Germany was calculated taking into consideration
  - For 80% of the total living area, the U-value (wall) of all existing single family homes in Germany that were built before 2011, which was defined to be the reference period. The average U-value was calculated as the sum of weighted U-values based on the relevant square meters of living space for the different building categories.
  - For 20% of the living area, that is the share of the already refurbished houses, an average U-value (wall) of 0.3 $W/(m^2*K)$[8] for all houses refurbished before 2011.
- This approach refers to a comparison to the weighted average based on the shares of all currently implemented technologies.

Selection of the Alternatives
Chemical product solution

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- For the refurbished house a U-value (wall) of 0.2 W/(m^2*K) was selected since this value
  - fulfills the requirements of the German Energy Savings Regulation EnEV 2009, which calls for a U-value (wall) of 0.24 W/(m^2*K) for renovated homes <u>and</u>
  - at the same time qualifies for participating in the KfW Bankengruppe loan and subsidy program, a well-established and frequently used loan program in Germany.

Selection of the Alternatives
The house

- The dimensions and geometry of the house including the number and size of windows were chosen to represent a typical single family detached house in Germany built in the 1960s. For more detailed information on the geometry and size of the house, please see Appendix B.
- Summary of building geometry:
  - Building envelope: 406 m^2
  - Building volume: 510 m^3
  - Heated air volume: 387.6 m^3
  - Living area: 163.2 m^2
  - Surface/volume ratio: 0.8

Selection of the Alternatives
Further building elements

- The U-values of the other construction components of the house (roof, windows and floor) that also affect the heating energy demand of the house but with equal impact on the different alternatives were selected according to the current requirements of the German Energy Savings Regulation EnEV 2009 for the refurbishment of buildings, again in conjunction with the criteria of the KfW Bankengruppe loan and subsidy program. Consequently, these building elements are state-of-the-art with a high thermal insulation.
- The table shows the selected values in comparison with the required U-values by EnEV 2009:

Building element	Selected U-Value	U-value required by EnEV 2009
Roof	0.14 W/(m^2*K)	0.24 W/(m^2*K)
Window	0.95 W/(m^2*K)	1.30 W/(m^2*K)
Floor	0.25 W/(m^2*K)	0.30 W/(m^2*K)

General Aspects

- Allocation procedures
  - No allocation was performed as no new processes were evaluated within the scope of this study. However, some of the used LCI inventory data (e.g. from LCI databases) are allocated inventories using common allocation approaches such as physical allocation or economic allocation. Credits and impact due to incineration of waste EPS are allocated 100% to ETIC System.
- Cut-off Rules
  - Cut-off for material and energy flows: not applicable

Time-related, Geographical and Technology Coverage

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- Time-related coverage: In this study, no primary data was collected for the different processes such as the production of the materials/energy or the end-of-life processes. Only the heating energy demand of the house and the thickness of the insulation material were calculated for the purpose of the study. The upstream process data (non-primary or secondary data) used mainly represent a time period from 2006 to 2012 but some process data refer back to the year 2000 and before.
- Geographical coverage: The geographical coverage of this study is Germany. However, some of the used upstream/secondary process data refer to the EU-27 (averaged data for Europe) or to Switzerland.
- Technology coverage: The study considers state-of-the-art processes for the production of the ETICS components, their disposal and for the extraction of the energy carriers. The heating technology represents the average technology currently used in Germany.

Service Life & Reference Period

- Service life: The service life was defined to be 40 years. As mentioned above, the life time of the insulation material is not limited to 40 years and may be as long as the life time of the building. A service life of 40 years was chosen in accordance with the assessment system for sustainable buildings, developed by the German Federal Ministry of Transport, Building and Urban Development (BMVBS) in collaboration with the German Sustainable Building Council (DGNB).[9]
- Reference period: The reference year of the study is 2011. Homes that were built until the end of 2010 are referred to as existing buildings. New buildings are homes built in 2011.

Reference Flow

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- The applied reference flows are:
  - The insulated house with 224 m^2 of an External Thermal Insulation Composite System (ETICS) with an EPS Board white (WLG 035 (λ= 0.035 W/(m*K)), density 20 kg/m^3) with a thickness of 14 cm achieving a U-value (wall) of 0.20 W/(m^2*K) and with a net heating energy demand of 10,018 KWh/a.
  - The insulated house with 224 m^2 of an External Thermal Insulation Composite System (ETICS) with an EPS Board grey (WLG 032 (λ = 0.032 W/(m*K)), density 15 kg/m^3) with a thickness of 14 cm achieving a U-value (wall) of 0.18 W/(m^2*K)[i] and with a net heating energy demand of 9,825 KWh/a.
  - The non-insulated house with a net heating energy demand of 20,875 KWh/a.

[i]In this alternative a U-value of 0.18 is obtained since commercially available insulation boards come with fixed thicknesses. With a thinner insulation board the required U-value of 0.2 W/(m2*K) had not been reached.

Data Sources

- In this study, primarily secondary data available from literature, previous LCA studies, and life cycle databases were used for the analysis.
- Only the thickness of the insulation material and the heating demand of the house for the different alternatives (foreground system) were calculated for the purpose of this study using the Hottgenroth Software[13] on the basis of the selected house and the defined energy requirements.
- For EPS white, the PlasticsEurope life cycle inventory data set was intentionally chosen before any company-specific profile in order to represent the industry average.

Software and Databases

- The LCA model was created using Excel 2010. The life cycle inventory data for the upstream production processes of the materials/energy carriers/electricity as well as for the disposal of the materials were taken either from the Boustead database (The Boustead Model, Version 5.0, extended by company-specific data) or from Simapro 7.3.2.
- Life cycle inventory data taken from different databases often represent different system boundaries. This likely inconsistency impairs the overall data quality.

Input Data
Overview time references *(1/2)*

Input Data	Time reference	Source
Heating energy demand of house	2013	Hottgenroth Software/Luwoge GmbH
Area and thickness of insulation material	2013	Hottgenroth Software/Luwoge GmbH
Life time of insulation system	2013	BMVBS/DGNB
Density of insulation material	2013	BASF/EUMEPS
U-value (wall) per building class	2005	IWU, Institut Wohnen und Umwelt
Living area per building class	2011	IWU, Institut Wohnen und Umwelt
Share of refurbished detached houses	2010	IWU, Institut Wohnen und Umwelt
U-value of insulated house	2013	EnEV 2009/KfW loan programm
U-value of other buildings components	2013	EnEV 2009/KfW loan programm
ETIC System components	2011/2012	EPD/BASF
Heating system	2009	Bundesverband Erneuerbare Energien
Mix of energy carriers	2010	IWU, Institut Wohnen und Umwelt
End-of-life scenario	2011	EPD

Input Data
Overview time references *(2/2)*

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Input Data	Time reference	Source
LCI data for upstream materials	2006-2011*	Boustead/Simapro
LCI data for transport	2005/2007	Simapro
LCI data end-of-life	2000	Simapro
LCI data energy carriers	2001	Boustead
LCI data heat	1996/2003	Simapro
LCI data electricity	2007	Simapro
Costs ETIC System	2012	Sto AG
Costs Disposal	2012	Waste management Schweinsfurt
Costs Transport	2007	Bfg & Planco Consulting GmbH
Costs Energy carriers/electricity/heat	2013	Various

* The LCI dataset for the aluminum eco-profile dates from 2000

Input Data
Key parameters of the study

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Key parameter	House w/o ETICS	House w/ ETICS-Styropor	House w/ ETICS-Neopor	Unit
Internal temperature of house		19		degree C
Façade, insulation area		224		m^2
U-value wall	0.96	0.20	0.18	$W/(m^2*K)$
U-value window		0.95		$W/(m^2*K)$
U-value roof		0.14		$W/(m^2*K)$
U-value floor		0.25		$W/(m^2*K)$
Thickness of insulation material	-	14	14	cm
Density of insulation material	-	20	15	Kg/m^3
Heating energy demand of house	20,875	10,018	9,825	KWh/a
Service life of house		40		years
Mix of energy carriers	50.3% natural gas, 35.9% oil, 6.3% biomass…			-
Efficiency of heating system	85% for natural gas, oil, coal, 75% for biomass			-

Input Data
House/Refurbishment data *(1/2)*

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	Unit	House w/o ETICS	House w/ ETICS-Styropor	House w/ ETICS-Neopor	Source
House volume	m^3	510	510	510	Luwoge Consult GmbH
Floor space	m^2	163.2	163.2	163.2	Luwoge Consult GmbH
Façade area	m^2	224	224	224	Luwoge Consult GmbH
U-value (wall)	$W/(m^2*K)$	0.96	0.20	0.18	Luwoge Consult GmbH
U-value (roof)	$W/(m^2*K)$	0.14	0.14	0.14	Luwoge Consult GmbH
U-value (floor)	$W/(m^2*K)$	0.25	0.25	0.25	Luwoge Consult GmbH
U-value (windows)	$W/(m^2*K)$	0.95	0.95	0.95	Luwoge Consult GmbH
Thermal conductivity EPS	W/(m*K)	-	0.035	0.032	BASF SE/EUMEPS/EPD[10]
Thickness insulation board	cm	-	14	14	Luwoge Consult GmbH
Density of EPS	Kg/m^3	-	20	15	BASF SE/EUMEPS/EPD[10]
Aluminum profile	Kg/m^2	-	0.14	0.14	BASF SE
Adhesive	kg/m^2	-	4.5	4.5	EPD[10]
Dowel	Pieces/m^2	-	8	8	EPD[10]
Reinforcing mesh*	m^2/m^2	-	1.1	1.1	EPD[10]

*Reinforcing mesh: 176 g/m2;

Input Data
House/Refurbishment data *(2/2)*

	Unit	House w/o ETICS	House w/ ETICS-Styropor	House w/ ETICS-Neopor	Source
Base coat	Kg/m^2	-	4	4	EPD[10]
Finishing coat	Kg/m^2	-	3	3	EPD[10]
Dowel -HDPE	g/piece	-	13.6	13.6	BASF SE
Dowel - steel	g/piece	-	21.0	21.0	BASF SE
Dowel- energy consumption	MJ/piece	-	0.3	0.3	EPD[11]
Net energy demand house*	KWh/a	20,875	10,018	9,825	Luwoge Consult GmbH

*Excluding the energy demand for warm water

Input data & Assumptions
Production and transport

- Installation of the ETIC System: Loss of insulation material (cuttings) during installation: 5%
- Transportation was considered with transport distances and modes as follows:[12]

Transport	Distance	Type of vehicle
EPS beads to converter	200 km	Lorry, 40 t
Insulation boards to construction site	200 km	Lorry, 40 t
Other materials to construction site	200 km	Lorry, 7.5 t
Insulation boards to disposal	26.5 km	Lorry, 22 t
Other materials to disposal	15.5 km	Lorry, 22 t

Input Data & Assumptions
Use phase *(1/2)*

- The pentane remaining in the EPS insulation boards after foaming is slowly released over time and was considered in the use phase.
- The heating energy demand of the single family detached house to keep the internal temperature at 19°C on average was calculated by Luwoge Consult GmbH, a subsidiary of BASF and a consultancy in the real estate area, based on a monthly energy balance of the house with and without the wall insulation system[13] (see appendix B). These calculations take into account various kinds of energy losses but also heat gains e.g. due to solar radiation and are based on heating degree days and thus on the temperature conditions in Germany.
- Energy carriers and assumed efficiencies of the heating systems were taken from statistics on the heating structure of detached and semi-detached houses in Germany[5] and from industry surveys[14].

Input Data & Assumptions
Use phase *(2/2)*

- Mix of energy carriers[5] and efficiencies of heating systems[14]

	Share in %	Efficiency of heating system
District heating	2.1	-
Natural gas	50.3	0.85
Oil	35.9	0.85
Biomass (wood)	6.3	0.75
Coal	0.7	0.85
Electricity (thereof 2% heat pump)	4.8	-

Input Data & Assumptions
End of life

- After use, the ETICS is destroyed.
  - A selective demolition was assumed according to Muster ESD-EVW-2011511-D[10]: 90 percent of the EPS (mono-material) is recovered and incinerated with energy recovery. The remaining EPS, plaster and other materials are landfilled.
  - For the incineration with energy recovery, the net energy produced in the municipal solid waste incinerator (3.67 MJ electricity/kg EPS and 7.39 MJ thermal energy/kg EPS) was accounted for as a credit.
  - The demolition itself was not considered.

Input Data & Assumptions
Costs *(1/2)*

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ETIC Systems	Unit	ETICS with Styropor 035	ETICS with Neopor 032
Total costs*	€/m^2	81	74

* Including material costs, salary and scaffolding costs; Source: Results of tender, Germany, 2012

Other costs	
Transport	0.113 €/t*km
Disposal EPS insulation board (incineration)	165 €/t
Disposal other materials (landfill)	53 €/t

Source waste management: Schweinsfurt, Germany; http://www.ihr-umweltpartner.de/Preisliste_Preisliste_awz_427_kkmenue.html
Source transport: 2007, bfg; Vergleich der Verkehrsträger ….

Input Data & Assumptions Costs *(2/2)*

Energy costs (purchase prices in 2013)	
Natural gas	0.0687 €/kWh*
Heating oil	0.0818 €/kWh*
Coal briquettes	0.05 €/kWh**
District heating	0.107 €/kWh***
Wood pellets	0.0555 €/kWh*
Electricity	0.285 €/kWh****

Sources: *DEPV: dt. Energieholz- und Pelletverband e.V; **http://www.elgato.de/brennstoffe%20im%20preisvergleich.html; 1 kg briquettes = 5.52 KWh; ***EnBW http://www.enbw.com/content/de/privatkunden/produkte/waerme/fernwaerme/index.jsp; ****Stadtwerke Frankenthal http://www.stw-frankenthal.de/fileadmin/user_upload/Strompreise_FT__01.01.2013_GV.pdf

- No development of costs such as future price increases was considered in the cost calculation (conservative approach).

Data Quality *(1/2)*

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Information	Source	Database	Year	Region	Quality
EPS beads, grey (Neopor)	BASF SE production plant	Boustead	2011	Germany	High
EPS beads, white (Styropor)	PlasticsEurope	Simapro	2006	Europe	High
Hexabromocyclododecane (HBCD)	Company data	Boustead	2008	Europe	High
EPS board production	EUMEPS	Boustead	2009	Europe	High
Aluminum profile	Environm. Profile Report for the EU Aluminum Industry	Boustead	2000	Europe	Medium
Dowel production	EPD-EJOT-2011112-D	-	2011	Germany	High
HDPE	Plastics Europe	Simapro	2007	Europe	High
Stainless steel	ELCD	Simapro	2007	Europe	Medium
Adhesive	Colformit	Boustead	2008	Germany	Medium
Reinforcing mesh	Colformit	Boustead	2008	Germany	Medium
Base coat	Company data	Boustead	2009	Germany	High
Fishing coat (organic)	Company data	Boustead	2009	Germany	High
Lorry transport	ELCD	Simapro	2005/2007	Europe	High
Incineration with energy recovery	Ecoinvent/BASF	Simapro	2000	Switzerland	Medium
Landfill	Ecoinvent	Simapro	2000	Switzerland	Medium

The data quality assessment was performed using a qualitative approach developed by BASF (see Appendix A for more details).

Data Quality *(2/2)*

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Information	Source	Database	Year	Region	Quality
Natural gas use	Boustead	Boustead	2001	Germany	Medium
Light fuel oil use	Boustead	Boustead	2001	Germany	Medium
Coal use	Boustead	Boustead	2001	Germany	Medium
District heating	ETH-ESU	Simapro	1996	Switzerland	Low
Heat from wood	Ecoinvent	Simapro	2003	Switzerland	Medium
Electricity	Ecoinvent	Simapro	2007	Germany	High

The data quality assessment was performed using a qualitative approach developed by BASF (see Appendix C for more details).

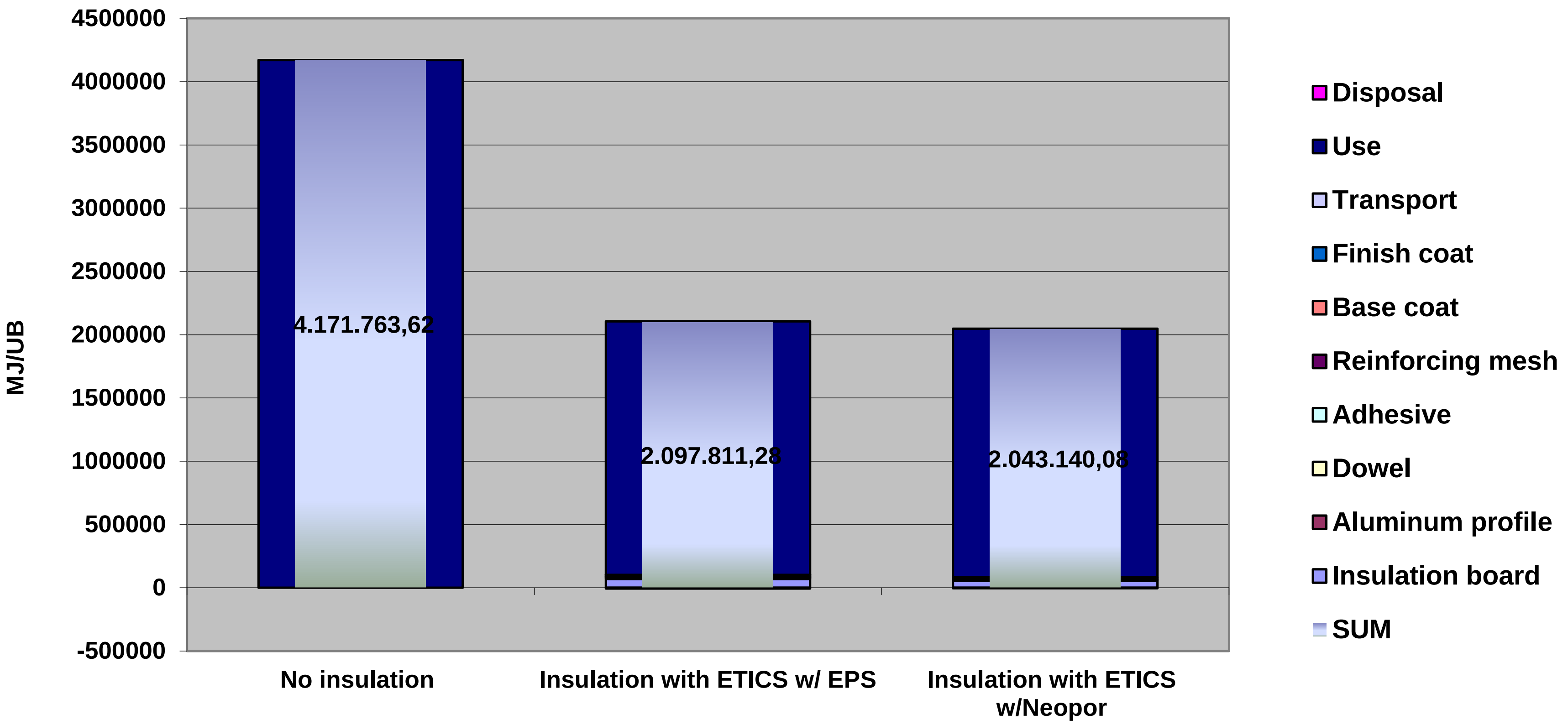
Summary Data Quality

- Overall, the quality of the data used in this study is considered to be sufficiently good and appropriate of the described solutions by the author of this study.
- The quality of the secondary data from the two life cycle databases ‘Boustead’ and ’Simapro’ to model the upstream processes is impaired by possible inconsistent system boundaries of the two databases and by the age of some data sets. However, individual data quality measures are applied in both databases to ensure coherent and appropriate quality data.
- The quality of the secondary data taken from literature to model the house (heating system, energy mix, components of the ETIC System etc.) is considered to be good and representative of the described system to represent an average situation in Germany.

Life Cycle Assessment Results

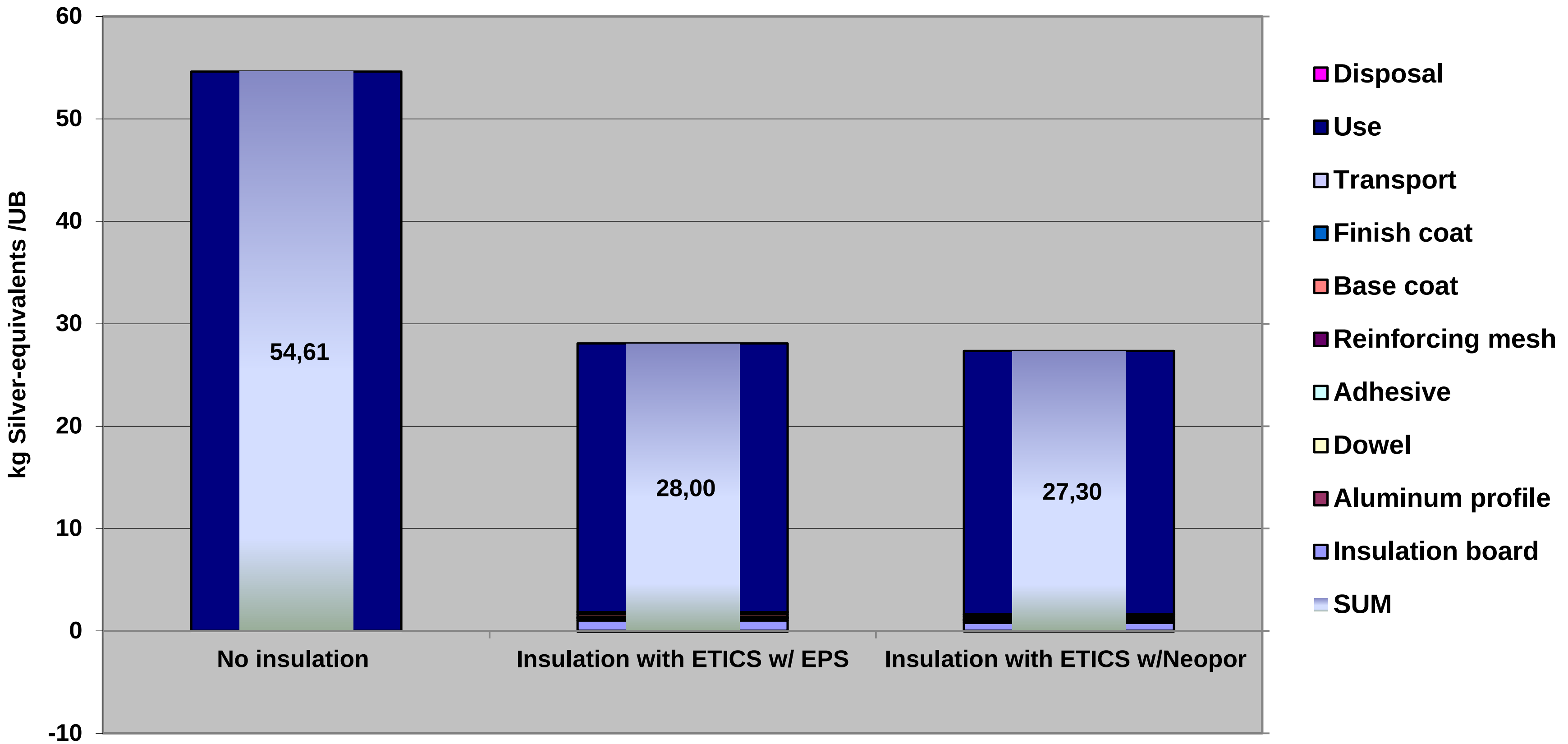
Cumulative Energy Demand

Calculation Factor: 20%



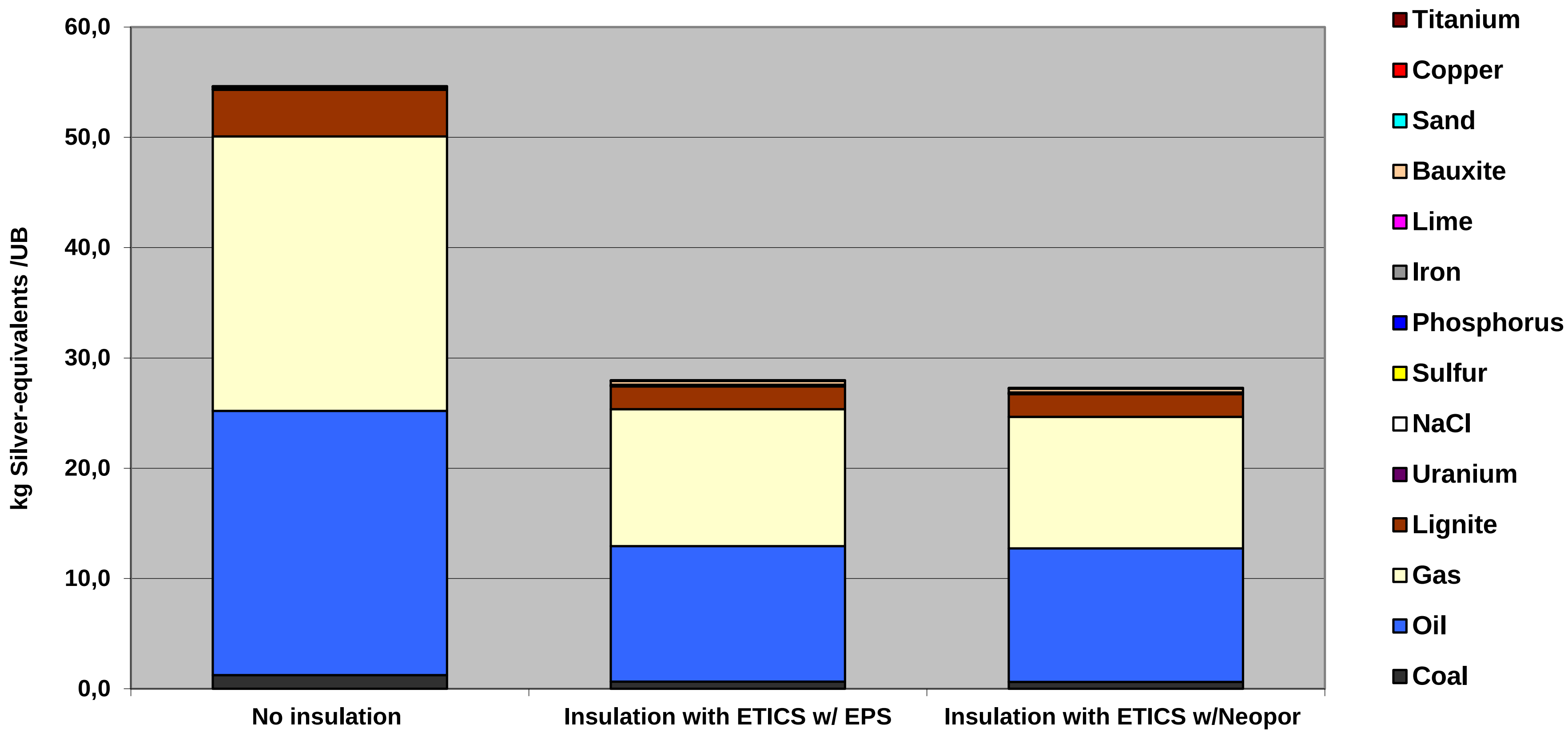
Abiotic Depletion Potential (ADP)

Calculation Factor: 16%



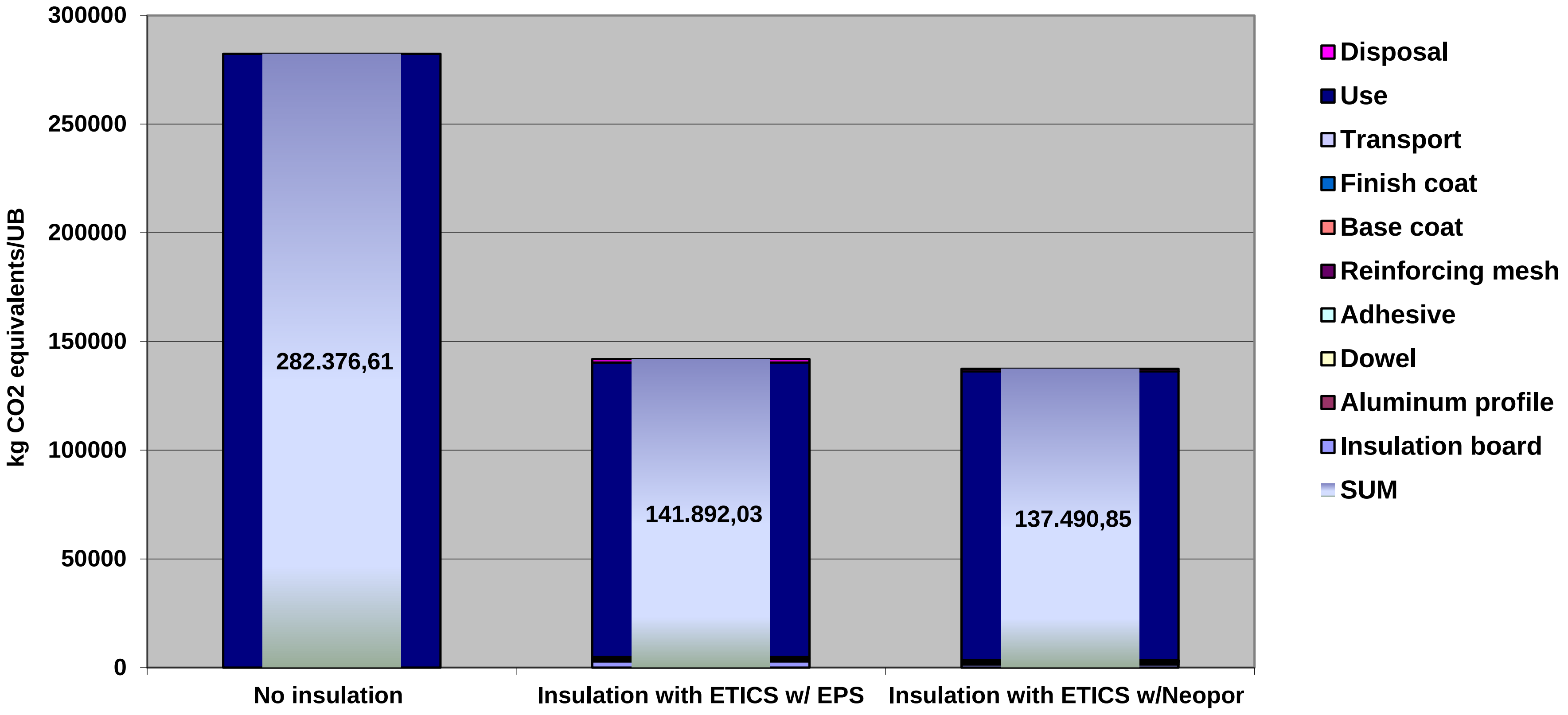
Abiotic Depletion Potential (ADP)

Calculation Factor: 16%



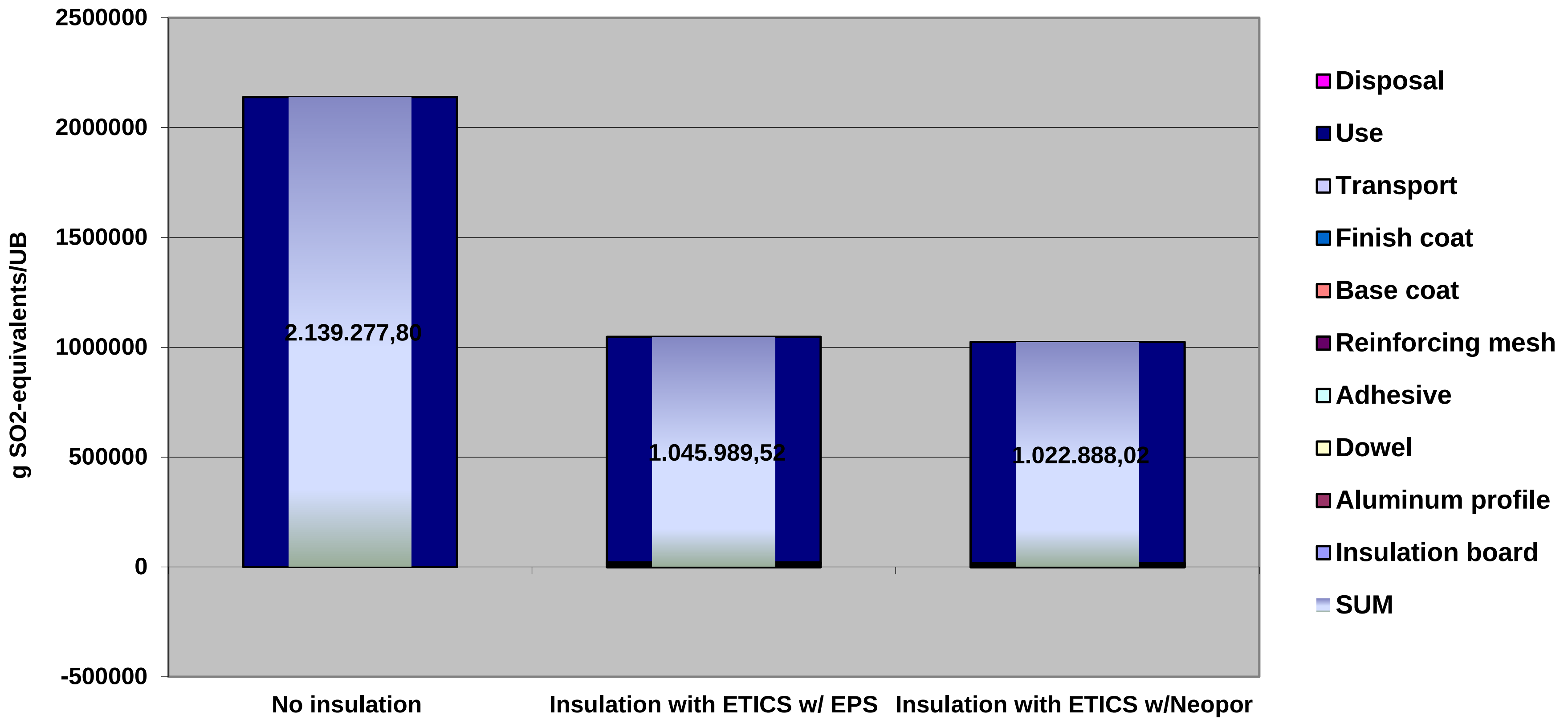
Global Warming Potential (GWP)

Calculation Factor: 7%



Acidification Potential (AP)

Calculation Factor: 9%



CED, ADP, GWP and AP: Comments

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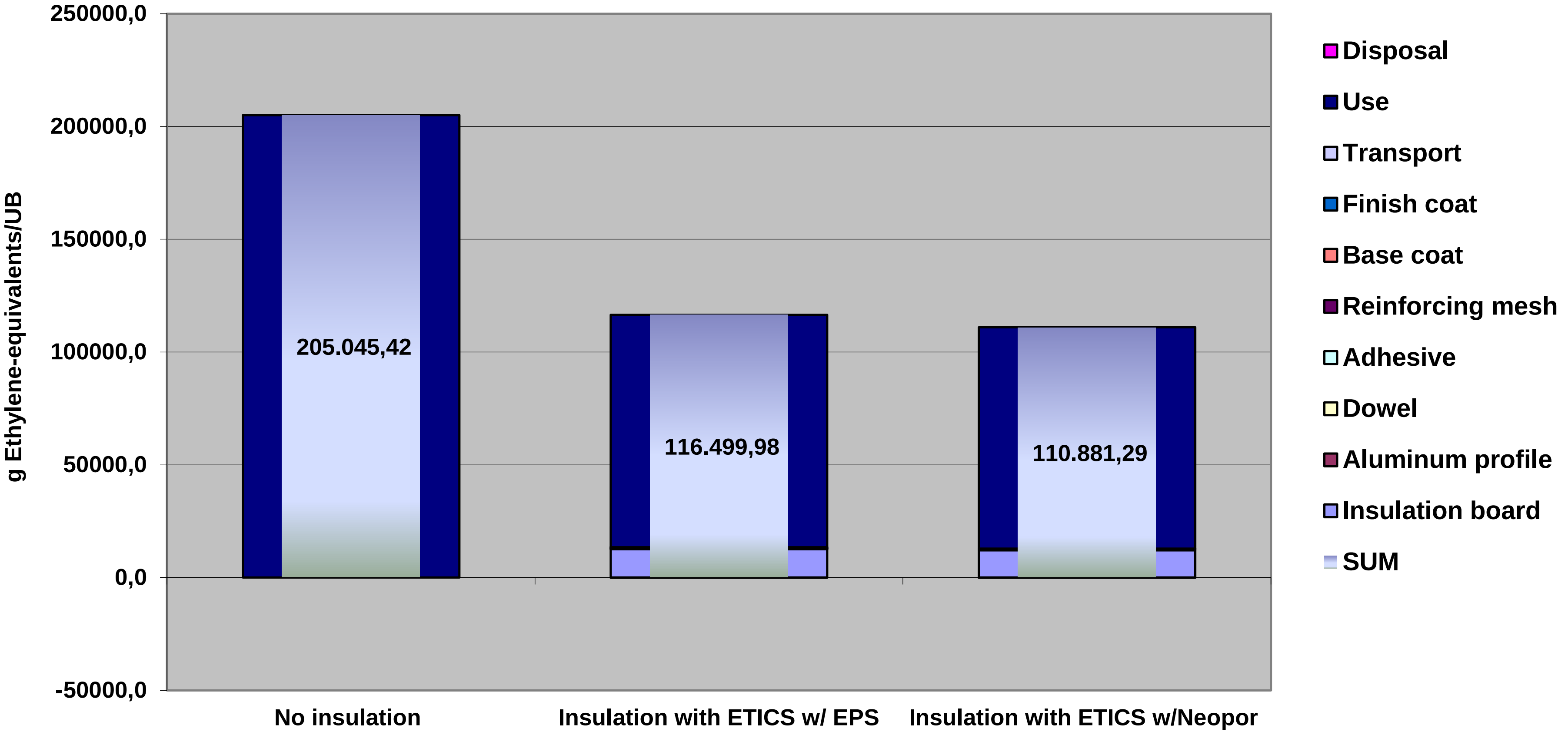
- The four environmental impact categories mentioned above, i.e. the cumulative energy demand (CED), the abiotic depletion potential (ADP), the global warming potential (GWP) and the acidification potential (AP), are primarily dominated by the use phase, i.e. by the use and combustion of fossil fuels for heating the house.
- The environmental impacts of the production and disposal of the ETIC Systems are comparably small and thus not visible in the graphs.
- The two alternatives 'Insulation with ETICS' show an enhanced performance in the different environmental impact categories compared with the alternative "no insulation" as they require less fossil fuel.
- The type of EPS insulation material (Neopor versus Styropor) does not affect the overall environmental performance of the respective systems. Both alternatives 'Insulation with ETICS' have about the same impact in the different impact categories.

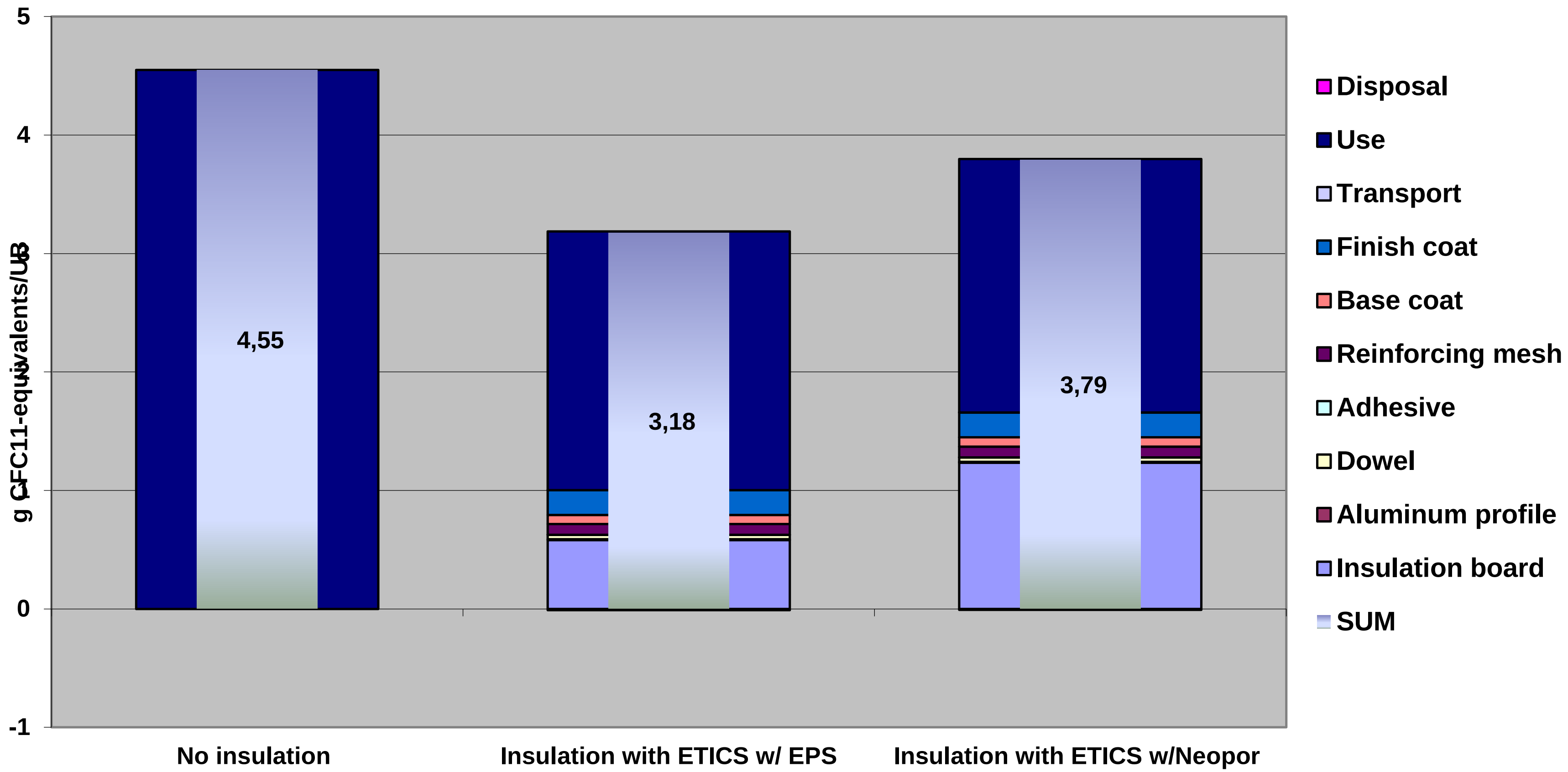
Photochemical Ozone Creation Potential (POCP)

Calculation Factor: 5%



Ozone Depletion Potential (ODP)

Calculation Factor: 0%

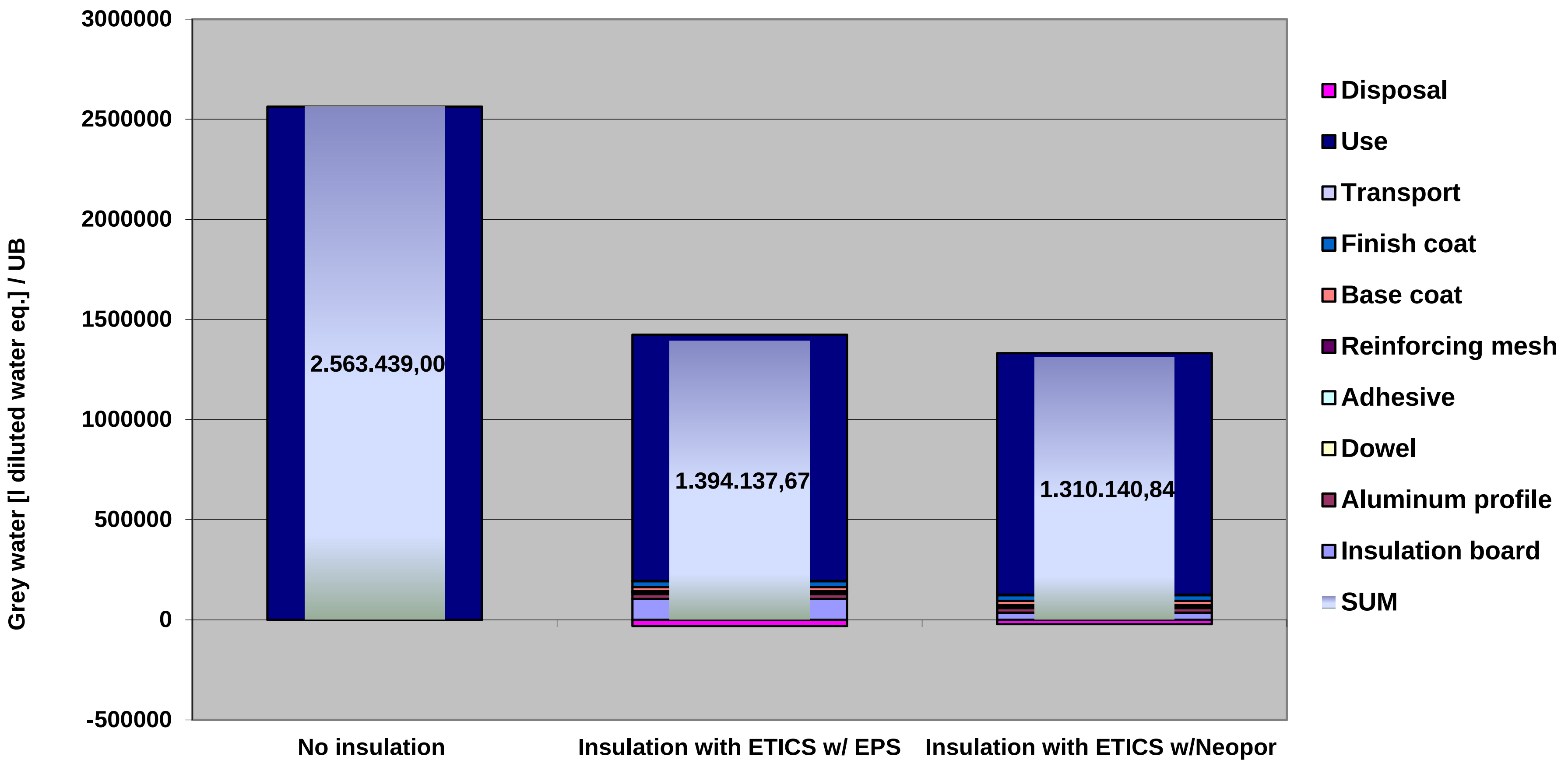


POCP and ODP: Comments

- Both, the photochemical ozone creation potential (POCP) and the ozone depletion potential (ODP) are, like the other environmental impact categories, dominated by the use phase, i.e. the combustion of fossil fuels and the use of electricity to heat the house (inter alia in conjunction with district heating). The latter particularly affects the ODP.
- The contribution of the insulation boards to the total POCP of the two alternatives ‘House with ETICS’ derives from respective emissions during the production of the EPS beads and the subsequent expansion of the beads by means of pentane to form insulation boards.
- The ozone depletion potential of the two ETICS alternatives is partly impacted by the production of the insulation boards or insulation material, respectively. The respective emissions result from halogenated hydrocarbons that are among others used for the production of the flame retardant used in the polymers.

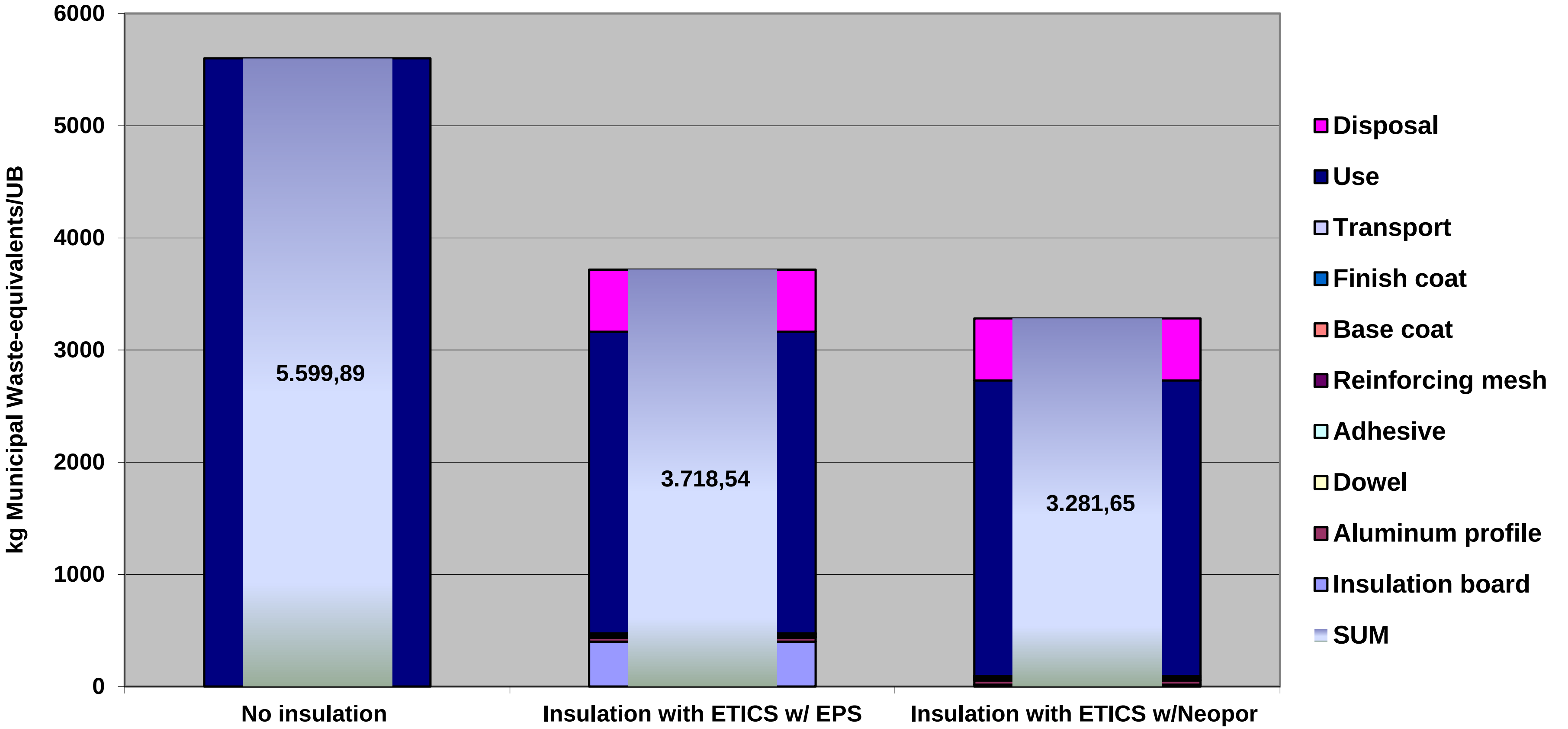
Water Emissions

Calculation Factor: 3%



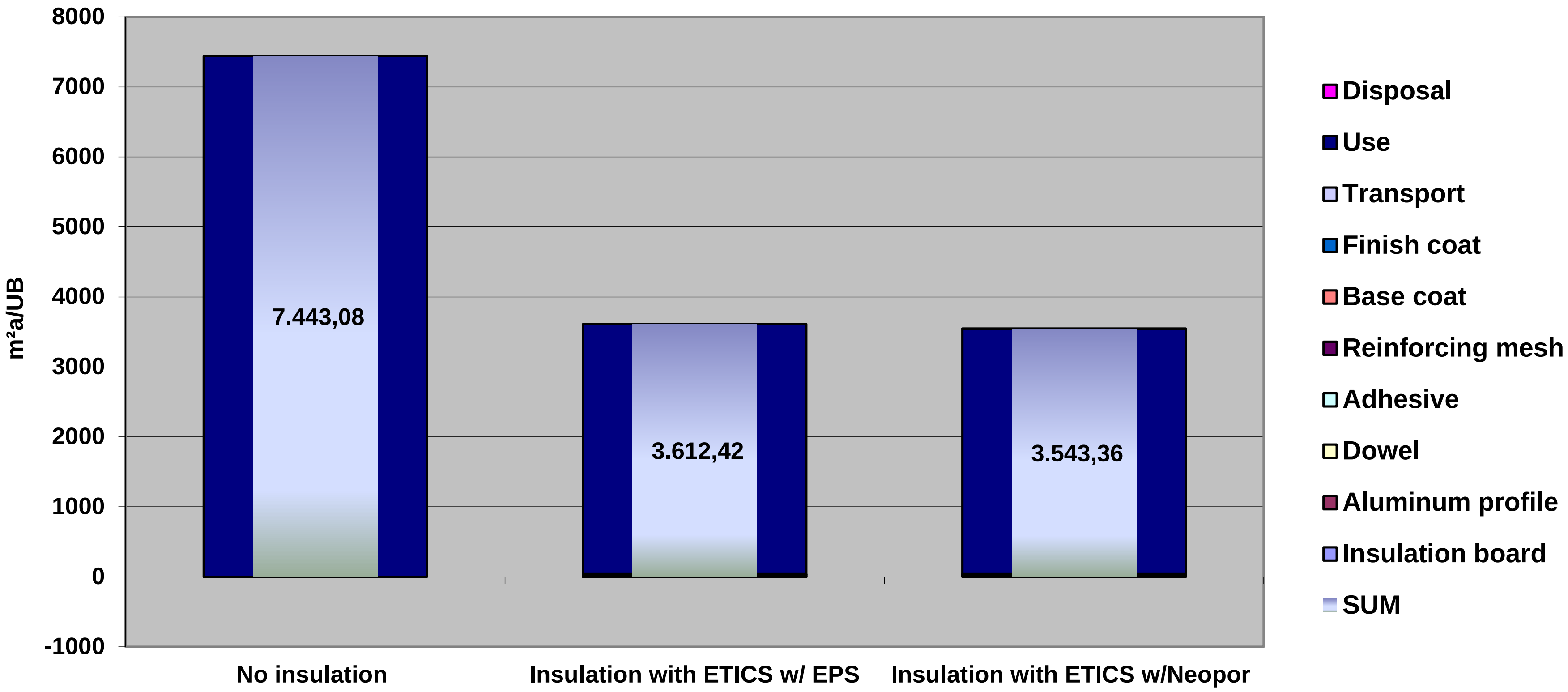
Solid Wastes

Calculation Factor: 4%



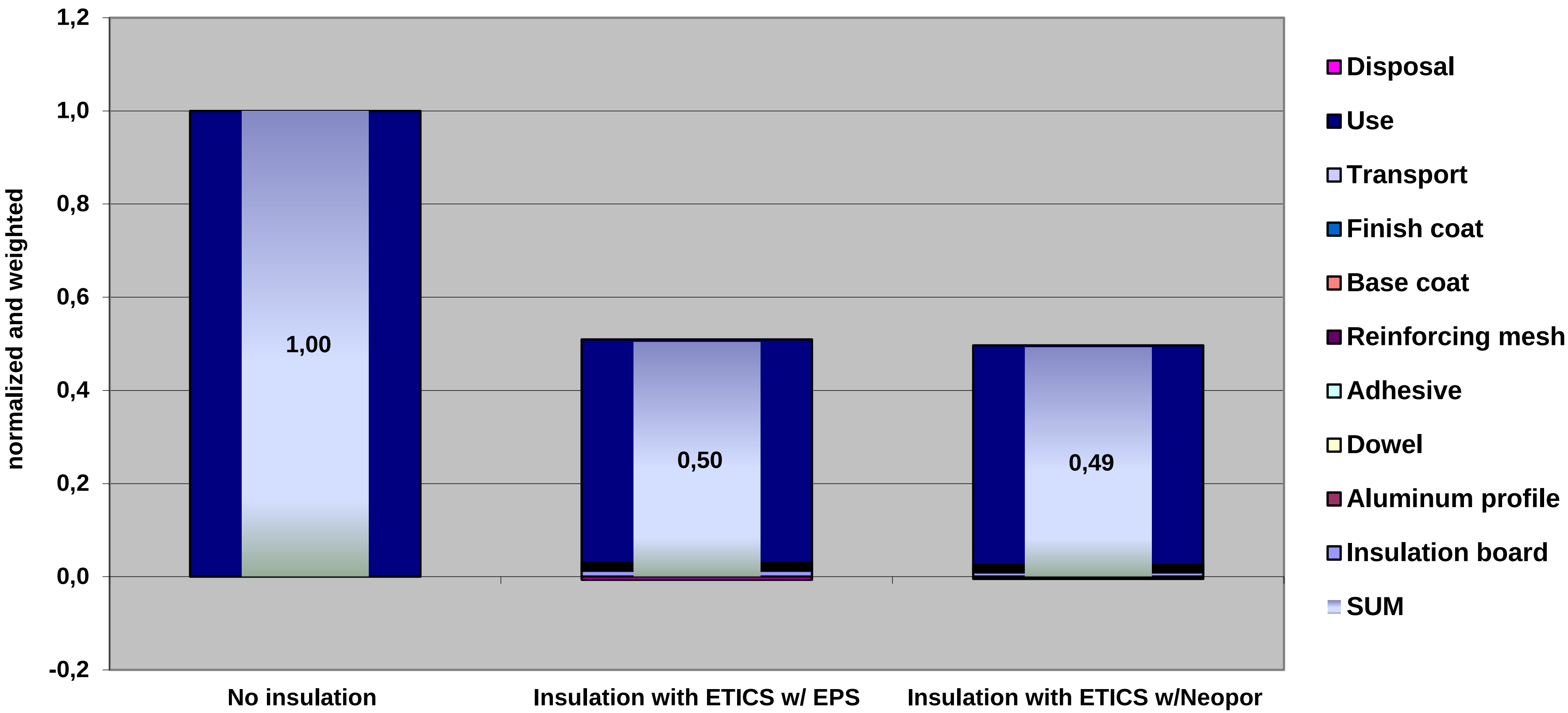
Land Use

Calculation Factor: 7%



Risk Potential

Calculation Factor: 7 %

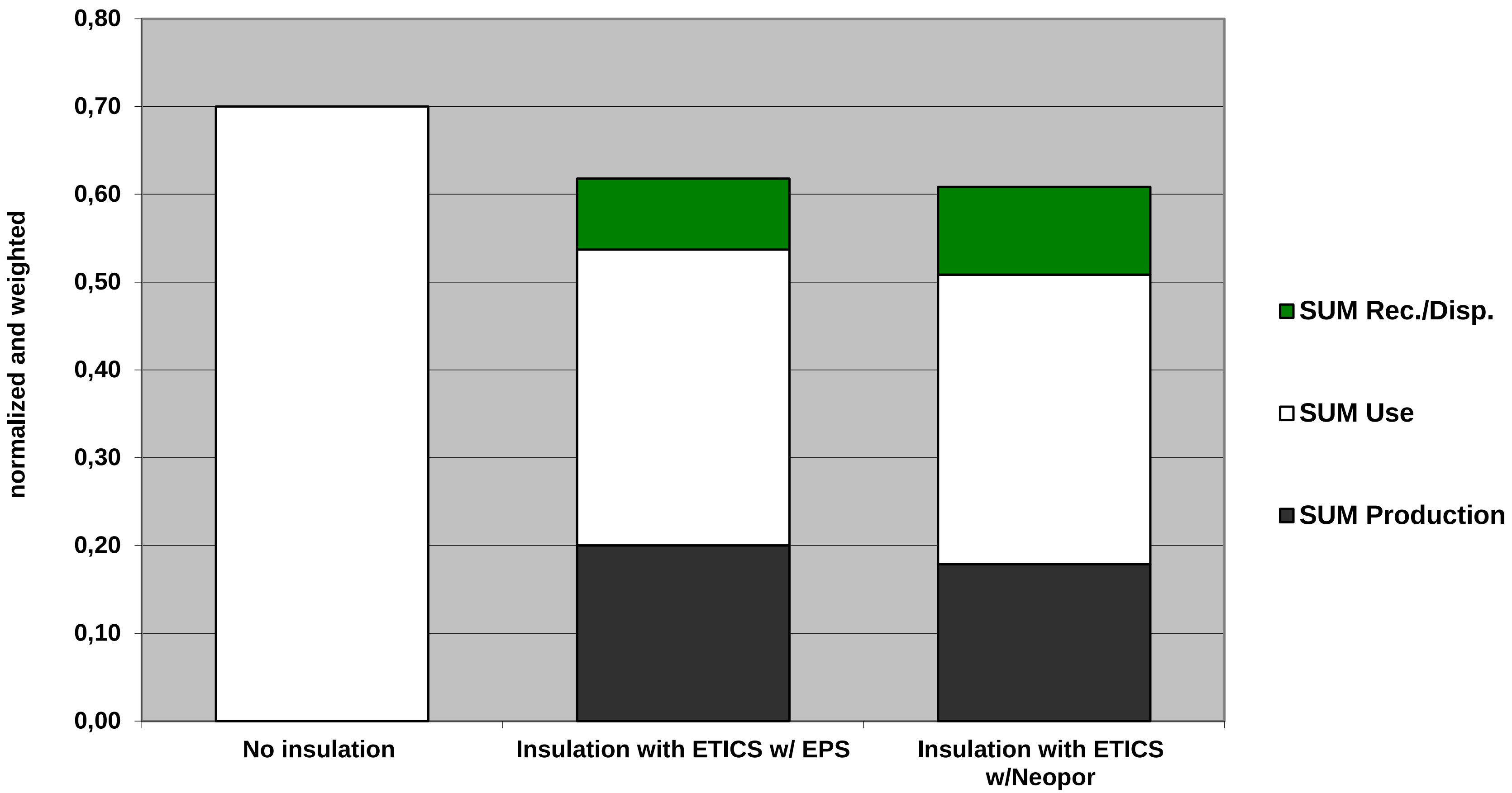


Water Emissions, Solid Waste, Land Use and Risk Potential: Comments

- The environmental impact categories water emissions, solid waste, land use and the risk potential are like the previous categories primarily dominated by the use phase i.e. the extraction and use/combustion of fossil fuels. Likewise, the environmental impacts related to the production and disposal of the ETIC System are comparably small.
- The insulated alternatives perform consistently better throughout the environmental impact categories than the non-insulated alternative. However, the type of insulation material hardly affects the overall system.
- The environmental impact category solid wastes shows for the two alternatives ‘Insulation with ETICS’ the contribution of the ETICS system, i.e. the solid wastes that are generated during production and disposal.
- The occupational illnesses & accidents potential is based on statistical values for occupational illnesses and accidents according to industrial branch (by NACE code) and is linked to the amounts of materials/energy carriers used to fulfill the user benefit.

Toxicity Potential

Calculation Factor: 22%

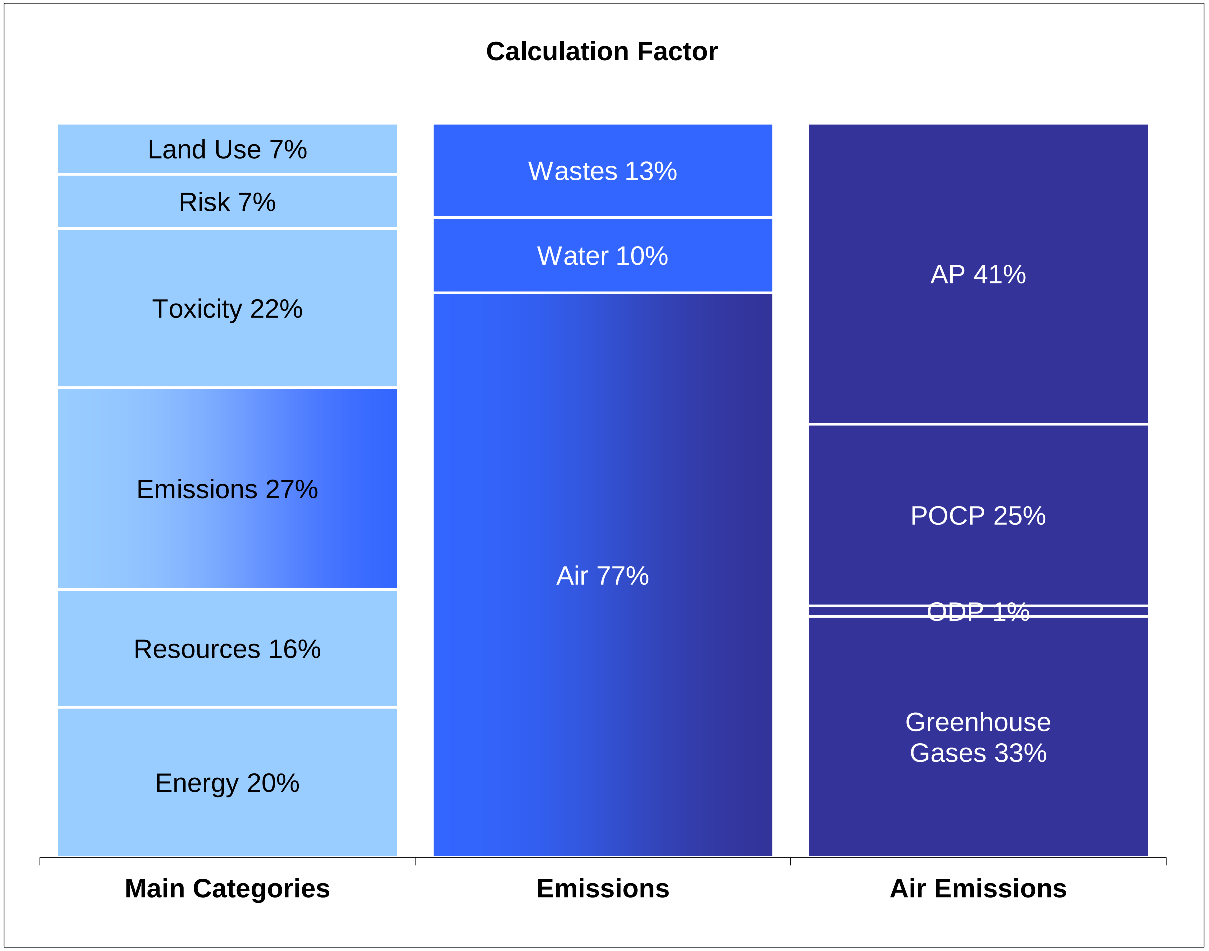


Toxicity Potential: Comments

- The toxicity potential has an influence of 20% (standard weighting factor) and is calculated separately for the production, use and disposal phase. The life cycle phases are differently weighted as follows: Production phase: 20%, use phase: 70 % and disposal:10%.
- The toxicity potential is determined using an assessment method developed by BASF based on the H-phrases of chemicals. The results of these assessments are expressed in dimensionless toxicity units which are then multiplied by the amount of material used to result in the overall toxicity potential.
- The toxicity potential of the alternatives is dominated by the use phase since the overall result is linked to the amount of material/energy used. For the two alternatives 'Insulation with ETICS' and additional effect occurs: Through the unequal weighting of the different life cycle phases, the impact of the production phase or of the chemicals respectively is reduced in relation to the use phase and visa verse.
- Note: The toxicity potential of the emitting pentane during the use phase was not considered due to its irrelevant low concentration.

Eco-Efficiency Results

Calculation Factors for this Eco-Efficiency Analysis



BIP-Relevance: 2.42

Environmental Fingerprint

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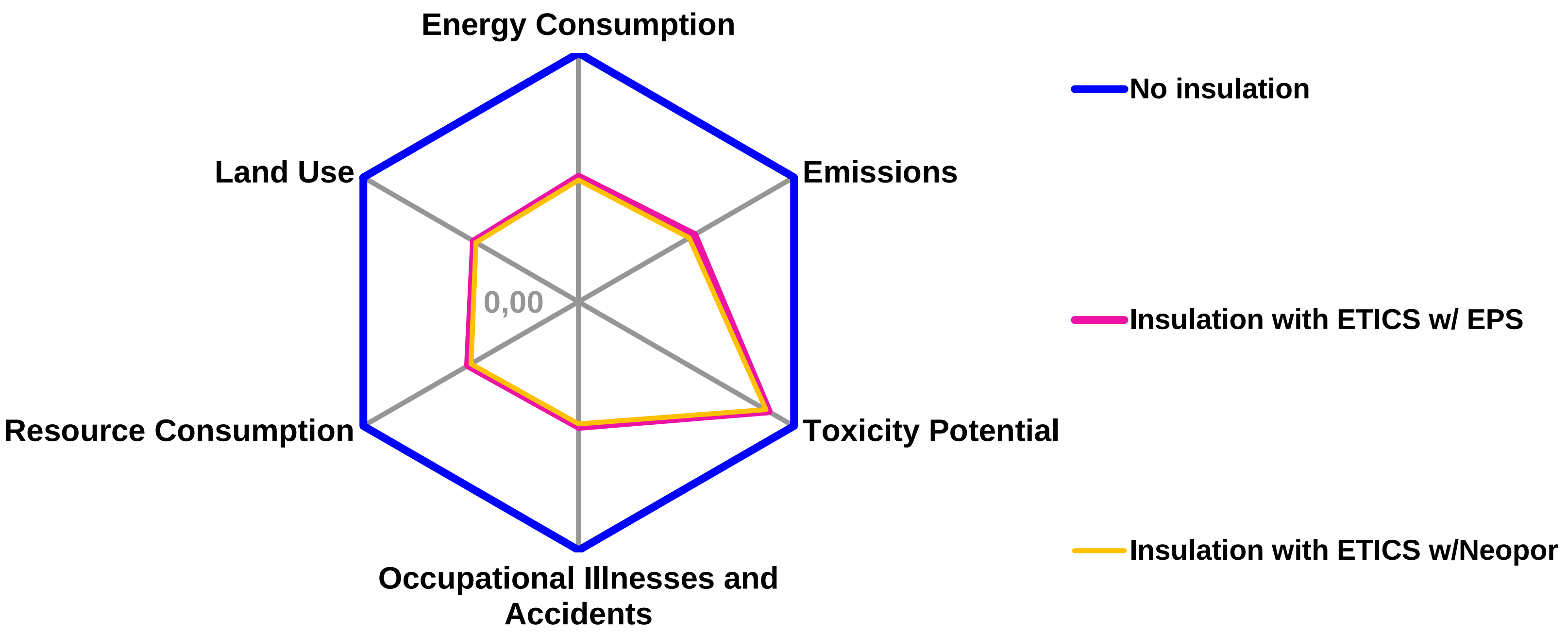

Environmental Fingerprint: Comments

- The ecological fingerprint shows the different environmental impact categories in a normalized style.
- A value of 1 represents the alternative with the highest impact in the concerning category, all other alternatives are rated in relation to 1.
- The two alternatives “insulation with ETICS” have an identical environmental performance, but a lower impact in all six environmental categories compared with the non-insulated house.

Costs Summary

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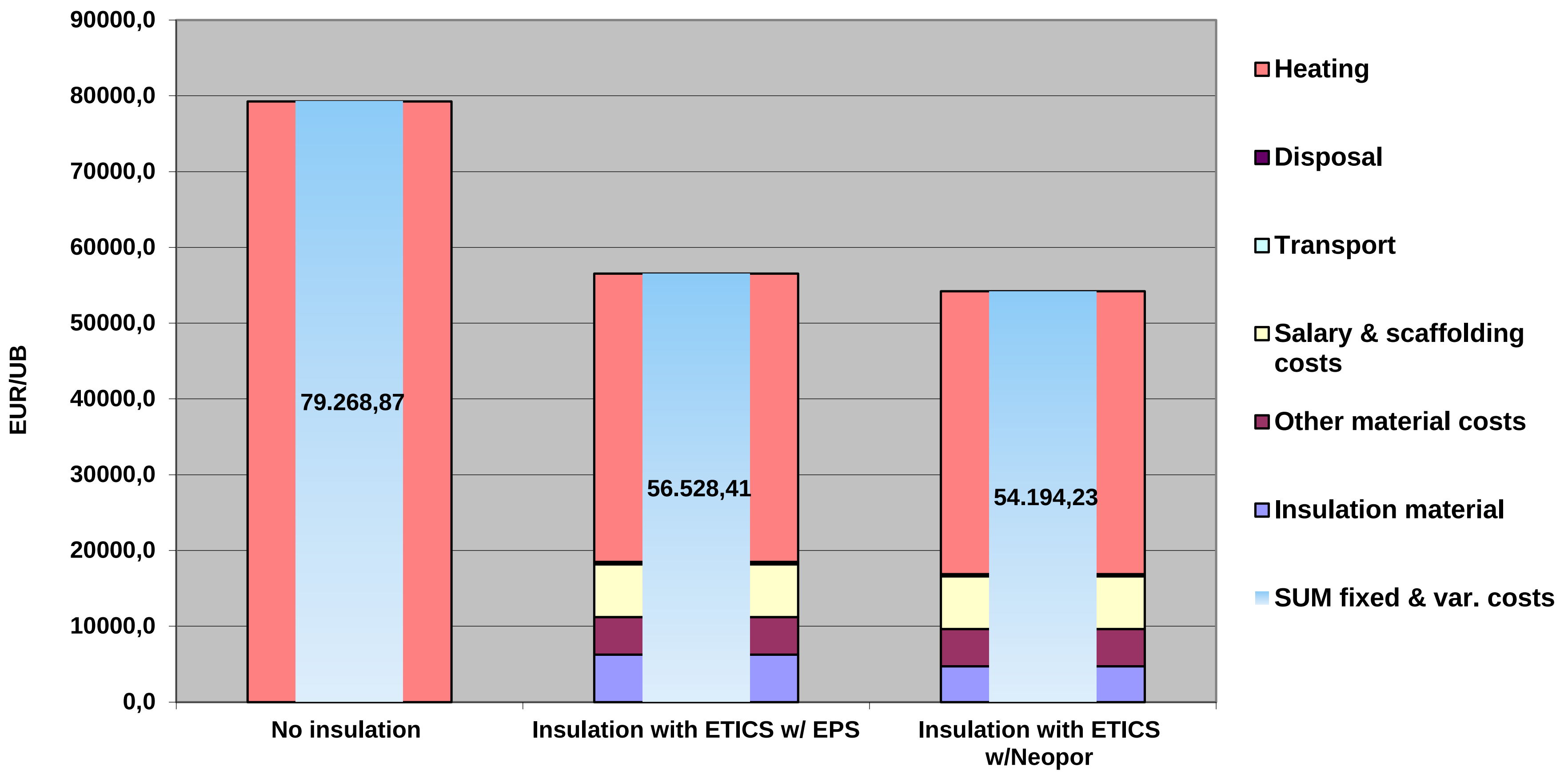

Costs Summary: Comments

BASF
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- Costs are actual costs of the year 2012/2013. An inflation rate was not considered.
- The life cycle costs of the different alternatives are determined by the use phase i.e. the costs for heating the house.
- Thus, the alternative without the insulation system results in the highest costs.

Eco-Efficiency Portfolio (Base Case)

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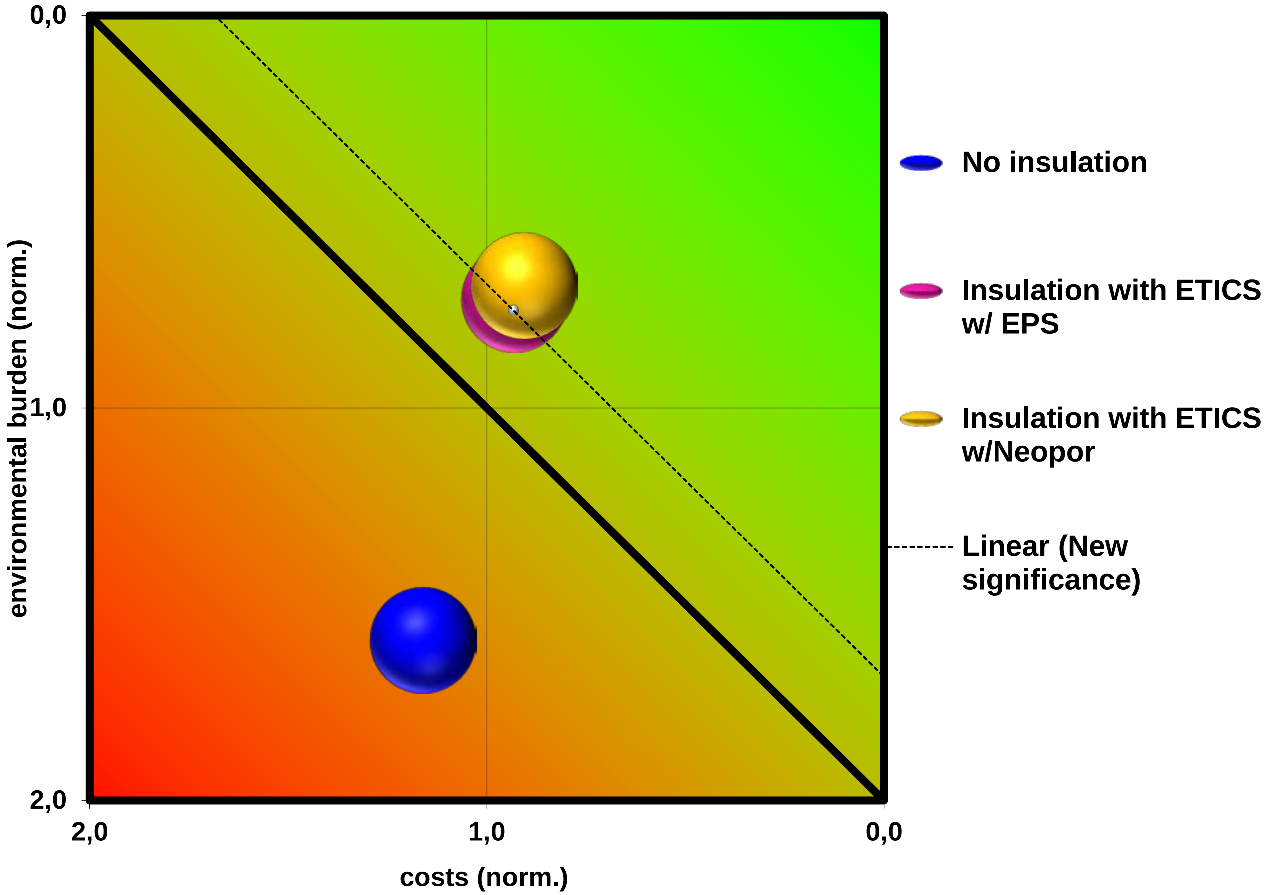
<u>Base Case:</u>
Living in an existing detached house in Germany at an average room temperature of 19°C for 40 years (2011-2051)



Eco-Efficiency Portfolio (Base Case): Comments

- The two ETICS alternatives are significantly more eco-efficient than the non-insulated alternative, both with significantly lower environmental impacts and lower costs.
- The type of insulation material used as part of the ETIC System does not have an impact on the eco-efficiency performance of the alternatives: Both insulated systems perform about equal as the results of this study are dominated by the use phase and thus by the different heating energy demands of the non-insulated and the insulated house, respectively.
- The environmental differences are significant and by far more pronounced than the economic differences.

Crucial Influencing Factors

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ENVIRONMENT

- The energy performance of the building and thus the combustion of fuels in combination with the use of electricity or district heating to heat the house.
- The fuel or energy carrier mix
- The service life of the house
- The efficiency of the heating systems

COSTS

- The energy performance of the building and thus the fuel costs in combination with costs for electricity and district heating for heating the house.
- The energy carrier mix
- The service life of the house
- Material costs for the production of the ETIC Systems

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Completeness and Consistency Check

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- Completeness check: All relevant processes regarding the different life cycle phases were considered and modeled in accordance with the goal and scope definition of the study and the defined system boundaries.
- Consistency check: The data, methods and assumptions applied throughout the analysis were selected to ensure consistency and allow consistent statements.

Conclusion *(1/2)*

- This study quantifies the environmental and economic performance of an existing detached house with and without a wall insulation system (ETICS) based on expandable polystyrene (EPS white or grey) over a life time of 40 years. The main focus of the study was to analyze the contribution of chemical insulation products as part of a wall insulation system to GHG emissions reductions. The study serves as the analytical foundation for a case study to be included in the *Guidelines from the Chemical Industry for accounting an reporting GHG emissions avoided along the value chain based on comparative studies*[1].
- The results of the study within its limited scope clearly demonstrate the environmental and economic benefits of wall insulation by saving energy to heat the house. Thus, the crucial lever in the study is the use phase.
- The quantified benefit such as the particular amount of GHG emissions that can be avoided by using wall insulation materials very much depends on the assumed conditions or the reference case. The impact of these changes on the results of the base case was modeled in the scenario analysis, in which a limited range of options was varied.

Conclusion *(2/2)*

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- The type of the insulation material (EPS white or EPS grey) does not affect the outcome of the study.
- The results of the study are very much affected by the energy performance of the non-insulated house (reference case): The worse it is the larger the positive contribution of the insulation system and visa verse (ref. scenarios 1 and 2)
- The contribution of insulation materials to reduce GHG emissions in the building sector will decrease with a changing energy sector towards a low-carbon energy mix based on renewable energies.

Study Limitations

- The present study analyzes just one of the many aspects in the low-energy modernization of a house and in this context only the impact of a chemical solution. This simplified approach does not (necessarily) reflect the current practice and thus limits the conclusiveness of the study.
- The study is based on specific conditions and assumptions that were selected to demonstrate an average situation for Germany. Consequently, the study results are less realistic and are not transferable to other conditions that might be present in the real case.
- The results of this analysis are dominated by the use phase, i.e. the heating energy demand of the house and the service life. Therefore these results are very sensitive to the applied heating mix or the underlying energy carriers, respectively, the efficiencies of the heating systems, the life time of the house as well as to the climatic conditions of the location of the studied house. Thus the conclusions of this study cannot be applied unreservedly to other conditions.

Recommendations

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- The results of the study should be seen within its limited boundaries and thus shall only be used in an appropriate manner in accordance with the goal and scope of the study.
- In future, assess the impact of different climate conditions on the outcomes of the study.
- When appropriate, update the underlying assumptions and input data as well as increase consistency among data sources.

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Scenario Analysis

- Scenario 1: “Worst Case”-scenario
- Scenario 2: “Best Case”-scenario
- Scenario 3: Refurbishment of a house from the 1960s
- Scenario 4: Shorter service life of the ETIC System/house
- Scenario 5: “Scenario 2050” - Base case with a low-carbon energy carrier mix
- Scenario 6: Transition to “Scenario 2050” - “Scenario 2030”
- Scenario 7: Consideration of the construction and disposal phases of the house

Scenario Analysis: Motivation *(1/2)*

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- Scenarios 1 and 2: The worst case scenario (walls of the reference house have a high heat loss and an ancient oil-based heating system is used) and the best case scenario (walls of the reference house have a low heat loss and a highly efficient gas heater is used) are supposed to show the two extremes of possible results as well as the variability of results of an actual insulation case since the base case of the study was designed to represent a less realistic average case.
- Scenario 3 shows the results of the refurbishment of a house from the 1960s or 1970s with an average U-value (wall) of 1.3 W/(m2*K). Single family houses built between 1959 and 1979 belong to the building classes E and F with the largest share in the total living area of existing single family homes in Germany. Both building classes together represent 30% of the existing building stock based on living area.
- Scenario 4 studies the impact of the service time/life time of the house on the results of the study.

Scenario Analysis: Motivation *(2/2)*

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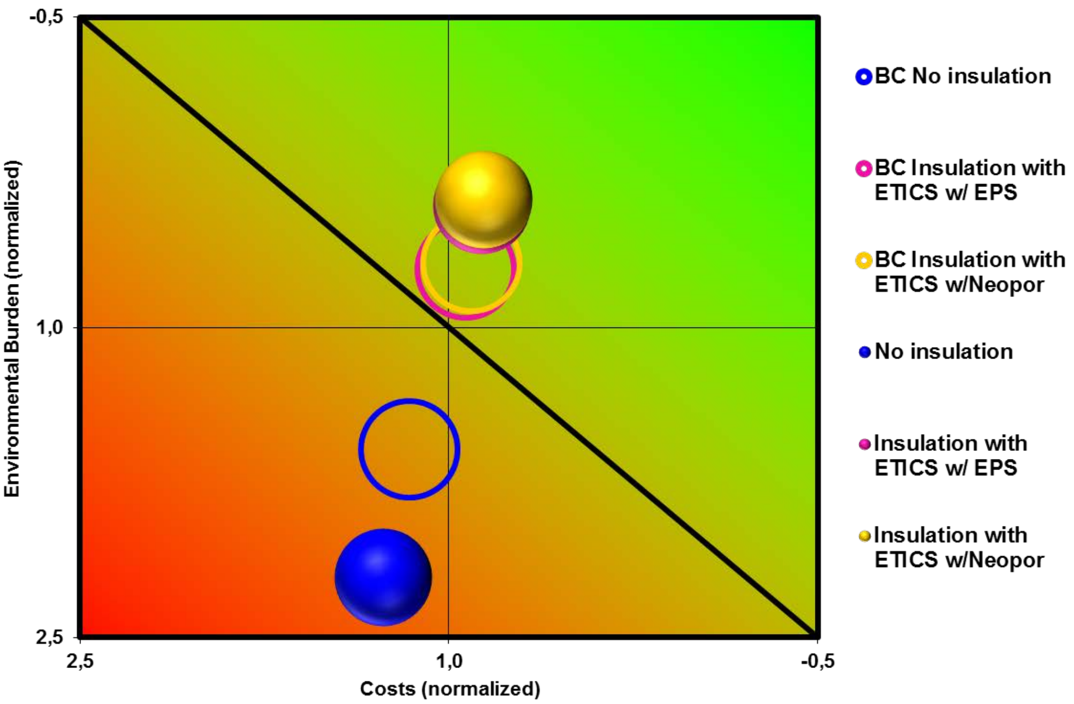
- Scenario 5 and scenario 6 evaluate the effect of a changing energy mix away from fossil-based fuels to biomass and non-biomass renewable energy on the results of the study. Looking at the policy goal of meeting the 2 degree C target, it is anticipated that in the long-term a complete change of the energy and building sector towards low-carbon energy will take place.
- Scenario 7 studies the impact of the construction and disposal phases of the house on the results, which were not considered in the base case of the analysis as they are identical for the alternatives.
- Note: A scenario linked to an increase in the energy prices (gas, oil, electricity, district heating etc.) was not performed as higher energy prices worsen the less eco-efficient alternative even more. In addition, economic aspects have not been the primary focus of this study.

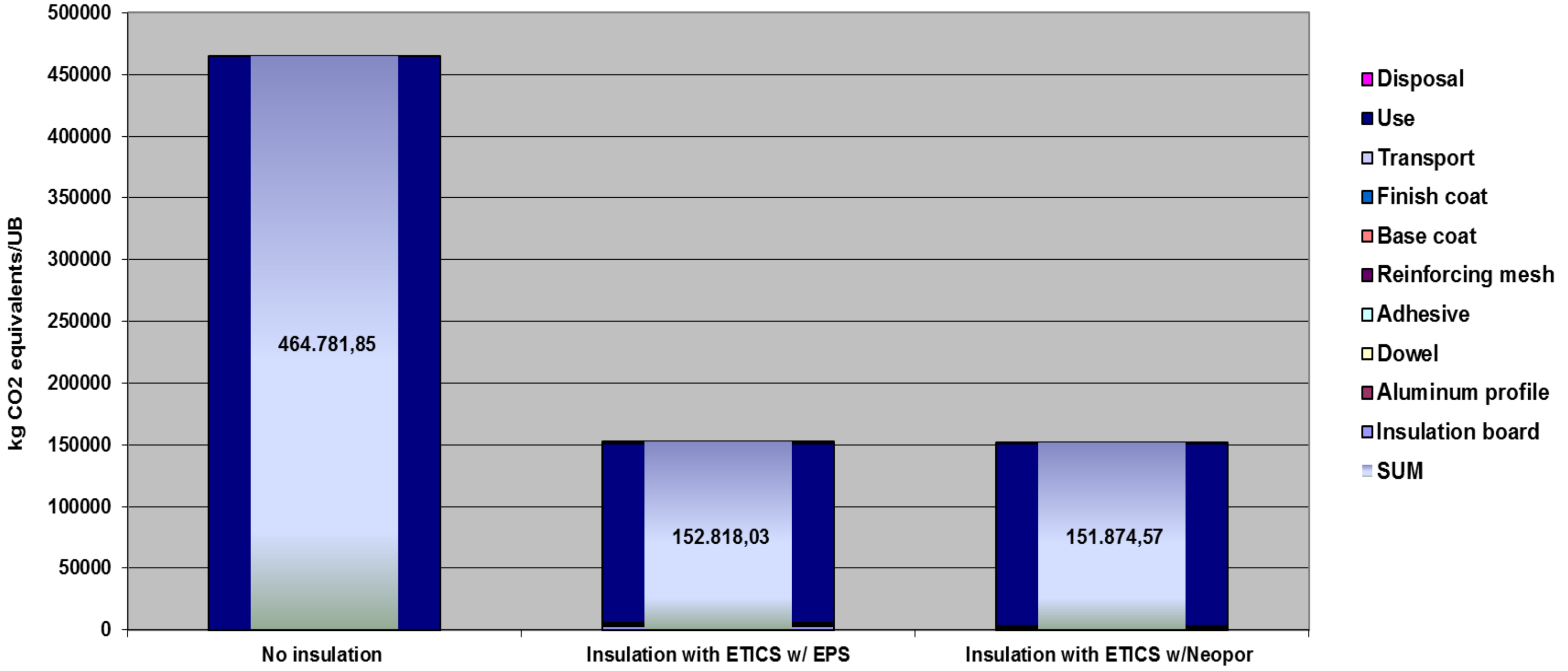
Scenario 1
Worst Case Scenario

- This scenario is based on a U-value (wall, non-insulated) of 1.7 W/(m^2*K)[i] and an oil-heating system with an efficiency of 85%.
- The environmental difference between the non-insulated and the insulated alternatives is significantly increased while the impact on the economic difference is less pronounced. This is consistent with the finding that the eco-efficiency portfolio of this study is dominated by the difference in the environmental impacts.
- In summary, the insulated alternatives are even more eco-efficient than in the base case.



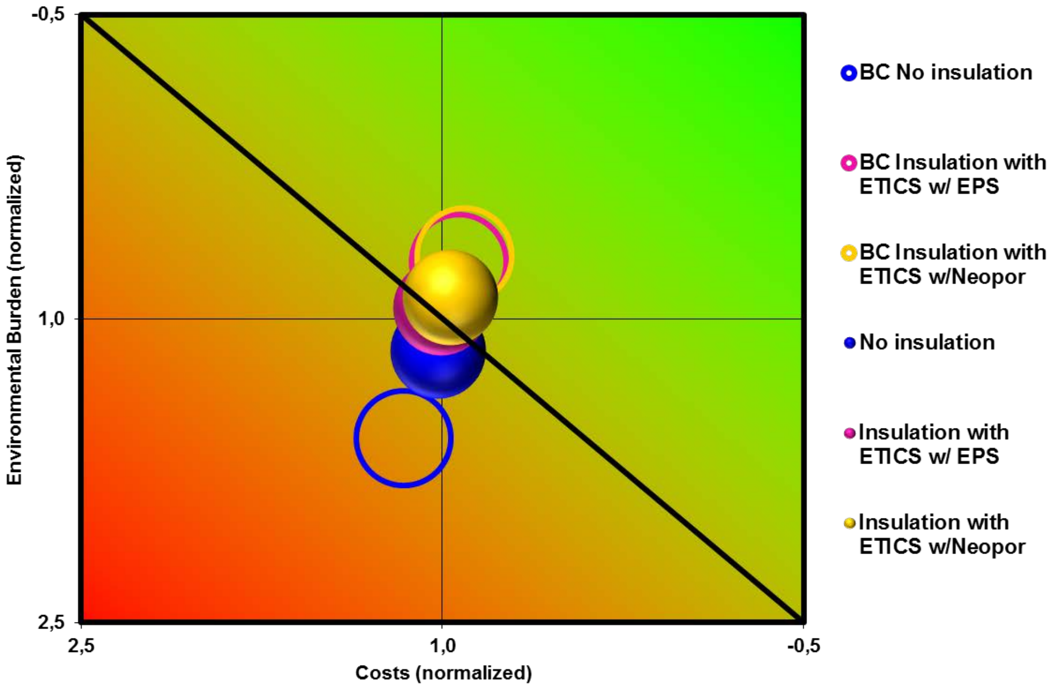
[i]This U-value refers to buildings built between 1861 and 1948 in Germany (building classes B and C).

Scenario 1:Global Warming Potential



Scenario 2
Best Case Scenario

- This scenario is based on a U-value (wall, non-insulated) of 0.68 W/(m^2*K)[i)] and a state-of the-art gas condensing boiler with an efficiency of 98%.
- The environmental difference between the non-insulated and the insulated alternatives is significantly decreased and the costs of the different alternatives are now about equal. However, the insulated alternatives remain the more eco-efficient alternatives (with a difference of about 20% between the Neopor-insulated and the non-insulated alternative).



[i)] This U-value refers to buildings built between 1984 and 1994 (building class H) before the first Heat Insulation Regulation in Germany became effective. Afterwards all buildings were built with a U-value (wall) of 0.5 W/(m2*K) and better.

Scenario 2: Global Warming Potential

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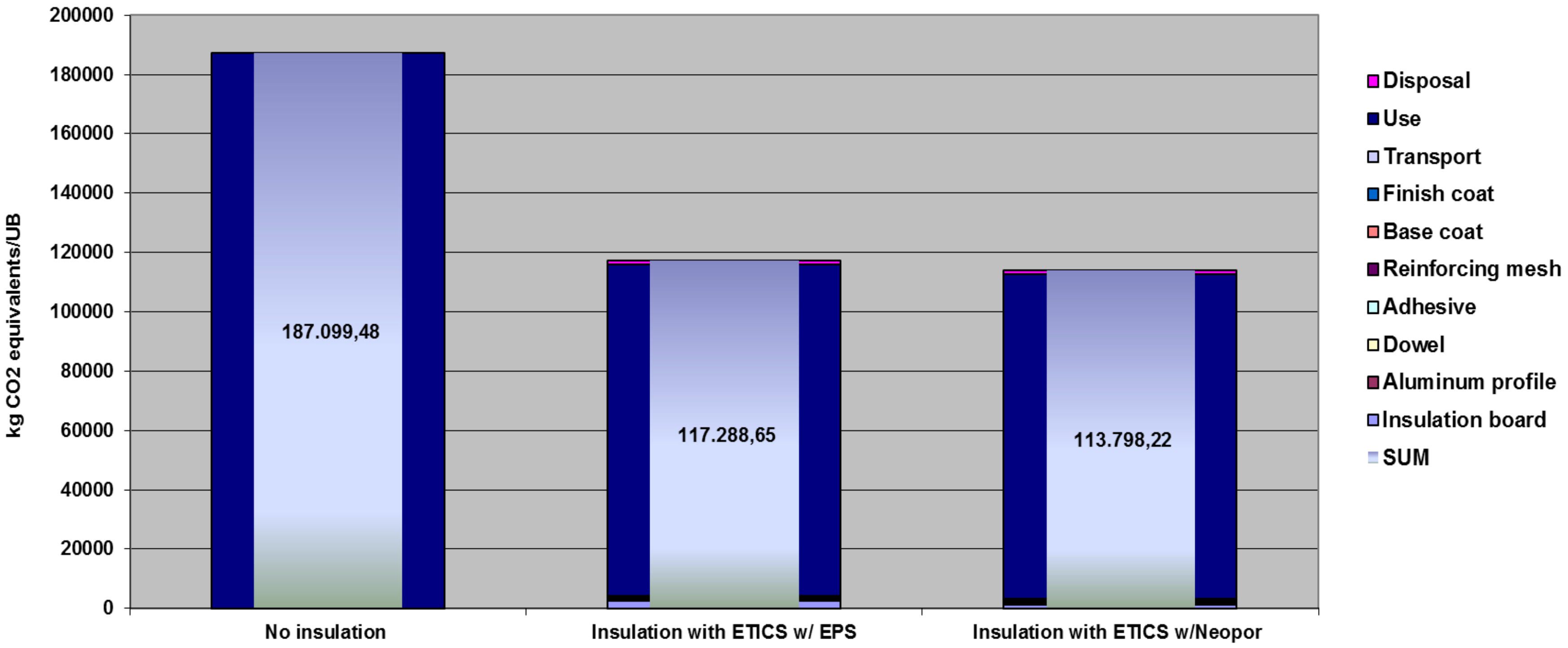
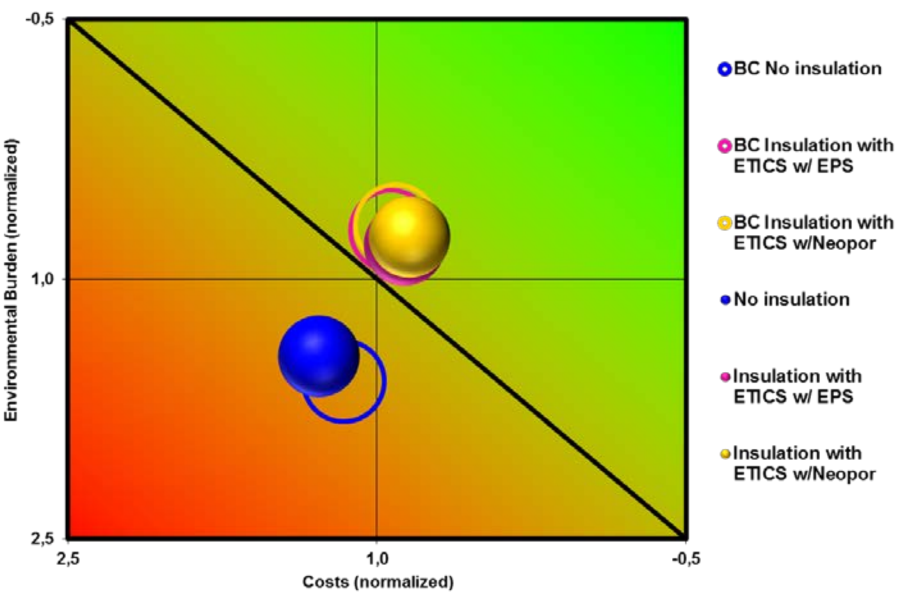
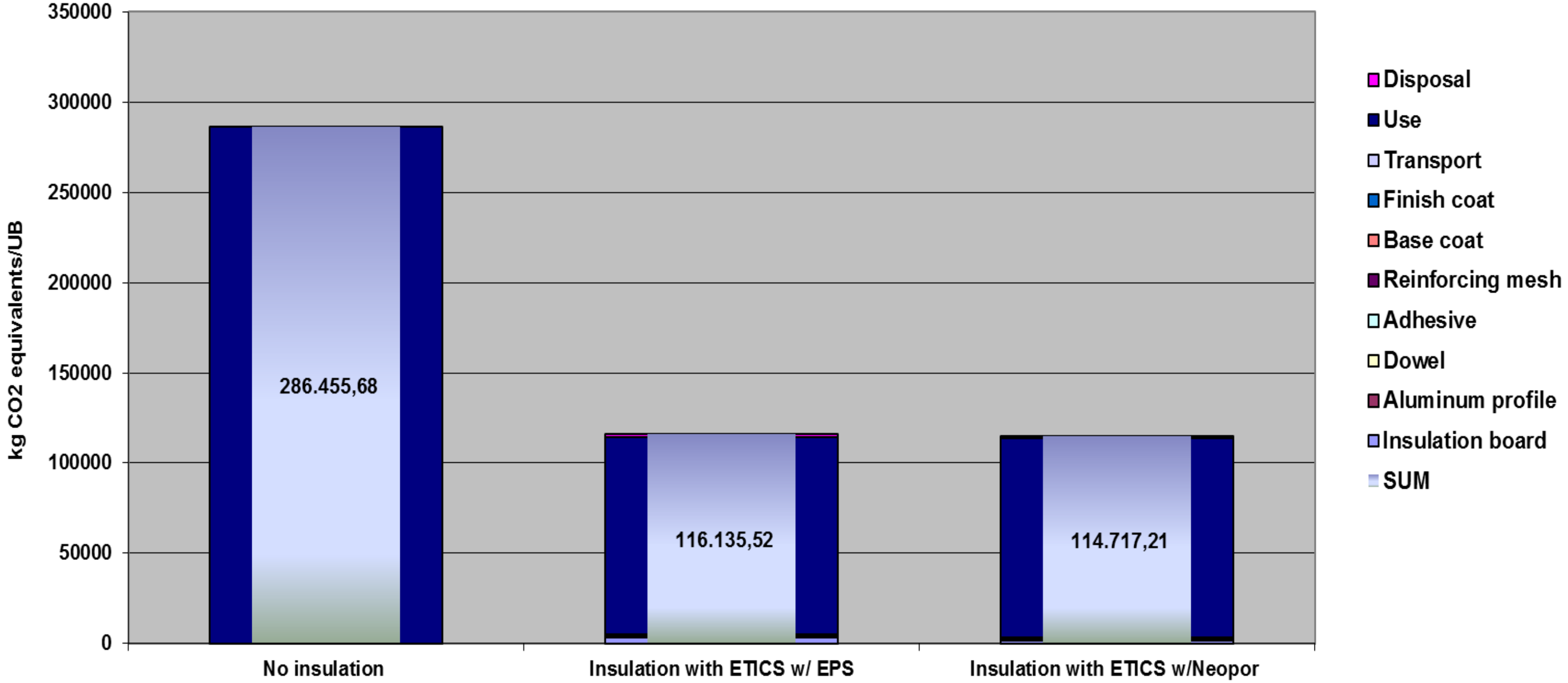


Scenario 3
Single family home from the 1960s

- This scenario is based on a U-value (wall, non-insulated) of 1.3 W/(m^2*K), which is typical for a house built in the 1960s in Germany, and a state-of-the-art gas condensing boiler with an efficiency of 98%.
- The environmental difference between the insulated and non-insulated alternatives is reduced whereas the economic difference is increased compared with the base case. This results from the fact that more fuel is necessary for heating the non-insulated house, but solely natural gas is used instead of the mix of energy carriers like in the base case.

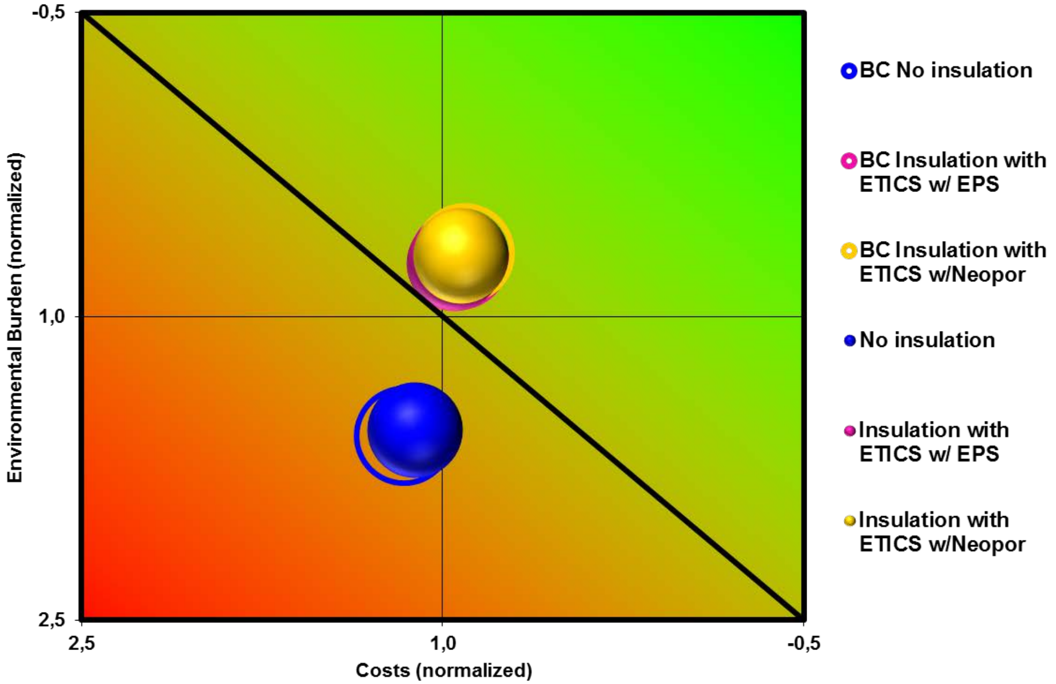


Scenario 3: Global Warming Potential

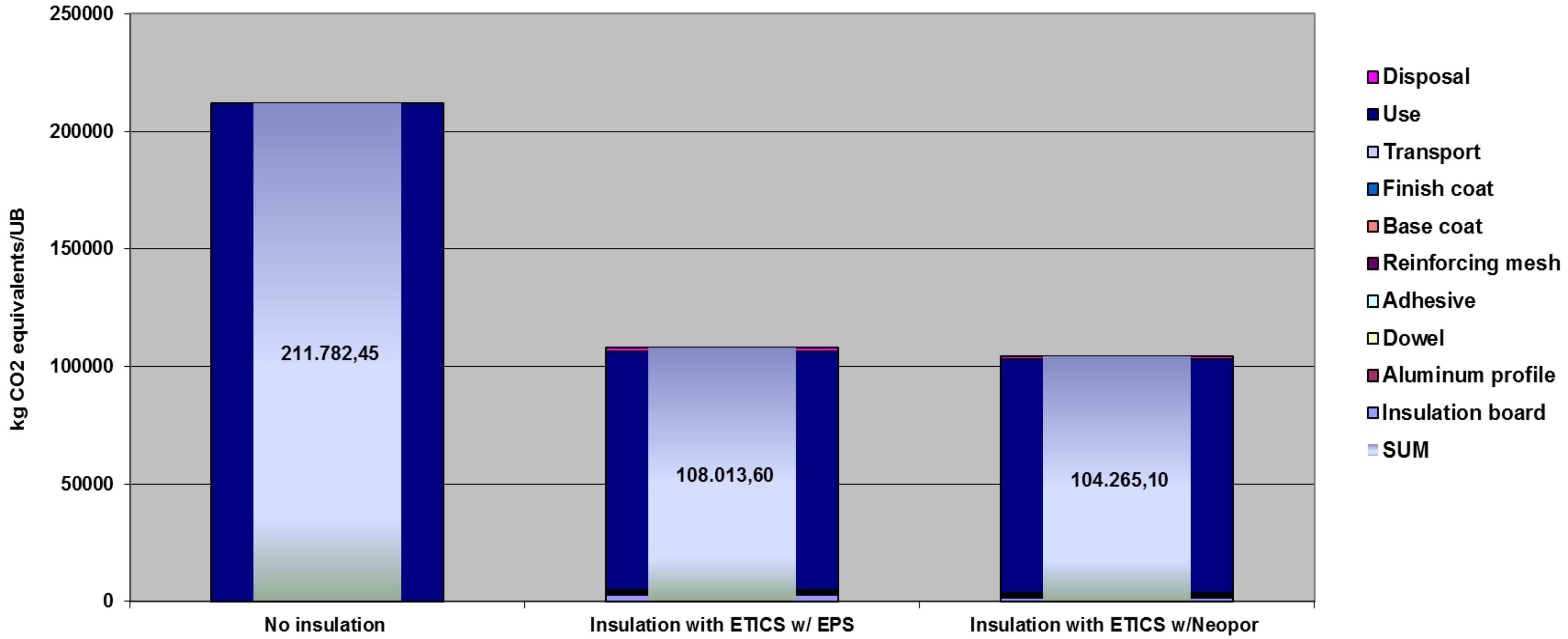


Scenario 4:
Reduced service life of 30 years

- This scenario shows the base case with a reduced service life of 30 years. A reduced service life is linked to an overall lower consumption of heating fuel in the use phase.
- The effect on the eco-efficiency portfolio is moderate, resulting in a lower cost and environmental differentiation of the alternatives.

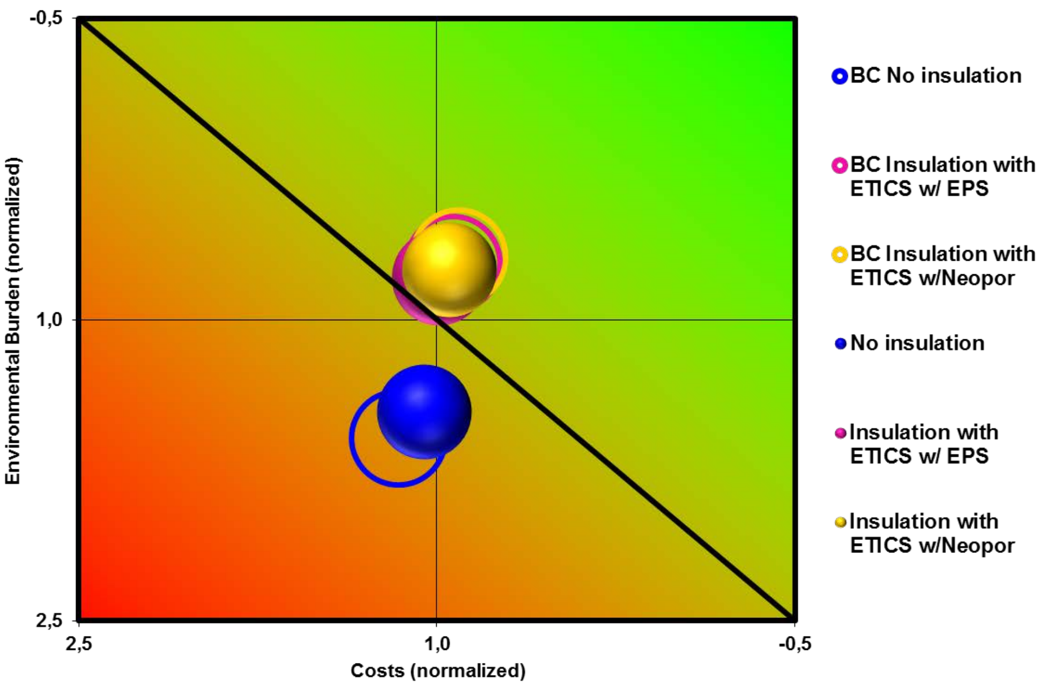


Scenario 4: Global Warming Potential



Scenario 5
“Scenario 2050”

- This scenario is built on the base case but considers a low-carbon energy carrier mix (for more details see next slide).
- The change in the energy mix away from fossil-based fuels towards more renewable energies reduces the environmental impact of the alternatives as well as the costs, mainly driven by the high share of solar energy. However, the insulated alternatives clearly remain more eco-efficient.



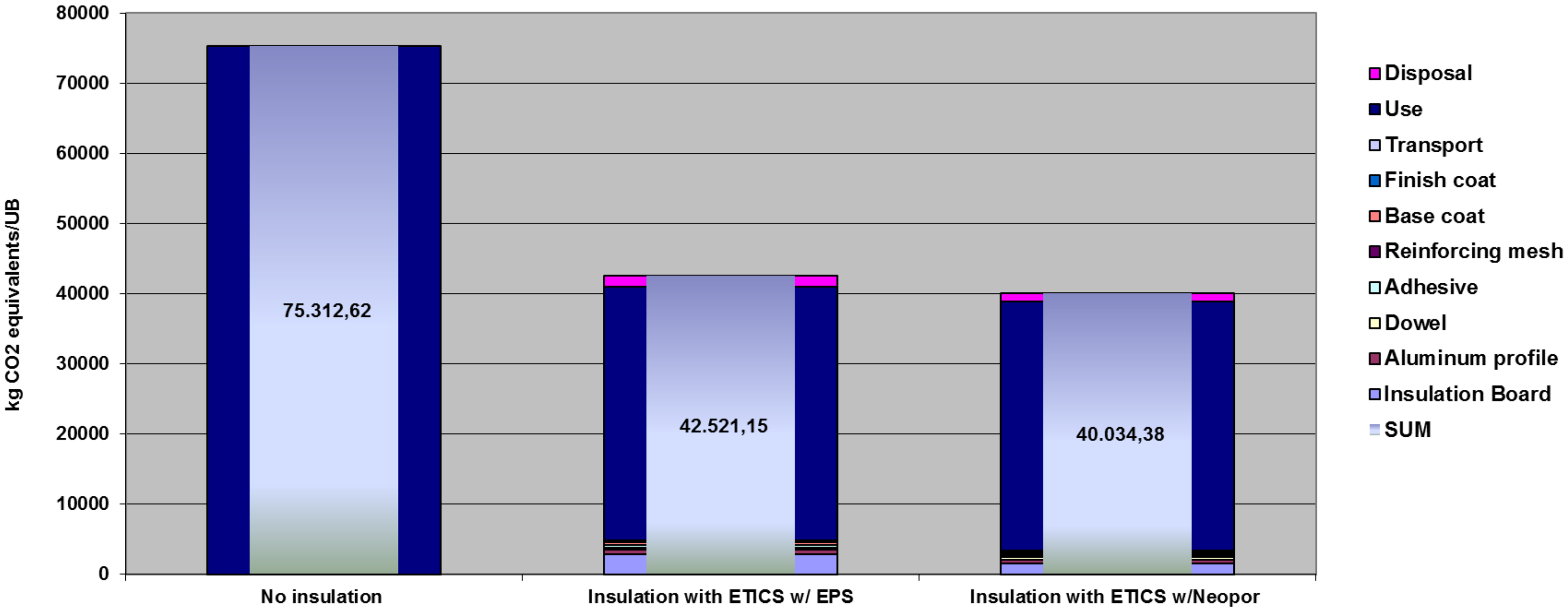
Scenario 5

Mix of energy carriers[*,15] and assumed efficiencies of the different heating systems

	Share in %	Efficiency of heating system
District heating	9.2	-
Natural gas	11.7	0.98
Oil	0.4	0.98
Biomass (wood)	19.2	0.75
Coal	0	-
Electricity	0	-
Heat pump	16.5	-
Solar	43.0	-

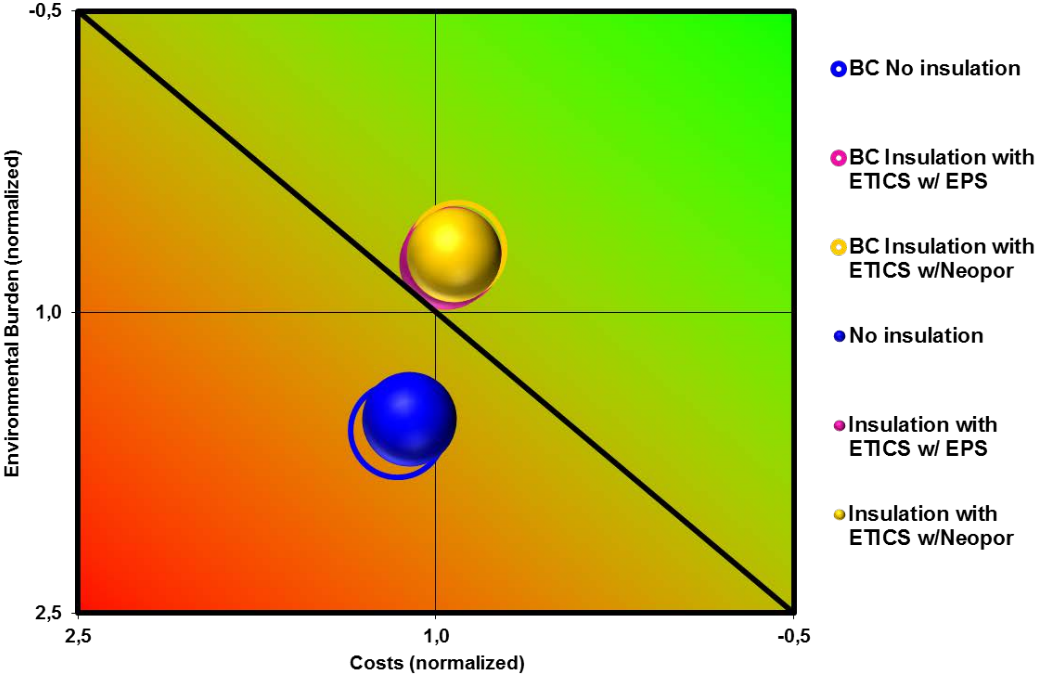
[*]Heating structure of existing detached and semi-detached buildings in Germany in the year 2050 (Scenario "Innovation"), according to the study Blue print Germany.

Scenario 5: Global Warming Potential



Scenario 6
Transition to "Scenario 2050"- "Scenario 2030"

- This scenario evaluates the transition to a low-carbon energy mix. It builds on the base case and considers the energy carrier mix of the Scenario 2030 (for more details see the table on the next slide).
- The eco-efficiency portfolio is similar to that of the previous scenario with less differentiation of the alternatives.



Scenario 6

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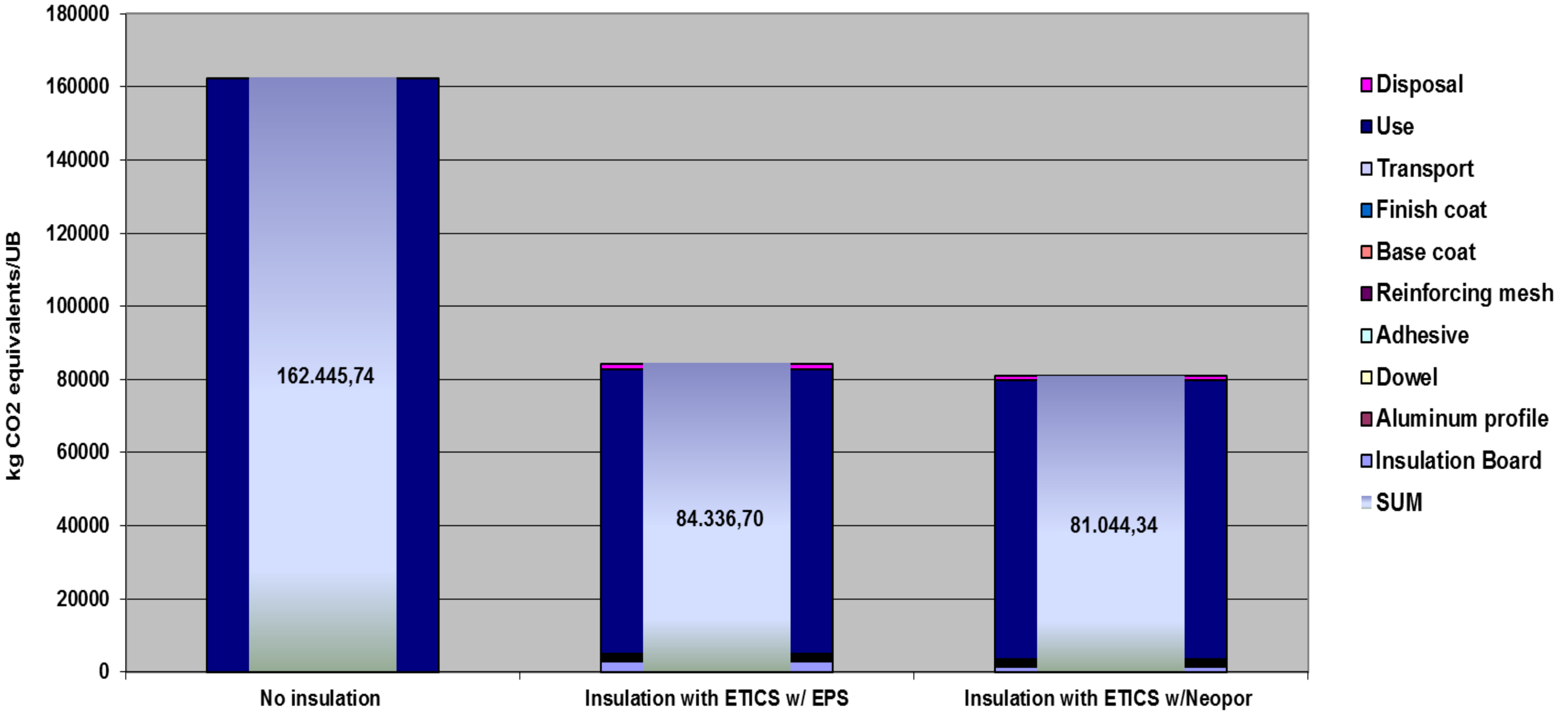
- Mix of energy carriers[*,15] and assumed efficiencies of the different heating systems in "Scenario 2030"

	Share in %	Efficiency of heating system
District heating	6.2	-
Natural gas	29.2	0.98
Oil	18.4	0.98
Biomass (wood)	11.0	0.75
Coal	0.6	0.90
Electricity	2.4	-
Heat pump	9.6	-
Solar	22.6	-

[*]Heating structure of existing detached and semi-detached buildings in Germany in the year 2030 (Scenario "Innovation"), according to the study Blue print Germany.

Scenario 6: Global Warming Potential



Scenarios 1-6: Comments

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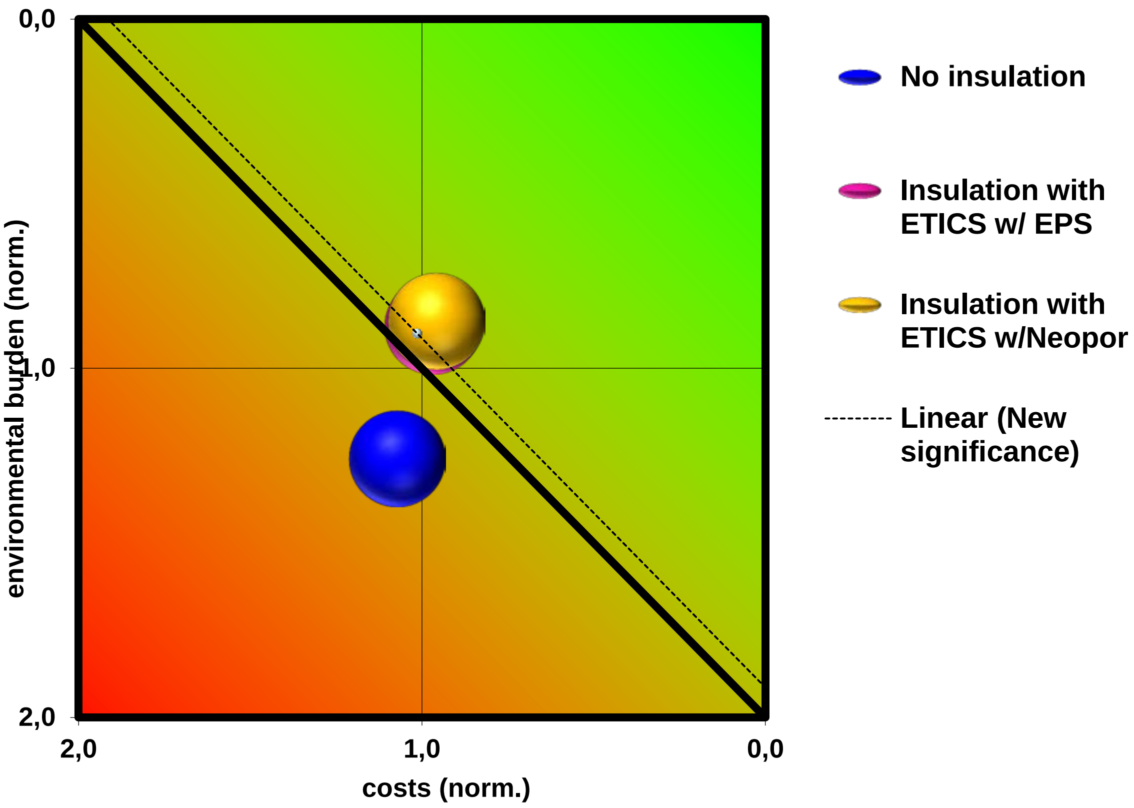
- Scenarios 1 to 6 demonstrate the impact of different heating energy demands and changing energy mixes on the eco-efficiency portfolio as well as on the global warming potential and thus underlines their variability in relation to the selected conditions.
- It is noticeable that for the global warming potential the use phase remains the dominant life cycle phase even in the case of a low-carbon energy mix. This changes at least for the two insulated alternatives, when the construction and disposal phases of the building are considered in the LCA model (Scenario 7).

Scenario 7: Evaluation of the impact of the construction and disposal phases of the house on the results of the analysis

- This scenario builds on the base case and additionally considers the construction and disposal phases of the building (in the base case) based on LCA data taken from literature.



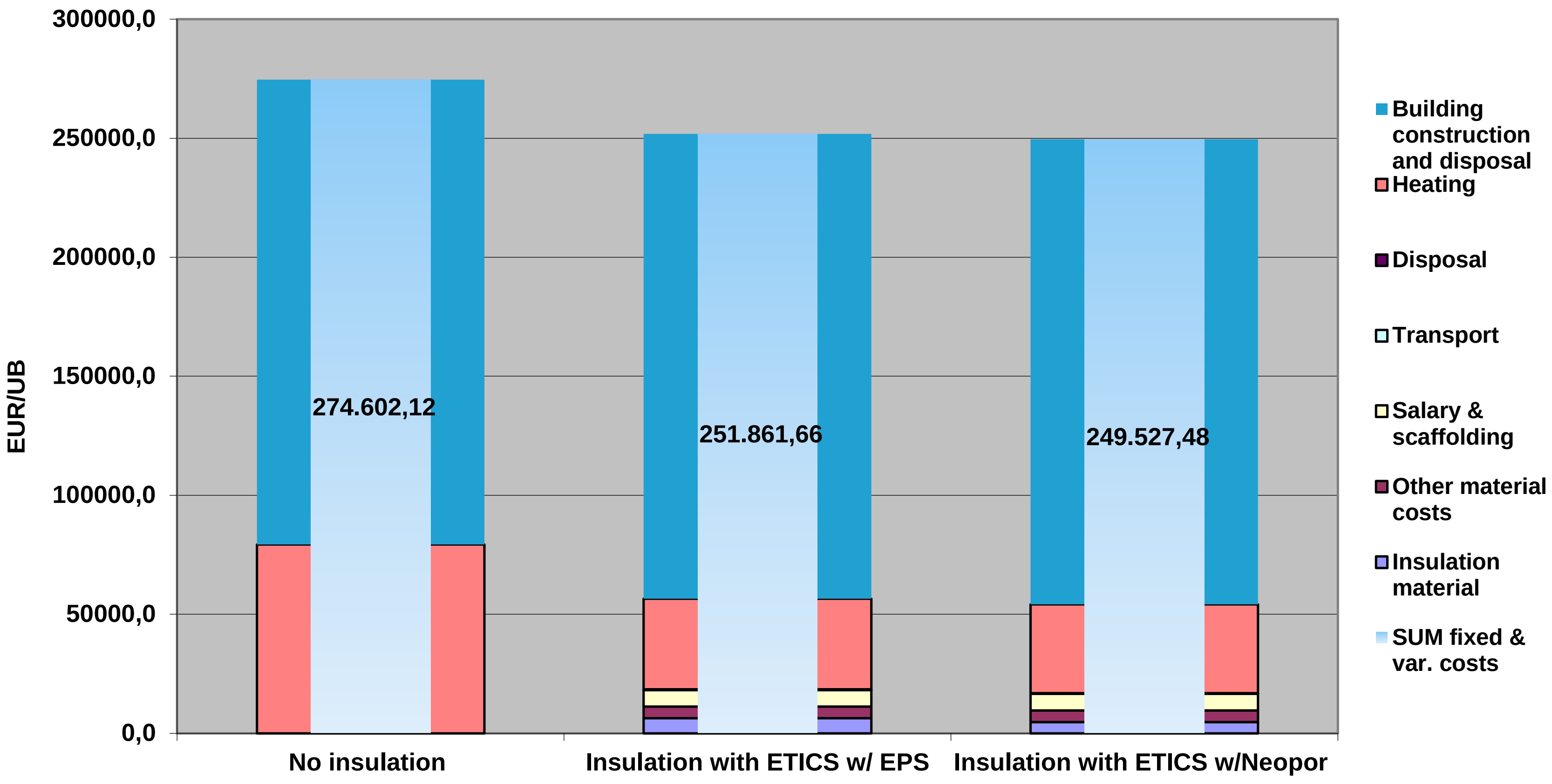
Scenario 7: Comments

- Scenario 7 was calculated by adding available LCIA results for the construction and demolition of a single family detached house (built in 1997 in Belgium) to the base case results of this study. The data were derived from a comprehensive LCA study on insulation in buildings conducted by PwC in 2013[16].
- The following LCIA results were available and used:

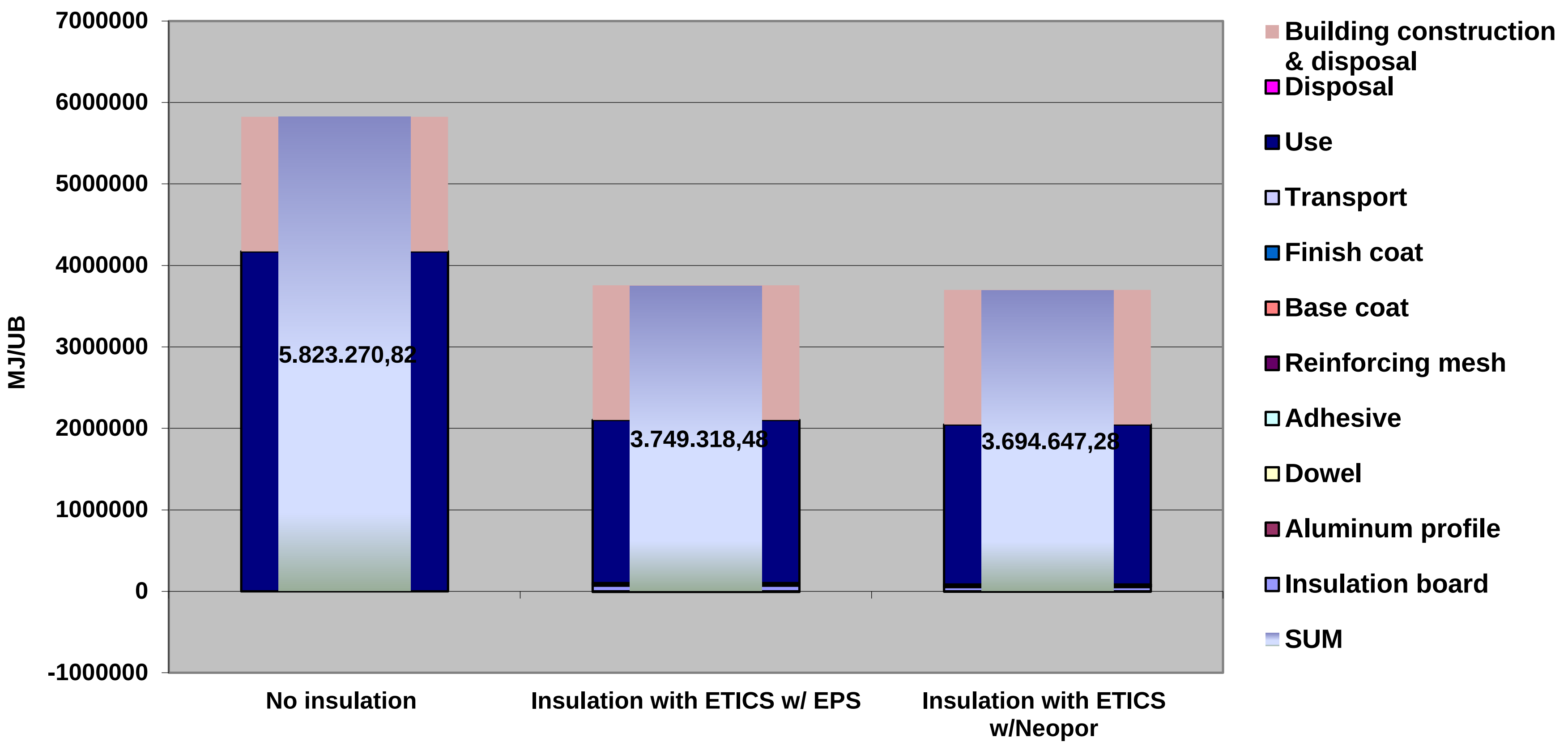
Environmental impact category	Value*	Unit
Primary energy demand	2048	kWh/m^2
Global warming potential	264	$Kg\ CO_2e/m^2$
Photochemical ozone creation potential	0.24	$Kg\ C_2H_4eq/m^2$
Acidification potential	1.64	$Kg\ SO_2eq/m^2$
Solid waste	178.7	$Kg\ waste/m^2$
Costs	872	€/m^2

* Values include shell, core , finishing & external openings. Not included are equipment and insulation as there are not applicable.

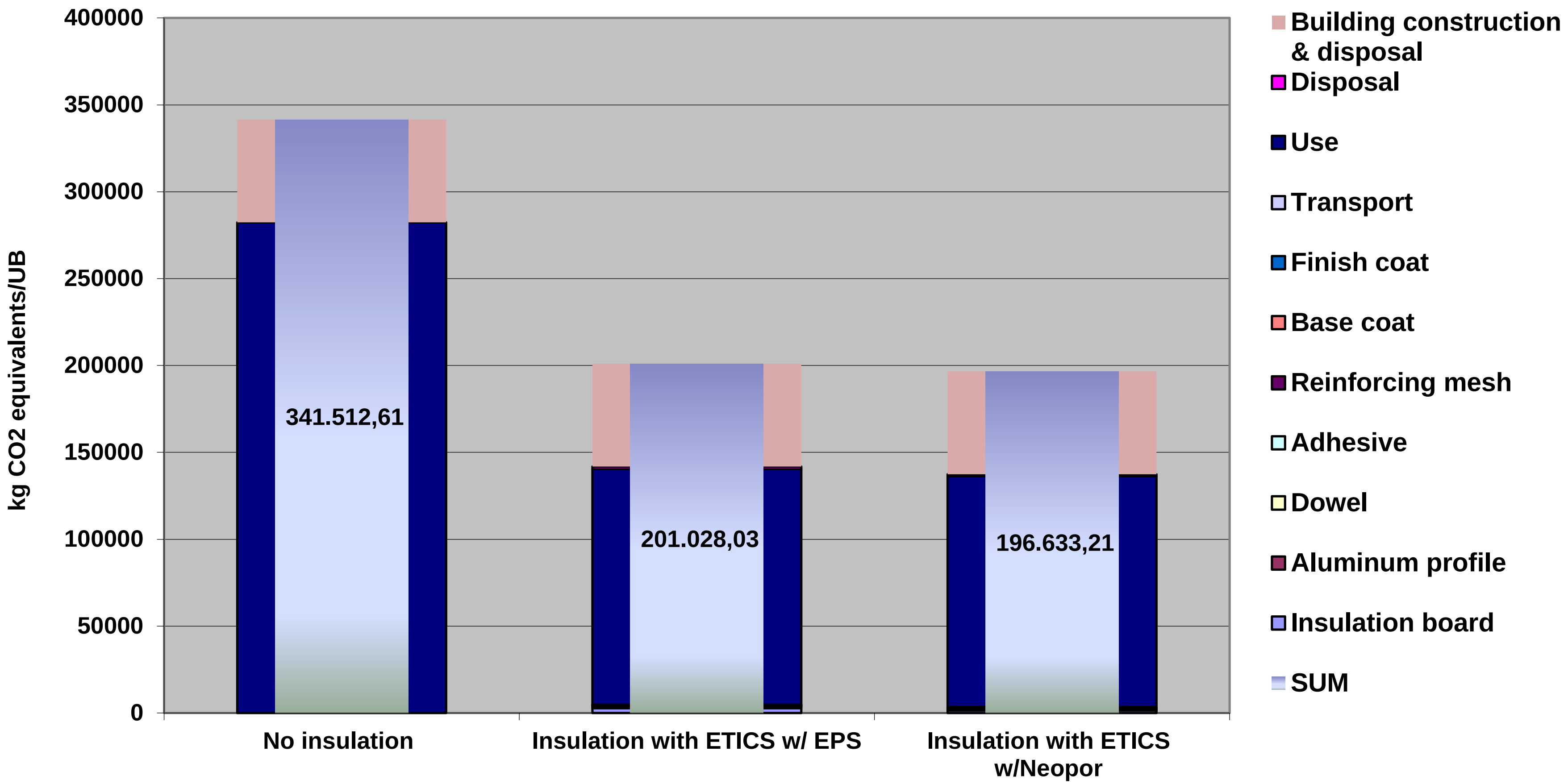
Scenario 7: Costs



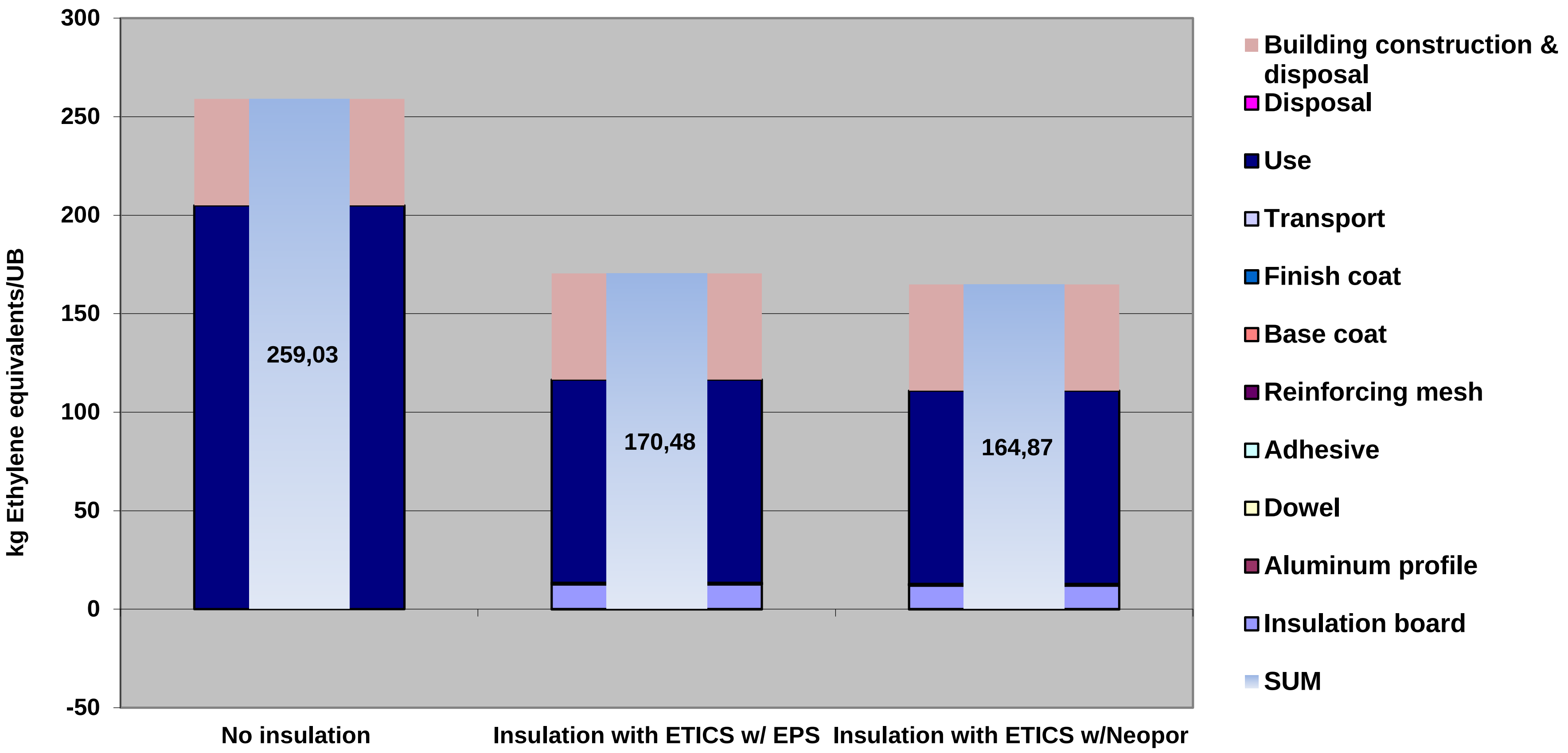
Scenario 7: Cumulative Energy Demand



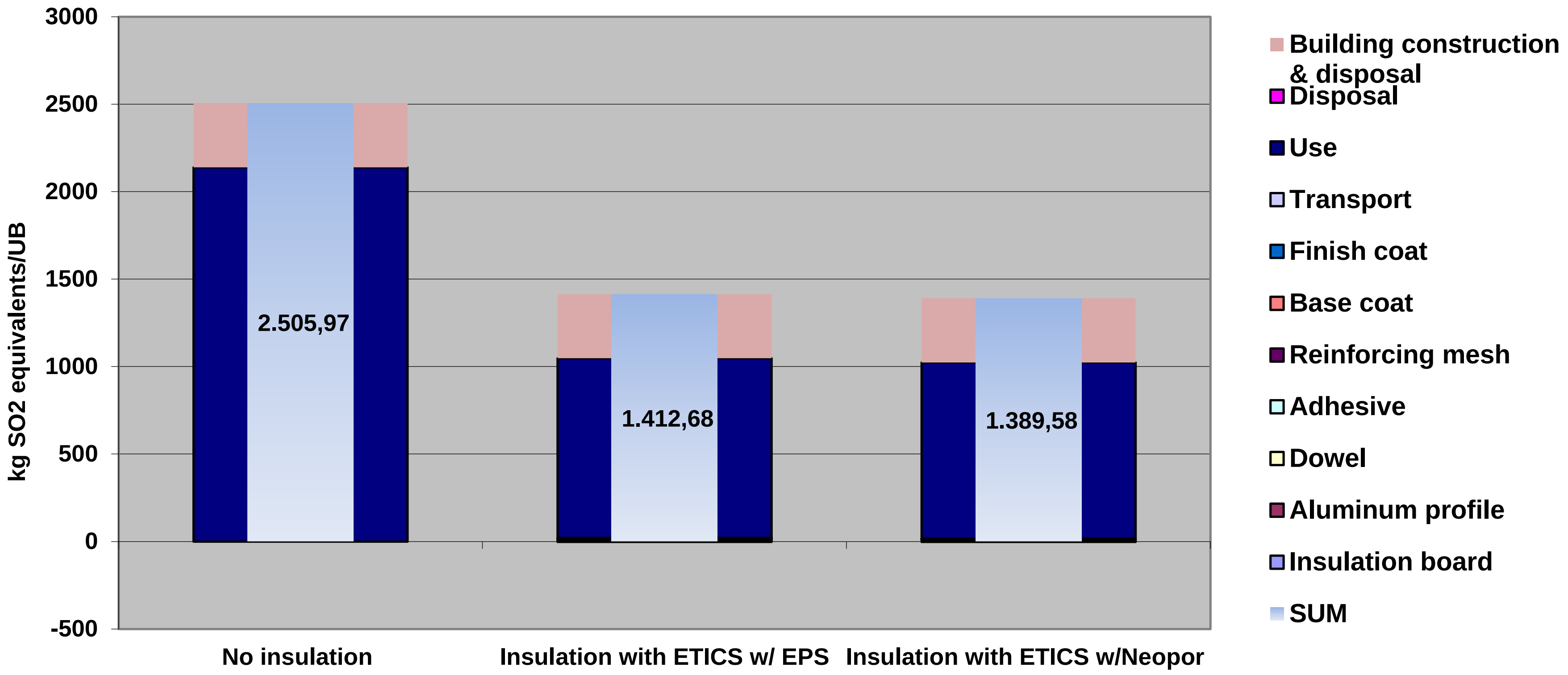
Scenario 7: Global Warming Potential



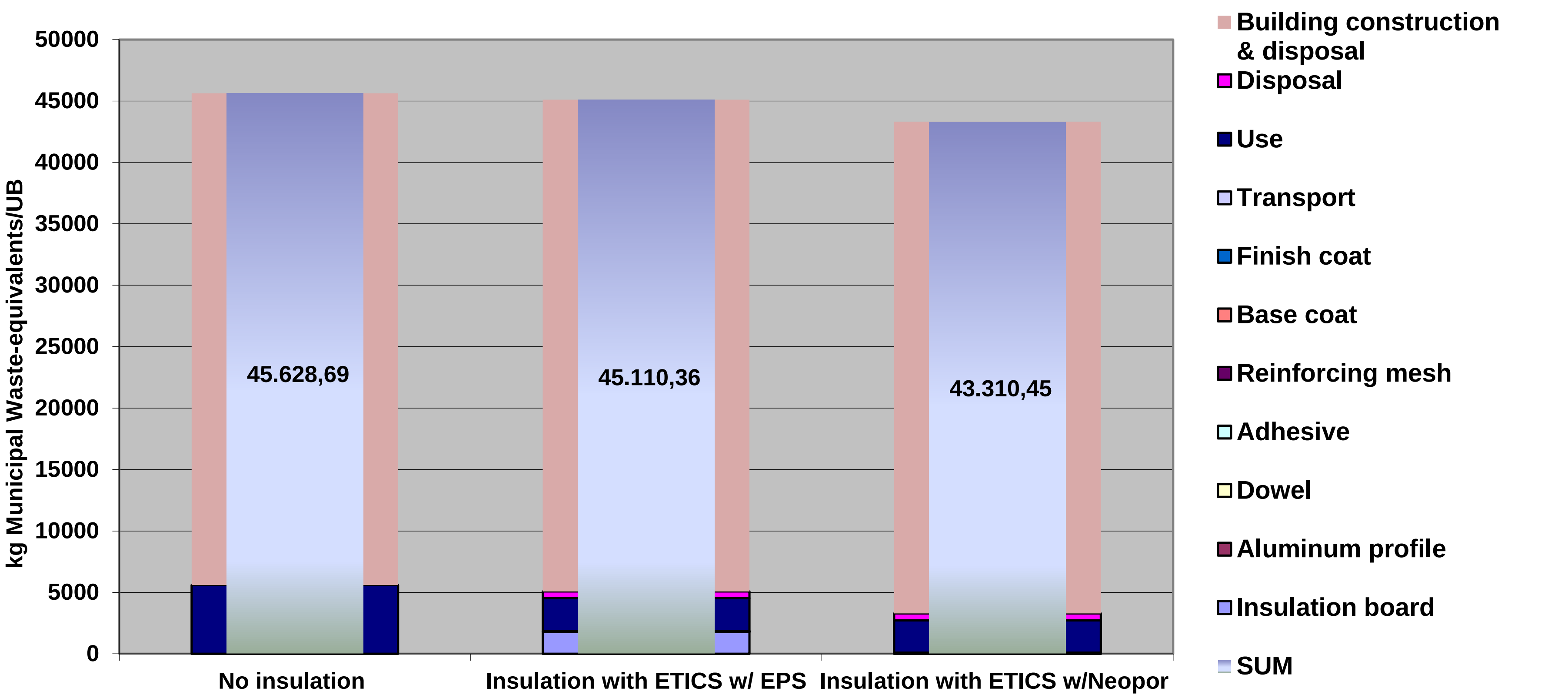
Scenario 7: Photochemical Ozone Creation Potential



Scenario 7: Acidification Potential



Scenario 7: Solid Wastes



Scenario 7: Comments *(1/3)*

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- Contribution of the building's construction and disposal on the total environmental impact of each impact category.

Environmental impact category	Contribution (Altn. „no insulation“)	Contribution (Altn. „insulation with ETICS“
Cumulative energy demand	28%	44%
Global warming potential	17%	29%
Photochemical ozone creation potential	21%	32%
Acidification potential	15%	26%
Solid waste	88%	92%

Scenario 7: Comments *(2/3)*

- The construction and disposal of the single family house contributes about 20 to 30% to the different environmental impact categories in the case of the non-insulated house and about 30 to 40% in the case of the insulated house. Only the contribution to the solid waste category is significantly higher.
- Notwithstanding, the absolute contribution of the construction and disposal phases of the house to the different alternatives is equal.
- The eco-efficiency portfolio of Scenario 7 shows that the consideration of the production and disposal phases of the house leads to a smaller differentiation of the two alternatives, but does not change the overall conclusion of the study. The evaluation of the individual impact categories confirms (with the exception of the impact category waste) that the environmental impacts are driven by the energy consumption in the use phase and thus it remains the dominant factor of the study.

Scenario 7: Comments *(3/3)*

BASF The Chemical Company

- Other published LCA studies underline this conclusion that operating energy represents by far the largest energy demand in a building during its life cycle.[17, 18]
- However, it has to be acknowledged that the use phase of a house becomes less significant the better the house is insulated.

Appendix (A)

References

References *(1/3)*

- (1) Guidelines from the Chemical Industry for accounting and reporting GHG emissions avoided along the value chain based on comparative studies, to be published in 2013.
- (2) Eco-Efficiency Analysis “Use and Possibly Refurbishment with Exterior Insulation Finishing System of Detached House (building year 1963) in Germany, Ludwigshafen, June 6, 2008.
- (3) B+L Marktdaten GmbH, Insulation Application Germany 2011 (market study).
- (4) Dena Gebäudereport 2012
- (5) IWU, Institut für Wohnen und Umwelt, Darmstadt, Germany, „Datenbasis Gebäudebestand,“ 9.12.2010.
- (6) IWU, Institut für Wohnen und Umwelt, Darmstadt, Germany; „Deutsche Gebäudetopologie“, 22.06.2005.

References *(2/3)*

- (7) IWU, „Basis für Hochrechnungen mit der deutschen Gebäudetopologie des IWU, 25.08.2011.
- (8) EnEV 2009, effective since October 2009, requires a U-value (wall, max) of 0.24 W/(m^2*K). Before 2009, the EnEV 2007 (2002) was in place calling for a U-value (wall, max) of 0.35 W/(m^2*K) in refurbished homes.
- (9) http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/nutzungsdauern-von-bauteilen.htm
- (10) Muster ESD-EVW-2011511-D; Institut Bauen und Umwelt e.V.
- (11) EPD-EJT-2011112-D, Institut Bauen und Umwelt e.V.
- (12) Diploma thesis Kremena Borisova, BASF SE, 2008.
- (13) Calculation program: „Energieberater 18599 3D Plus 7.4.0 - Hottgenroth Software“

References *(3/3)*

BASF
The Chemical Company

- (14) Industry survey of the Bundesverband Erneuerbare Energien e.V. and Agentur für Erneuerbare Energien, status 10/2009: Installed heating systems in Germany: 70% are 10 -24 years old and have an efficiency of <85%, 18% are older than 24 years with an efficiency <65% and 12% are younger than 10 years with an efficiency of >98% ; average efficiency corresponds to 83%.
- (15) Blue print Germany – A strategy for a climate safe in 2050, a study conducted on behalf of WWF, Germany, prepared by PROGNOS/Öko-Institut.
- (16) PUEurope, Environmental and economic analysis of insulation products in low energy buildings, PwC, April 2013.
- (17) *Energy and Building* 39 (2007), 249-257.
- (18) Master Thesis, Norwegian University of Science & Technology: “Life Cycle Assessment of a Single Family Residence”.

Appendix (B)

House data

House data *(1/2)*

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Enveloping surfaces

Wall	Exterior Wall Surface	Windows	
		Share	Surface
Exterior wall North	72.8 m^2	10%	7.3 m^2
Exterior wall East	39.2 m^2	14%	5.5 m^2
Exterior wall South	72.8 m^2	17%	12.4 m^2
Exterior wall West	39.2 m^2	14%	5.5 m^2
Basement floor	91 m^2	-	
Attic	91 m^2	-	

Summary heating requirements

	U-value wall [W/(m2*K)]	Thickness of insulation board [cm]	Final heating demand* [kWh/a]
Base case			
Wall w/o insulation	0.96	-	20875
With insulation – EPS white	0.20	14	10018
With insulation – EPS grey	0.18	14	9825

* Excluding warm water

House data *(2/2)*

BASF
The Chemical Company

Scenario Analysis : Summary heating requirements

	U-value wall [W/(m2*K)]	Thickness of insulation board [cm]	Final heating demand** [kWh/a]
Worst case scenario			
Wall w/o insulation	1.7	-	31774
With insulation – EPS white	0.19	16	9961
With insulation – EPS grey	0.20	14	10069
Best case scenario			
Wall w/o insulation	0.68	-	16933
With insulation – EPS white	0.2	12	10104
With insulation – EPS grey	0.19	12	9927

*Including warm water ** excluding warm water

Geometry of the Building

4.1 Gebäudegeometrie - Flächen

Nr.	Bezeichnung	Orientierung Neigung	Berechnung	Fläche brutto	Fläche netto	Flächen-anteil
				m²	m²	%
1	Dachboden	0,0°		91,00	91,00	22,4
2	Kellerdecke	0,0°		91,00	91,00	22,4
3	AW N	N 90,0°		72,80	65,50	16,1
4	Fenster N	N 90,0°	6 * 1,21 * 1,01	-	7,30	1,8
5	AW Ost	O 90,0°		39,20	37,98	9,4
6	Fenster Ost	O 90,0°	1,21 * 1,01	-	1,22	0,3
7	AW S	S 90,0°		72,80	60,40	14,9
8	Fenster S	S 90,0°		-	12,40	3,1
9	AW W	W 90,0°		39,20	33,70	8,3
10	Fenster W	W 90,0°		-	5,50	1,4

Energy Balance Existing Building
U-value (wall) = 0.96 W/(m²*K) *(1/4)*

BASF
The Chemical Company

- Energy losses

Wärmeverluste in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Transmissionswärmeverluste												
Transmissionsverluste	3555	2911	2610	1610	1068	559	175	123	780	1734	2424	3100
Wärmebrückenverluste	613	502	450	278	184	96	30	21	134	299	418	535
Summe	4169	3413	3060	1888	1253	656	205	144	914	2033	2842	3635
Lüftungswärmeverluste												
Lüftungsverluste	1393	1141	1023	631	419	219	69	48	306	679	950	1215
reduzierte Wärmeverluste durch Nachtabschaltung, -senkung												
reduzierte Wärmeverluste	-367	-287	-240	-142	-94	-49	-15	-11	-69	-153	-221	-301
Gesamtwärmeverluste												
Gesamtwärmeverluste	**5195**	**4266**	**3842**	**2377**	**1577**	**826**	**259**	**181**	**1151**	**2559**	**3570**	**4548**

Energy Balance Existing Building *(2/4)*

BASF The Chemical Company

- Energy gains (without heating)

Wärmegewinne in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Interne Wärmegewinne												
Interne Wärmegewinne	607	548	607	588	607	588	607	607	588	607	588	607
Solare Wärmegewinne												
Fenster N 90°	22	32	52	95	125	148	154	108	72	51	27	15
Fenster O 90°	6	9	14	31	34	37	40	30	22	13	7	4
Fenster S 90°	146	144	209	347	311	329	353	293	291	212	137	86
Fenster W 90°	29	39	61	140	152	168	181	133	101	59	31	17
Solare Wärmegewinne	203	223	337	613	622	682	728	564	486	335	202	123
Gesamtwärmegewinne in kWh/Monat												
Gesamtwärmegewinne	**811**	**772**	**944**	**1201**	**1229**	**1270**	**1335**	**1171**	**1074**	**942**	**789**	**730**

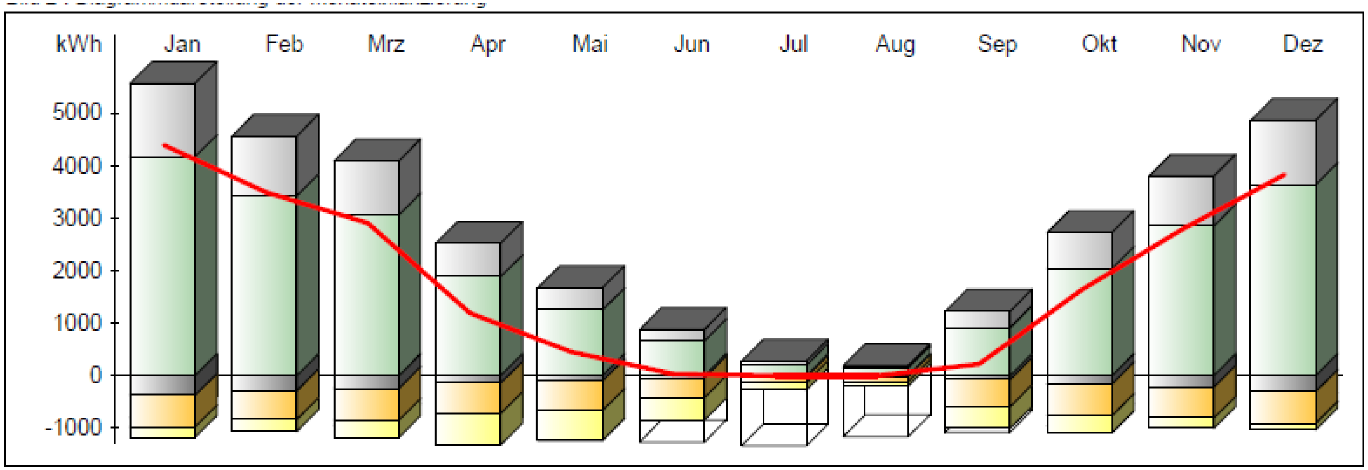
Energy Balance Existing Building *(3/4)*

- Energy balance

Heizwärmebedarf in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Ausnutzungsgrad Gewinne	1,000	1,000	1,000	0,987	0,926	0,626	0,194	0,155	0,870	0,997	1,000	1,000
Heizwärmebedarf	**4384**	**3495**	**2898**	**1191**	**439**	**31**	**0**	**0**	**217**	**1620**	**2781**	**3818**
Heizgrenztemperatur in °C und Heiztage												
Heizgrenztemperatur	16,51	16,37	16,10	15,19	15,22	14,97	14,90	15,40	15,59	16,11	16,49	16,76
Mittl. Außentemperatur:	-1,30	0,60	4,10	9,50	12,90	15,70	18,00	18,30	14,40	9,10	4,70	1,30
Heiztage	**31,0**	**28,0**	**31,0**	**30,0**	**31,0**	**7,6**	**0,0**	**0,0**	**24,0**	**31,0**	**30,0**	**31,0**

Energy Balance Existing Building *(4/4)*

- Summary



<u>Ergebnisse des Monatsbilanzverfahrens</u>

Jahres-Heizwärmebedarf = 20.875 kWh/a

flächenbezogener
Jahres-Heizwärmebedarf = 127,91 kWh/(m²a)

volumenbezogener
Jahres-Heizwärmebedarf = 40,93 kWh/(m³a)

Zahl der Heiztage = 274,6 d/a

Heizgradtagzahl = 3.501 Kd/a

- Heizwärmebedarf
- Lüftungswärmeverluste
- Transmissionswärmeverluste
- Reduzierung der Wärmeverluste (Heizungsunterbrechung, etc.)
- nutzbare interne Wärmegewinne
- nutzbare solare Wärmegewinne
- nicht nutzbare Wärmegewinne

Energy Balance Insulated Building
U-value (wall) = 0.20 W/(m²*K) *(1/4)*

BASF The Chemical Company

- Energy losses

Wärmeverluste in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Transmissionswärmeverluste												
Transmissionsverluste	1314	1076	965	595	395	207	65	45	288	641	896	1146
Wärmebrückenverluste	613	502	450	278	184	96	30	21	134	299	418	535
Summe	1928	1578	1415	873	579	303	95	66	423	940	1314	1681
Lüftungswärmeverluste												
Lüftungsverluste	1393	1141	1023	631	419	219	69	48	306	679	950	1215
reduzierte Wärmeverluste durch Nachtabschaltung, -senkung												
reduzierte Wärmeverluste	-144	-111	-91	-52	-35	-18	-6	-4	-25	-56	-83	-115
Gesamtwärmeverluste												
Gesamtwärmeverluste	**3177**	**2608**	**2347**	**1452**	**963**	**504**	**158**	**111**	**703**	**1563**	**2181**	**2780**

Energy Balance Insulated Building *(2/4)*

BASF
The Chemical Company

- Energy gains (without heating)

Wärmegewinne in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Interne Wärmegewinne												
Interne Wärmegewinne	607	548	607	588	607	588	607	607	588	607	588	607

Wärmegewinne in kWh/Monat (Fortsetzung)												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Solare Wärmegewinne												
Fenster N 90°	22	32	52	95	125	148	154	108	72	51	27	15
Fenster O 90°	6	9	14	31	34	37	40	30	22	13	7	4
Fenster S 90°	146	144	209	347	311	329	353	293	291	212	137	86
Fenster W 90°	29	39	61	140	152	168	181	133	101	59	31	17
Solare Wärmegewinne	203	223	337	613	622	682	728	564	486	335	202	123
Gesamtwärmegewinne in kWh/Monat												
Gesamtwärmegewinne	**811**	**772**	**944**	**1201**	**1229**	**1270**	**1335**	**1171**	**1074**	**942**	**789**	**730**

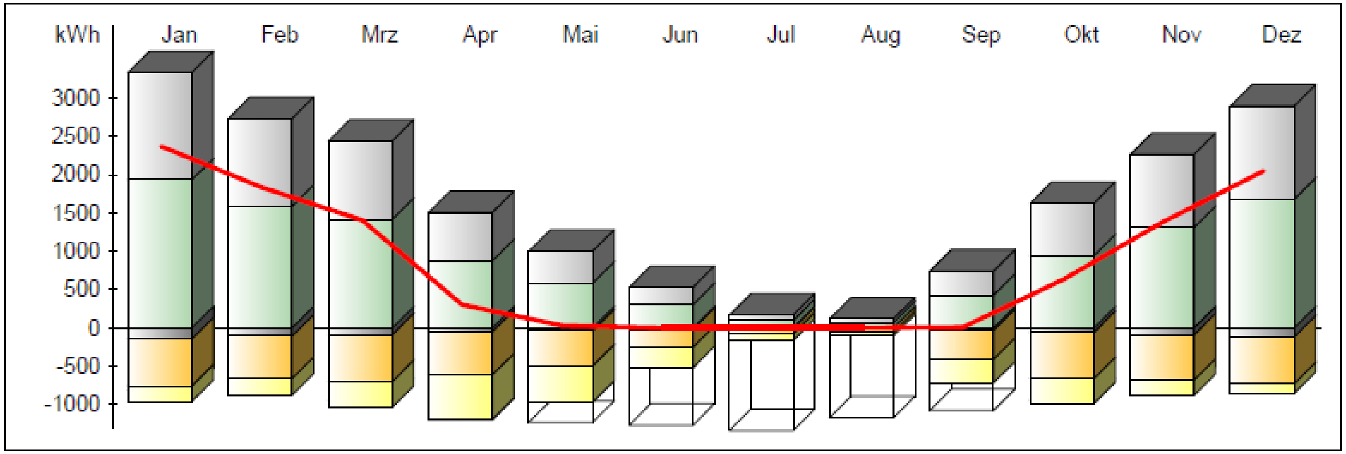
Energy Balance Insulated Building *(3/4)*

- Energy balance

Heizwärmebedarf in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Ausnutzungsgrad Gewinne	1,000	1,000	1,000	0,956	0,759	0,397	0,118	0,094	0,648	0,994	1,000	1,000
Heizwärmebedarf	**2367**	**1836**	**1403**	**303**	**31**	**0**	**0**	**0**	**8**	**627**	**1392**	**2050**
Heizgrenztemperatur in °C und Heiztage												
Heizgrenztemperatur	14,58	14,34	13,85	12,23	12,30	11,85	11,72	12,62	12,95	13,86	14,55	15,02
Mittl. Außentemperatur:	-1,30	0,60	4,10	9,50	12,90	15,70	18,00	18,30	14,40	9,10	4,70	1,30
Heiztage	**31,0**	**28,0**	**31,0**	**30,0**	**9,6**	**0,0**	**0,0**	**0,0**	**8,0**	**31,0**	**30,0**	**31,0**

Energy Balance Insulated Building (4/4)

- Summary



<u>Ergebnisse des Monatsbilanzverfahrens</u>

Jahres-Heizwärmebedarf = 10.018 kWh/a

flächenbezogener
Jahres-Heizwärmebedarf = 61,38 kWh/(m²a)

volumenbezogener
Jahres-Heizwärmebedarf = 19,64 kWh/(m³a)

Zahl der Heiztage = 229,6 d/a

Heizgradtagzahl = 3.271 Kd/a

- Heizwärmebedarf
- Lüftungswärmeverluste
- Transmissionswärmeverluste
- Reduzierung der Wärmeverluste (Heizungsunterbrechung, etc.)
- nutzbare interne Wärmegewinne
- nutzbare solare Wärmegewinne
- nicht nutzbare Wärmegewinne

Energy Balance Insulated Building
U-value (wall) = 0.18 W/(m²*K) *(1/4)*

BASF The Chemical Company

- Energy losses

Wärmeverluste in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Transmissionswärmeverluste												
Transmissionsverluste	1274	1043	935	577	383	200	63	44	279	621	868	1110
Wärmebrückenverluste	613	502	450	278	184	96	30	21	134	299	418	535
Summe	1887	1545	1385	855	567	297	93	65	414	920	1286	1645
Lüftungswärmeverluste												
Lüftungsverluste	1393	1141	1023	631	419	219	69	48	306	679	950	1215
reduzierte Wärmeverluste durch Nachtabschaltung, -senkung												
reduzierte Wärmeverluste	-140	-108	-88	-51	-34	-18	-6	-4	-25	-55	-81	-113
Gesamtwärmeverluste												
Gesamtwärmeverluste	**3140**	**2577**	**2319**	**1435**	**952**	**498**	**156**	**109**	**695**	**1545**	**2155**	**2747**

Energy Balance Insulated Building *(2/4)*

BASF
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- Energy gains (without heating)

Wärmegewinne in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Interne Wärmegewinne												
Interne Wärmegewinne	607	548	607	588	607	588	607	607	588	607	588	607

Wärmegewinne in kWh/Monat (Fortsetzung)												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Solare Wärmegewinne												
Fenster N 90°	22	32	52	95	125	148	154	108	72	51	27	15
Fenster O 90°	6	9	14	31	34	37	40	30	22	13	7	4
Fenster S 90°	146	144	209	347	311	329	353	293	291	212	137	86
Fenster W 90°	29	39	61	140	152	168	181	133	101	59	31	17
Solare Wärmegewinne	203	223	337	613	622	682	728	564	486	335	202	123
Gesamtwärmegewinne in kWh/Monat												
Gesamtwärmegewinne	**811**	**772**	**944**	**1201**	**1229**	**1270**	**1335**	**1171**	**1074**	**942**	**789**	**730**

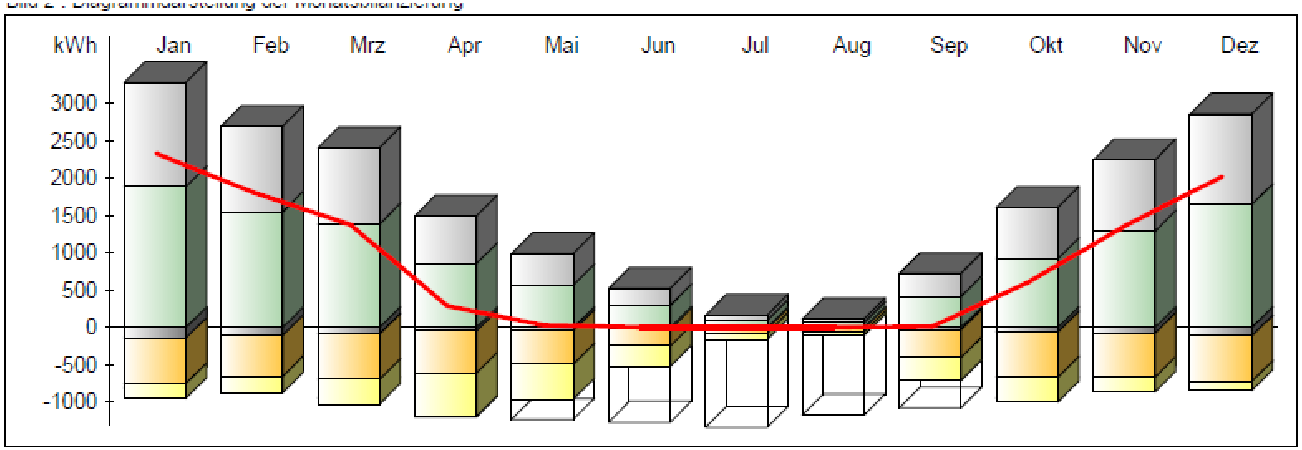
Energy Balance Insulated Building (3/4)

- Energy balance

Heizwärmebedarf in kWh/Monat												
Monat	**Jan**	**Feb**	**Mrz**	**Apr**	**Mai**	**Jun**	**Jul**	**Aug**	**Sep**	**Okt**	**Nov**	**Dez**
Ausnutzungsgrad Gewinne	1,000	1,000	1,000	0,954	0,752	0,392	0,117	0,093	0,641	0,994	1,000	1,000
Heizwärmebedarf	**2329**	**1805**	**1376**	**289**	**28**	**0**	**0**	**0**	**7**	**609**	**1366**	**2017**
Heizgrenztemperatur in °C und Heiztage												
Heizgrenztemperatur	14,52	14,28	13,78	12,14	12,21	11,75	11,62	12,53	12,87	13,79	14,49	14,97
Mittl. Außentemperatur:	-1,30	0,60	4,10	9,50	12,90	15,70	18,00	18,30	14,40	9,10	4,70	1,30
Heiztage	**31,0**	**28,0**	**31,0**	**30,0**	**8,8**	**0,0**	**0,0**	**0,0**	**7,6**	**31,0**	**30,0**	**31,0**

Energy Balance Insulated Building *(4/4)*

- Summary



<u>Ergebnisse des Monatsbilanzverfahrens</u>

Jahres-Heizwärmebedarf = 9.825 kWh/a

flächenbezogener
Jahres-Heizwärmebedarf = 60,20 kWh/(m²a)

volumenbezogener
Jahres-Heizwärmebedarf = 19,26 kWh/(m³a)

Zahl der Heiztage = 228,4 d/a

Heizgradtagzahl = 3.265 Kd/a

- Heizwärmebedarf
- Lüftungswärmeverluste
- Transmissionswärmeverluste
- Reduzierung der Wärmeverluste (Heizungsunterbrechung, etc.)
- nutzbare interne Wärmegewinne
- nutzbare solare Wärmegewinne
- nicht nutzbare Wärmegewinne

Appendix (C)

Methodology

Assessment of Human-Toxicity and Eco-Toxicity

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- Human toxicity is a standard category for eco-efficiency analysis. The evaluation is based upon hazard phrases of products and of their pre-chain, as published in the safety data sheets.
- The materials are evaluated separately in two phases of their life cycle: production of materials, use and end of life.
- The evaluation of eco-toxicity potential is a standard assessment for SEEBALANCE and AgBALANCE. The eco-toxicity potential is determined with USEtox, an environmental model developed under the UNEP-SETAC Life Cycle Initiative.
- The evaluation of ecotoxicity is based on physico-chemical properties (MW, water solubility, water/octanol partition coefficient, etc.) bio-degradability and toxicity towards water organisms, plants, bacteria. These data are usually available in the USEtox database (over 3,000 datasets), in EPIsuite or in the safety data sheets.

Determination of the Human-Toxicity Potential

BASF The Chemical Company

Reference:

- **R. Landsiedel, P. Saling, Int. J. LCA 7 (5), 261-268, (2002)**

- The toxicity potential is determined using an assessment method developed by BASF based on the H-phrases of the **Globally Harmonized System of Classification and Labelling of Chemicals** (GHS). In cooperation with toxicologists numerical values ranging between 0 and 1000 were assigned to each H-phrase according to their risk potential. For example, the classification H 330 (Fatal if inhaled) is worth 750 points and the considerably less critical category H 312 (Harmful in contact with skin), 300 points (see example on next page). These H-phrase-based values are determined for all intermediate and final products that are used during the life cycle of each alternative, taking into account the likelihood of human exposure.
- The calculated index figures are multiplied by the amounts of substances used and added up to yield the overall toxicity potential over the life cycle.
- In the use category only the actual H-phrases of a substance are considered. In contrast, in the production phase, the H-phrases of the pre-chain are evaluated as well as of the substance being produced.
- The results of these assessments are expressed in dimensionless toxicity units.
- Only potential toxicity values are calculated. In order to be able to assess an actual risk to humans, additional calculations on the exposure of humans, uptake of the substance, etc., are needed.

Determination of the Human-Toxicity Potential: Example

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Toxicity Potential

H 330 = 750 points,
Fatal if inhaled

H 331 = 550 points,
Toxic if inhaled

H 301 = 400 points,
Toxic if swallowed

H 314 = 300 points,
Causes severe skin burns and eye damage

H 319 = 100 points,
Causes serious eye irritation

Calculation

Substance 1
H 330: 750 P
Prechain: 0 P
Total : 750 P

↓

Input: 0.5 kg
Factor:
0.5*750 = 375 P

Substance 2
H 314: 300 P
Prechain: 0 P
Total: 300 P

↑

Input: 0.5 kg
Factor:
0.5*300 = 150 P

→

Substance 3
H 311: 400 P
Prechain: 525 P
Total: 925 P

↑ Use: 400 P

↓ Prod: 925 P

Determination of Cumulative Energy Demand (CED)

BASF The Chemical Company

- The impact category cumulative energy demand (CED) is based on the consumption of primary energy cradle-to-gate. Cradle-to-gate is an assessment of a *partial* product life cycle from resource extraction ('cradle') to the factory gate (i.e., before it is transported to the consumer). The use phase and disposal phase of the product are omitted in this case. The sum of fossil fuels before production and of the renewable energy before harvest or use is shown. Thus conversion losses from the generation of electricity and steam are taken into account. In the case of BASF processes, company-specific data is used. In the case of non-BASF processes, the UCPTE data set [1] is used. However, consideration of specific scenarios for the production of electricity and steam are possible, e.g. for site comparisons.
- The CED figures are assigned to the individual types of energy carriers. In the category of CED, there is no further conversion to specific impact categories. The consumption of the various forms of primary energy is taken into account in the abiotic depletion potential.
- In order to calculate the total energy requirement the lower calorific value of the primary energy equivalent is used. The following forms of energy are taken into account: coal, oil, gas, lignite, nuclear energy, hydraulic power, wind power, biomass and others.

[1] West European Electricity Coordination System
(UNION POUR LA COORDINATION DE LA PRODUCTION ET DU TRANSPORT DE L`ÉLÉCTRICITÉ)

Determination of Abiotic Depletion Potential (ADP)

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The Chemical Company

- The mass of raw materials necessary for each alternative is determined. The individual materials are then weighted according by a factor incorporating the life span and the fractional consumption of that material [2].
- In the case of renewable raw materials, sustainable farming is assumed. Therefore, the resource that has been removed has been replenished in the period under consideration. This means an endless life span and thus a weighting factor of zero. Of course, in the case of renewable raw materials from non-sustainable farming (e.g. rainforest clearance), an appropriate (non-zero) weighting factor is used for the calculation.
- High CED can be correlated with low ADP if renewable raw materials such as wood or hydraulic power are used. What therefore appears to be double counting of raw material and energy consumption does not occur with these two categories.

[2] U.S. Geological Survey, Mineral Commodity Summaries, 1997; Römpp Chemie Lexikon, Thieme, Stuttgart; Institut für Weltwirtschaft, Kiel; D. Hargreaves et al, World Index of Resources and population, Dartmouth Publishing, 1994; World Resources, Guide to the Global Environment, Oxford 1996; Deutsches Institut für Wirtschaftsforschung, Berlin

Determination of Abiotic Depletion Potential (ADP)

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Raw Material	Resources	Reserves	Weighting
	[Years]	[Mio t]	[kg Ag eq.]
Coal	147	478.771,0	0,00022
Oil	41	164.500,0	0,00073
Gas	63	163.314,0	0,00059
Lignite	241	142.000,0	0,00032
Uranium	37	2,3	0,20442
NaCl	1000	18.000.000,0	0,00001
Sulfur	9091	600.000,0	0,00003
Phosphorus	122	18.000,0	0,00127
Iron	70	71.000,0	0,00085
Lime	500	18.000.000,0	0,00002
Bauxite	197	25.000,0	0,00085
Sand	1000	18.000.000,0	0,00001
Copper	31	490,0	0,01520
Titanium	120	730,0	0,00638
Silver	13	0,3	1,00000

Determination of Air Emissions

- Air emissions of different gases are recorded separately and added up over the whole life cycle. In most processes, the emission of carbon dioxide is the largest air emission. This emission is typically followed (in terms of quantity) by emissions of sulfur and nitrogen oxides as well as N2O and hydrocarbons. All emissions occurring during the life cycle are considered, for example for the generation and use of electricity as a source of energy.
- The effect of these air emissions in the environment varies depending on the type of gas. In order to take account of this, the various emission quantities are linked to scientifically determined assessment factors [ex. IPCC 2007 Fourth Assessment Report]. Using this method, the emissions of 25 kg of carbon dioxide have the same greenhouse effect as 1 kg of methane. These so-called impact categories are used for each emission. Some emissions, for example the emission of methane, play a role in several impact categories. The impact categories that are taken into consideration in the eco-efficiency analysis are the greenhouse gas emissions, photochemical ozone creation potential (summer smog), acidification potential (acid rain) and ozone depletion potential.

CO2: carbon dioxide
SOX: sulphur oxides
NOX: nitrogen oxides
CH4: methane
HC: sum of hydrocarbons
Hal HC: halogenated hydrocarbons NH3: ammonia
N2O: dinitrogen oxide
HCl hydrochloric acid

	GWP	ODP	POCP	AP
CO2	**1**			
SOX				**1,00**
NOX				**0,70**
CH4	**25**		**0,006**	
HC			**1,000**	
Hal. HC	**4.750**	**1**		
NH3				**1,88**
N2O	**298**			
HCl				**0,88**

Determination of Water Use

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The Chemical Company

- While water cannot disappear, it can be made unavailable to specific users either by displacement or quality degradation, thereby affecting human life, ecosystems and natural resources (SETAC 2009; Boulay, A.-M. CIRAIG - École Polytechnique, MONTREAL, Canada).
- The assessment of water use combines water use metrics (Water Footprint Network) with water impact assessment (Water Scarcity Index) in order to characterize both water use and water quality issues at a regional level.
- Freshwater degradative use (gray water) and consumptive use (release of withdrawn water back into the original watershed does not occur) are assessed in the Eco-Efficiency Analysis.

  Gray water refers to polluted water that is associated with the production of goods or services. It is assessed through a distance-to-target approach because it is the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains at or above agreed water quality standards. See section on water emissions for more information.

  Consumptive water use includes freshwater withdrawal (blue water) which is evaporated, incorporated into products and waste, transferred into different watersheds or disposed into the sea after use.
- The volume of consumptive water use (WU) is multiplied with a regional damage factor (DF) to assess the impact.
- The damage factors are adopted from *S. Pfister et al, ES&T - Assessing the Environmental Impacts of Freshwater Consumption in LCA (2009)*. The values are either country- or watershed-specific depending on the resolution needed. The damage factors include the damage to the ecosystem quality, to resources and to human health.

Determination of Water Emissions

BASF The Chemical Company

- The assessment of water pollution is carried out by means of the “critical volume” model. For selected pollutants that enter the water, the theoretical water volume affected by the emission up to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the “critical volume”.
- The factors for calculating the critical volume are shown in the table. The requirements that are made on sewage at the entry point into surface water, listed in the appendices to the German Waste Water Regulation (AbwV), are the basis for the factors.
- These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues were taken into account in establishing the statute. In spite of this restriction, BASF uses this method for several reasons:
  - existence of complete database for most of the emissions
  - recognition of the Waste Water Regulation and broad acceptance of the associated limit values

parameter	*Appendix to Waste Water Regulation (AbwV)*	requirement on waste water (mg/l)	factors for calculating ‚critical volumes’ (l/mg)
COD	*Nr. 22*	75	1/75
N-total	*Nr. 22*	13	1/13
P-total	*Nr. 22*	2	1/2
AOX	*Nr. 22*	1	1
Hg	*Nr. 22*	0,001	1.000
Cd	*Nr. 22*	0,005	200
Cr	*Nr. 22*	0,05	20
Zn	*Nr. 22*	0,2	5
Cu	*Nr. 22*	0,1	10
Ni	*Nr. 22*	0,05	20
Pb	*Nr. 22*	0,05	20
Sn	*Nr. 22*	0,2	5
SO_4^{2-}		10.000	1/10.000
Cl^-		10.000	1/10.000

COD: chemical oxygen demand; N-total: total nitrogen; P-total: total phosphorus; AOX: adsorbable organic halides; Hg: mercury; Cd: cadmium; Zn: zinc; Cu: copper; Ni: nickel; P; lead; Sn: tin; SO_4^{2-}*: sulfate;* Cl^-*: chloride.*

Determination of Solid Wastes

- The results of the material balance on solid waste emissions are summarized into four waste categories:
  - Municipal Waste
  - Chemical (special) Waste
  - Construction Waste
  - Mining Waste
- Due to lack of other assessment criteria, the average costs (normalized) for the treatment or disposal of each type of waste are used as weighting factors to form the overall impact potential.
- Production residues that are incinerated are considered in the overall calculation by including the incineration energy and the emissions that occur during incineration.

Evaluation of Land Occupation and Transformation: Ecosystem Damage Potential

BASF The Chemical Company

- The evaluation is derived from the Ecosystem Damage Potential (EDP) by Köllner and Scholz (2008)
- The EDP assessment is based on a biodiversity indicators calculated from vascular plant species richness
- The present method employs 13 land use types for land occupation, and
- 15 land use types for land transformation (see next slides)

- Koellner, T., and Scholz, R., Assessment of Land Use Impacts on the Natural Environment, Part 1: An Analytical Framework for Pure Land Occupation and Land Use Change, International Journal LCA 12(1) 16-23, 2007.
- Koellner, T., and Scholz, R., Assessment of Land Use Impacts on the Natural Environment, Part 2: Generic Characterization Factors for Local Species Diversity in Central Europe, International Journal LCA 2006

Evaluation of Land Occupation: Ecosystem Damage Potential

BASF
The Chemical Company

land use class	Factor (EDPocc)
Occupation, urban	**0,70**
Occupation, industrial area	**0,80**
Occupation, traffic area	**0,59**
Occupation, mineral extraction site	**0,70**
Occupation, dump site	**0,70**
Occupation, arable	**0,61**
Occupation, arable, monotone-intensive	**0,74**
Occupation, arable, organic	**0,36**
Occupation, permanent crop	**0,57**
Occupation, pasture and meadow	**0,33**
Occupation, forest	**0,36**
Occupation, shrub land, sclerophyllous	**-0,26**
Occupation, water areas	**0,61**

Evaluation of Land Transformation: Ecosystem Damage Potential

BASF The Chemical Company

	Factor (EDPtrans)
Transformation, from urban	**0,03**
Transformation, from industrial area	**0,00**
Transformation, from traffic area	**0,05**
Transformation, from mineral extraction site	**0,03**
Transformation, from dump site	**0,03**
Transformation, from arable	**0,10**
Transformation, from arable, monotone-intensive	**0,03**
Transformation, from arable, non-irrigated, organic	**1,10**
Transformation, from permanent crop	**2,88**
Transformation, from pasture and meadow	**1,18**
Transformation, from forest	**11,00**
Transformation, from shrub land, sclerophyllous	**13,25**
Transformation, from water areas	**0,05**
Transformation, from tropical rain forest	**780,00**
Transformation, from unknown	**0,04**

	Factor (EDPtrans)
Transformation, to urban	**-0,03**
Transformation, to industrial area	**0,00**
Transformation, to traffic area	**-0,05**
Transformation, to mineral extraction site	**-0,03**
Transformation, to dump site	**-0,03**
Transformation, to arable	**-0,10**
Transformation, to arable, monotone-intensive	**-0,03**
Transformation, to arable, organic	**-1,10**
Transformation, to permanent crop	**-2,88**
Transformation, to pasture and meadow	**-1,18**
Transformation, to forest	**-11,00**
Transformation, to shrub land, sclerophyllous	**-13,25**
Transformation, to water areas	**-0,05**
Transformation, to tropical rain forest	**-780,00**
Transformation, to unknown	**-0,04**

Determination of the Risk Potential

BASF
The Chemical Company

- Statistical data on accidents and occupational diseases in various industries or in various occupations are included. The statistical values are multiplied by the amount of product used within the analysis to give a statistical risk potential.
- The risk potential of additional risks in the Eco-Efficiency Analysis is established using expert judgments. For example safety data on various types of reactions in the chemical industry may be included.
- In the risk potential category, different types of risks can be considered. For example, possible damage due to physical reactions (explosion or fire hazards and transportation risks), impurities in the product, incorrect handling, incorrect storage, etc.
- The criteria of the risk potential are variable and may be different in each study, because they are adapted to the circumstances and special features of the particular alternatives. The number of risk categories may vary.
- All aspects of the complete life cycle are included in the assessment.
- Risk potentials are calculated values. In order to be able to estimate a risk actually occurring to a human, additional calculations and estimates are required

Risk Potential
Assessment of Working Accidents and Occupational Diseases (statistical data)

BASF
The Chemical Company

Statistics A

Working Accidents in Branch 24, Chemical Industry (2001)

12.217 Accidents

/

Statistics B

Total Production of branch 24, Chemical Industry (2001)

~ 210 Mio. t

~ 58 Accidents / Mio. t chemical Products

NACE 24:

- 24.1: Base Chemicals
- 24.2: Plant Protecting Agents
- 24.3: Coatings
- 24.4: Pharmaceuticals
- 24.4: Detergents
- 24.X: ...

Sources:

- Statistisches Bundesamt
- Dt. Bundestag
- Bundesanstalt für Arbeits-schutz und Arbeitsmedizin
- Verbände
- Berufsgenossenschaften
- Companies (BASF,..)

The Environmental Fingerprint According to BASF

BASF The Chemical Company

- The impact categories are normalized (and, in the case of emissions and material consumption, also weighted) and plotted on the environmental fingerprint. This plot shows the environmental advantages and disadvantages of the alternatives relative to one another. The alternative with a value of one is the least favorable alternative in that category; the closer an alternative is to zero, the better its performance.
- The axes are independent of each other so that an alternative which is, for example, favorable in terms of cumulative energy demand may be less favorable in terms of emissions.
- Using the environmental fingerprint, it is possible to find the areas in which improvements are necessary in order to optimize the whole system effectively.

Determination of the Overall Environmental Impact

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- The values obtained for the life cycle inventories and the impact estimated for each single environmental category (greenhouse potential, ozone depletion potential, photochemical ozone formation potential, acidification potential, water emissions, solid waste, cumulative energy demand, raw material consumption and area requirement) are aggregated with calculation factors to yield an overall environmental impact value. The calculation factors consist of the following:
  - a societal factor:
    - What value does society attach to the reduction of the individual potentials?
  - a relevance factor:
    - What is the fractional contribution of the specific emission (or consumption) to the overall countrywide emissions?
- As an overall Risk Potential or Toxicity Potential cannot be determined at present, the calculation factors of Risk Potential and Toxicity fit the societal weighting factors of these categories.
- The calculation factors are obtained from the relevance and societal factors by geometric mean. The calculation factors are weighting the normalized values from the environmental fingerprint.

Determination of Calculation Factors

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RELEVANCE FACTOR

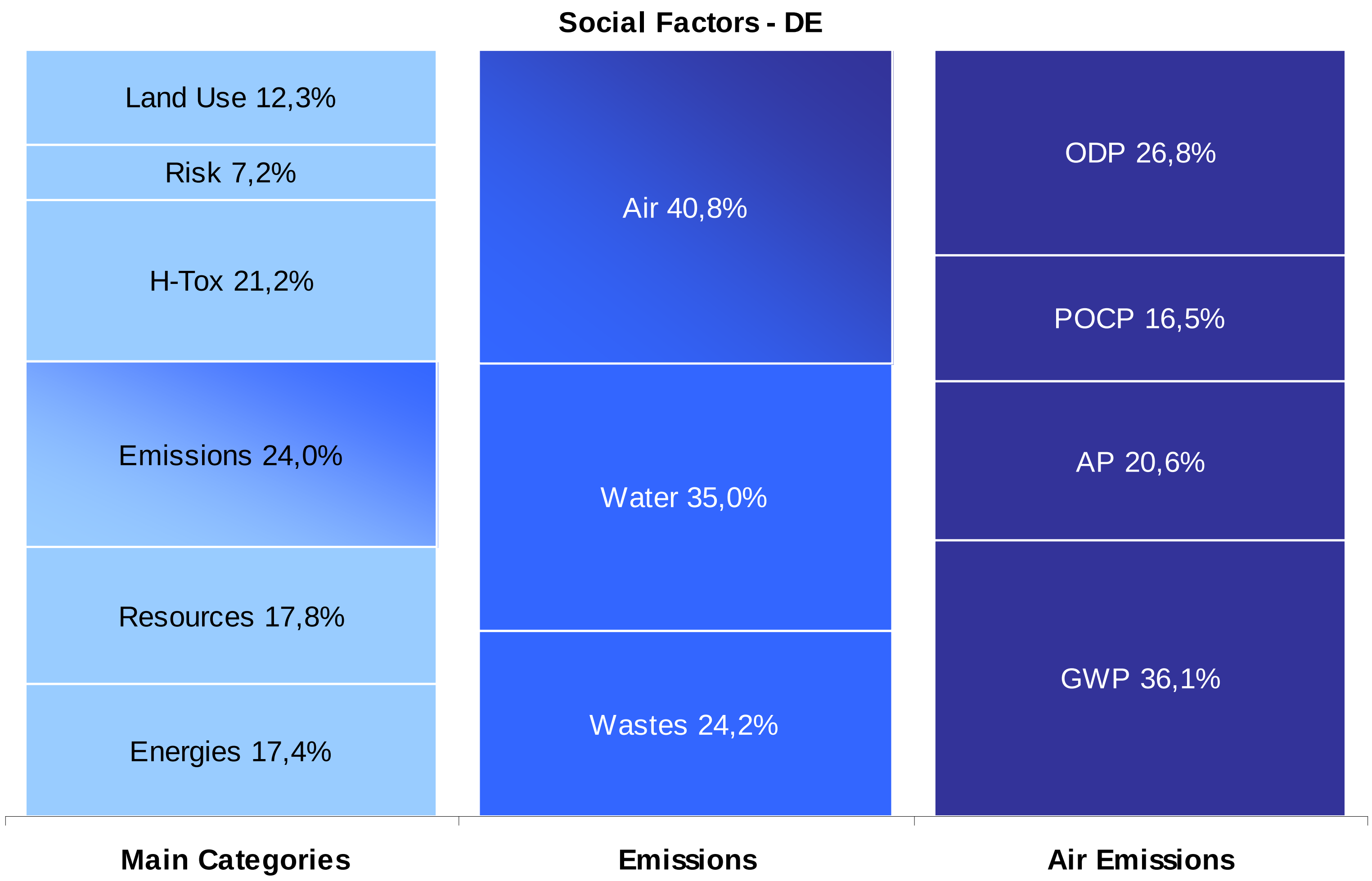
- What does the emission (energy use,...) contribute to the overall emissions (energy use,...) of the region/country?
- Based on statistics
- Changes from analysis to analysis depending on the hot spots

SOCIETAL FACTOR

- What value does society/an expert panel attach to the reduction of the individual potentials
- Based on public polls/expert survey
- Fixed for all analysis referring to the same region

$$\text{Calculation Factor} = \sqrt{\text{Relevance Factor} * \text{Societal Factor}}$$

Social Factors Germany, 2009 (tns infratest)



The Eco-Efficiency Portfolio According to BASF

BASF The Chemical Company

Reference:

- **P. Saling, A. Kicherer et al., Int. J. LCA 7 (4), 203-218, (2002)**
- **A. Kicherer, S. Schaltegger, et al., Int. J. LCA 12 (7), 537 – 543 (2007)**

- BASF has developed the Eco-Efficiency Portfolio to allow a clear illustration of eco-efficiency.
- The overall cost calculation and the calculation of the ecology fingerprint constitute independent calculations of the economic and environmental considerations of a complete system with different alternatives. Since ecology and economy are equally important in a sustainability study, a system can compensate for weaknesses in one area by good performance in the other. Alternatives whose sums of environmental and economic performance are equal are considered to be equally eco-efficient.
- The values obtained from the environmental fingerprint are multiplied by weighting factors (description of fingerprint and weighting factors can be found on subsequent pages) and added up in order to determine the environmental impact of each alternative. The various environmental impact values are normalized by the mean environmental impact and plotted on the eco-efficiency portfolio.

Qualitative data quality assessment by BASF

BASF The Chemical Company

Reliability

Score	General Qualitative Criteria	BASF Specific Criteria	General Criteria
High	Verified data based on measurements	BASF dataset with documentation available	Data from published LCA, EPD, Plastics Europe documentation available
Medium-high	Verified data partially based on assumptions	Company (ex.customer) dataset with documentation available	Data from published LCA, EPD, Plastics Europe documentation available
Medium	Non verified data partially based on qualified estimates	BASF dataset, no documentation available	
Low	Qualified estimate (e.g. by industrial expert)	Company (ex.customer) no documentation available	Data from general literature (Römpp, Ullmann, Patent) documentation available
Very Low	Non Qualified estimate	No documentation available	No documentation available

Completeness

Score	General Qualitative Criteria	BASF Specific Criteria	Completeness (percentage of flow that is measured or estimated)
High	All input and output flows: energy and material inputs, all emissions and wastes		
Medium-high	Only two emission output flows out of three (air, water, solid)		
Medium	All input flows: energy and material inputs. Partial output flows (emissions, waste not completely available)		
Low	Only input flows: energy and material inputs	Data from "Verbundsimulator"	
Very Low	Only partial input flows: material inputs	Kostenstelle	

Appendix (D)

Glossary

Glossary of Abbreviations and Technical Terms I

BASF The Chemical Company

- **AOX**: abbr. for adsorbable organic halogen, a category of water emissions
- **AP**: abbr. for acidification potential or acid rain. In this impact category, the effects of air emissions that lower the local pH values of soils and can thus e.g. cause forest death are taken into account.
- **BOD**: abbr. for biological oxygen demand. This is a method for determining wastewater loads.
- **CB**: abbr. for customer benefit. All impacts (costs, environment) are specific to this customer benefit which all alternatives being evaluated have to fulfill.
- **CH_4**: abbr. for methane.
- **Cl^-**: abbr. for chloride.
- **COD**: abbr. for chemical oxygen demand. This is a method for determining wastewater. loads.
- **CO_2**: abbr. for carbon dioxide.
- **critical volume**: operand for assessing the extent to which wastewater is polluted by mathematically diluting the wastewater with fresh water until the allowed limit value is reached. This volume of fresh water that has been added is referred to as the critical volume.
- **municipal waste**: waste that may be deposited on a normal household landfill.
- **emissions**: emissions are categorized as emissions into air, water and soil. These broad groupings are further subdivided into more specific categories.

Glossary of Abbreviations and Technical Terms II

BASF
The Chemical Company

- **energy unit**: energy is expressed in mega joules (MJ). 1 MJ is equivalent to 3.6 kilowatt hours (kWh).
- **feedstock**: the energy content that is bound in the materials used and can be used e.g. in incineration processes.
- **GWP**: abbr. for global warming potential. This impact category takes into account the effects of air emissions that lead to global warming of the earth’s surface.
- **hal. HC**: abbr. for halogenated hydrocarbons.
- **halogenated NM VOC**: abbr. for halogenated non-methane volatile hydrocarbons.
- **HC**: abbr. for various hydrocarbons or hydrocarbon emissions into water.
- **HCl**: abbr. for hydrogen chloride.
- **HM**: abbr. for heavy metals.
- **impact potential**: name of an operand that mathematically takes into account the impact of an emission on a defined compartment of the environment.
- **material consumption**: in this category, the consumption of raw materials is considered along with worldwide consumption and remaining reserves. Thus, a raw material with smaller reserves or greater worldwide consumption rates is more critically weighted.

Glossary of Abbreviations and Technical Terms III

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- **NH_3**: abbr. for ammonia emissions.
- **NH_4^+:** abbr. for emissions of ammonium into water.
- **NM VOC**: abbr. for non-methane volatile organic compound.
- **N_2O**: abbr. for N2O emissions.
- **NO_x**: abbr. for various nitrogen oxides.
- **normalization**: in the eco-efficiency analysis, the worst performance in each environmental category is normalized to a value of one. Thus alternatives with better performance in that category will lie between zero and one on the environmental fingerprint.
- **ODP**: abbr. for ozone depletion potential, damage to the ozone layer. This impact category takes into account the effects of air emissions that lead to the destruction of the ozone layer of the upper layers of air and thus to an increase in UV radiation.
- **PO_4^{3-}**: abbr. for emissions of phosphate into water.
- **POCP**: abbr. for photochemical ozone creation potential. This effect category takes into account the effects of local emissions that lead to an increase in ozone close to the ground and thus contribute to what is known as summer smog.

Glossary of Abbreviations and Technical Terms IV

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- **risk potential**: impact category assessing the effects of risk factors over the complete life cycle. Risks such as transportation risks, dangers of explosion, dangers of accidents, etc. may be included
- **SO_x**: abbr. for various sulfur dioxides.
- **SO_4^{2-}**: abbr. for emissions of sulfates into water.
- **special waste**: waste that has to be deposited on a special landfill.
- **system boundary**: determines what aspects are considered in the study.
- **Time span:** The period for which a raw material is still available and can be used. The current use of the raw material in relation to what is currently known to be the amount that is still available and can be used industrially is the basis for the assessment.
- **Total N**: Collective term for all water pollutants that contain nitrogen and that cannot be included in one of the other categories.
- **Toxicity potential**: In this category, the effect of the substances involved is assessed with regard to their effect on human health. It relates solely to possible material effects in the whole life span. Further data have to be used to assess a direct risk.
- The symbols have the following meanings: T+: very toxic; T: toxic; Xn: harmful; C: corrosive; Xi: irritating.