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TAJDA POTRČ OBRECHT

AN ADVANCED METHODOLOGY FOR THE ASSESSMENT OF ENVIRONMENTAL IMPACTS OF BUILDING REFURBISHMENT IN THE ENTIRE LIFE CYCLE

DOCTORAL DISSERTATION

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TAJDA POTRČ OBRECHT

NAPREDNA METODOLOGIJA ZA VREDNOTENJE OKOLJSKIH VPLIVOV PRENOVE STAVB V CELOTNI ŽIVLJENJSKI DOBI

Doktorska disertacija

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Izvleček

Učinkovita in trajnostna obnova obstoječega stavbnega fonda bo pri zmanjševanju toplogrednih emisij na področju gradbeništva v prihodnosti ključna. Okoljski vplivi prenov se določajo z analizo življenjskega cikla (metodo LCA), pri čemer se prenova običajno obravnava kot začetek novega življenjskega cikla stavbe. V okviru doktorske naloge smo razvili napredno metodologijo LCA za ocenjevanje okoljskih vplivov prenov, ki vključuje tudi faze pred prenovo in rabo časovno ustreznih podatkov za analizo življenjskega cikla stavbe (LCA). S tem zagotavlja, da so vključeni vsi vplivi prenove stavb in se eliminira podvajanje vplivov.

Napredna metodologija je sestavljena iz dveh delov. Prvi del omogoča prilagajanje trenutno dostopnih podatkov tako, da ustrezajo dejanskemu času proizvodnje. Drugi del metodologije zagotavlja ustrezno razporejanje (alokacijo) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej. Oba dela metodologije lahko uporabimo tudi ločeno. Vzporedno smo razvili LCA metodologijo za primerjanje ukrepov prenove, ki poleg utelešenih vplivov vključuje tudi okoljske vplive v času rabe stavbe.

V nalogi je bilo dokazano, da je uporaba časovno ustreznih podatkov pri analizi okoljskih vplivov izjemno pomembna. Za prenove stavb pa je ključno tudi, da se okoljske vplive alocira na življenjski cikel pred obnovo in po njej, kar je pomembno zlasti kadar se materiali reciklirajo in ponovno uporabijo. Primerjalne okoljske analize prenove fasadnega ovoja so pokazale, da v našem geografskem področju položaj toplotnoizolacijskega sloja ne vpliva bistveno na toplotni akumulacijski potencial stavbe in da je povračilna doba okoljskih vplivov fasadnega ovoja v veliki meri odvisna od okoljskih vplivov same toplotne izolacije.

BIBLIOGRAPHIC-DOCUMENTALISTIC INFORMATION AND ABSTRACT

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Abstract

The refurbishment of the building stock is one of the key tasks for reducing future environmental emissions. The environmental emissions are mostly assessed with the Life Cycle Assessment (LCA) method, where the refurbishment is usually considered as the beginning of the new life cycle, and all the impacts associated with the life cycle before the refurbishment are neglected. In order to overcome this inconsistency, in the PhD study an advanced LCA methodology was developed that allocates the impacts between the life cycle before and after the refurbishment, and assures the use of time-corresponding data. In this sense, the neglecting of the environmental impacts before the refurbishment, as well as the double-counting, is eliminated.

The developed methodology consists of two sub-methodologies. The first sub-methodology is used for remodelling the input data, in order to make them time-corresponding. The second sub-methodology enables the allocation of environmental impacts before and after a refurbishment and calculation of the residual value of materials. Both sub-methodologies can be used also individually. Additionally, a methodology for the comparison of the environmental impacts of refurbishment measures that also includes operational EI was developed.

The thesis proved that the use of time-appropriate data for the analysis of environmental impacts is extremely important. For building refurbishment, it is also crucial that environmental impacts are allocated to the life cycle before and after renovation, especially when materials are recycled or reused. The comparative methodology for the refurbishment measures indicated that in Central Europe the position of the thermal insulation layer does not significantly affect the heat storage capacity of buildings, and that the environmental payback period for the façade refurbishment is mainly dependent on the environmental impacts of the thermal insulation itself.

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KAZALO PREGLEDNIC

OKRAJŠAVE IN SIMBOLI / ABBREVIATIONS AND SYMBOLS

ADP	Abiotic depletion potential
AG	Aerogel
AP	Acidification potential of soil and water
CL	Cellulose
EI	Environmental impacts
EP	Eutrophication potential
EPB	Energy performance in buildings
EPD	Environmental Product Declaration
EPS	Expanded polystyrene
EoL	End-of-Life
GHG	Greenhouse gas
GWP	Global Warming Potential
IPCC	International Panel of Climate Change
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MW	Mineral wool
ODP	Depletion potential of the stratospheric ozone layer
PCR	Product Category Rules
PEF	Product Environmental Footprint
PF	Phenolic foam
POCP	Formation potential of tropospheric ozone
RSL	Reference Service Life
RSP	Reference Study Period

1 INTRODUCTION

1.1 Problem description

Climate change is one of the main threats that humanity is currently facing. The alarming reports of the Intergovernmental Panel on Climate Change (IPCC) state that the greenhouse gas (GHG) emissions caused by human activity are responsible for the rise of global temperatures (IPCC, 2021). The mitigation of climate change is one of the most important tasks for the future and this is also globally recognized within the Sustainable Development Goals (SDGs) (United Nations, 2019). Action has to be taken in several fields, among others in the construction sector, which is one of the largest contributors to climate change according to the annual status report of the UN Environment and the International Energy Agency (IEA) (IEA and UNEP, 2019).

The construction sector accounts for 40 % of the total energy and 30 % of the raw materials consumed; 25 % of waste is generated and 12 % of all land is used for this purpose. Buildings account for 33 % of GHG (Chau et al., 2015a). An even worse situation exists in the European Union, where buildings are directly or indirectly responsible for 40 % of all energy consumed and generate 36 % of GHG emissions. For this reason, increasing the performance of the building is one of the priority tasks in the future (EED, 2012). Different proposals aim to set GHG emission budgets for individual countries and regions to limit emissions from buildings (Habert et al., 2020).

It is anticipated that 80 % of the entire building stock that will be used in 2050 has already been built (Vilches et al., 2017). This means that already existing buildings will be responsible for a large share of greenhouse gas emissions in the future. Therefore, the refurbishment of public and private buildings is an important measure and has been identified as a key initiative to drive energy efficiency in the construction sector in the European Green Deal, which is a set of EU policy initiatives with the overarching aim of achieving climate neutrality of the EU by 2050. A strategy called "renovation wave" aims to double annual renovation rates in the coming years (EC, 2020). The current refurbishment rate is estimated at 1.2 % annually and should increase to 3 % in order to meet international emission reduction requirements by 2050 (Long - term strategy for energy renovation of buildings until 2050, 2021). Besides increasing the refurbishment rate, it is important that the quality of the refurbishment measures is improved. Steininger et al. (2021) highlight that climate neutrality can only be achieved by deep refurbishments of the building envelopes, the substitution of their heating systems or a combination of both actions. Less ambitious refurbishment actions will not bring the desired results.

So far, the focus of building refurbishment has been primarily on more efficient use of energy in the operational phase of the building (energy used for heating in the winter and also for cooling in the summer). Before the introduction of low-energy buildings, which drastically reduced the use of energy throughout the operational phase, this was justified. Consequently, the environmental impacts of the operational phase are less dominant, but the influence of other phases, such as the extraction of raw materials, transport, production of materials, and construction, as well as the phase after the end of service life (decomposition and recycling), is increasing. For a comprehensive evaluation of the environmental impacts caused by the refurbishment of a building, the entire life cycle of the building, including the production phase, the use phase and the end-of-life (EoL) phase must be analyzed.

The Life Cycle Assessment (LCA) method is recognized as one of the methods appropriate for assessing the environmental impacts of buildings. It systematically analyzes the environmental impacts of products and processes throughout their lifetime (European Commission - Joint Research Centre - Institute for Environment and and Sustainability, 2010; ISO 14040, 2006).

LCA for buildings was primarily developed to evaluate the environmental impacts of new buildings and has to be adapted in order to evaluate the impact of refurbishments. According to the EN 15978 standard, refurbishment is a sub-phase in the use phase of buildings, but the practice has shown that there are various possibilities for how to define the boundaries and scenarios when we are assessing the environmental impacts of refurbishments (EN 15978, 2021). This can significantly affect the results of the LCA analysis itself. Most of the studies of refurbishments are a comparison of different scenarios of renewal, which enables certain simplifications of the methodology according to EN 15978 (Agostino et al., 2017; Ardente et al., 2011; Asadi et al., 2012; Oregi et al., 2017a, 2015a; Passer et al., 2012). The prevailing methodology for evaluating the environmental impacts of building refurbishment takes into account only the environmental impacts of the production and installation of new built-in materials and neglects the existing materials (Oregi et al., 2015a) which is fully legitimate in comparative studies but it also presents certain problems. For example, the stages before refurbishment are not taken into account. If we consider that standard EN 15978 defines the refurbishment only as a sub-phase at the stage of building use, it is obvious that the preliminary phases, such as the production phase and the use phase, should be taken into account for a holistic analysis of the environmental impacts with the LCA method, including the phases prior to refurbishment. Consideration of these phases also reduces the complications in evaluating the EoL, since for this evaluation we also need information about the materials that remained in the building after the refurbishment. It also enables the evaluation of potential damage connected with the environmental impacts due to the early replacement of materials that have not yet reached their intended (reference) lifetime.

At the same time, taking into account the environmental impacts of pre-renovated materials also means a greater environmental impact of the refurbished buildings. In order to avoid the paradox that the refurbished building has a greater impact than an equivalent new construction, a system should be developed through which a comprehensive environmental assessment of the refurbishment of the building could be established and the advantages and disadvantages of the refurbishment compared to its replacement new construction presented.

Additionally, if we are considering also the part of the life cycle before the refurbishment, we need data on the environmental impact of materials and processes from the past, which are relatively rarely available. Another issue that we observed is that the existing studies focus only on individual impact categories, such as CO_2 emissions or embodied energy, and do not address the environmental impacts of other categories as envisaged in SIST EN 15804. The contribution of the refurbishment can differ for each of the environmental impact categories; therefore, for a more comprehensive environmental consideration, the various impact categories should be observed (Vilches et al., 2017).

Special emphasis was placed on the refurbishment of the building envelope. Various studies define the refurbishment of the building envelope as the most important part of the refurbishment (Ardente et al., 2011; Passer et al., 2012; Pomponi et al., 2015; Vilches et al., 2017). The envelope (exterior wall, roof, floor, windows and doors) represents the physical boundary between conditioned (indoor) and unconditioned (outdoor) space. The most common method of energy refurbishment is the installation of different types of thermal insulation outside or inside the envelope. The added thermal insulation has low thermal conductivity and thus increases the thermal resistance of the envelope. Consequently, heat flows or transmission losses through the envelope are reduced. Studies have shown that in the climate zones where there are high temperature differences over the course of the day, the accumulation of the heat in the materials and the position of the insulation can have a big impact on the heating and cooling of the building (Ozel, 2014). Due to the anticipated climate changes caused by the increased greenhouse gas (GHG) emission by humans it is likely that the temperature differences during the day and cooling needs will become more important in climates where this was not an issue before, as highlighted in the current IPCC report (IPCC, 2021). With the tools that enable the dynamic simulation of energy use it is possible to determine the influence of the positioning of the thermal insulation (inside, outside) on the energy use. It was also discovered that most of the existing studies deal with the reduction of energy use during the refurbishment and only rarely discuss the related environmental impacts, especially for the climate region of Slovenia. The evaluation of environmental impacts with the LCA method is more often carried out for individual insulating materials and is not applied to buildings where they are also amortized. Studies that evaluate the environmental impacts for areas with similar climatic conditions as Slovenian climatic conditions (e.g. Ljubljana) are rare, so it is estimated that such a study would be very important.

Greater focus on the refurbishment of the building will increase the circular economy (CE) concept in the built environment since it is one of the value retention processes (also known as imperative Rs), such as refuse, reduce, reuse, repair, refurbish, recycle and recover. CE is considered to be a restorative and regenerative approach in which emissions, resource use and waste generation are reduced through the principles of narrowing (efficient resource use), slowing (temporary extended use) and closing (cycling) current and future resource loops (Eberhardt et al., 2020). This is actively promoted in international policy and at the European level.

1.2 Structure of the thesis

The structure of the dissertation together with the papers published is presented in Figure 1. After a brief introduction to the problematic, the background knowledge of the research work is presented. Basic information about the LCA methodology and its use in the refurbishment of buildings is provided. Based on this information, the research hypotheses are formed and the aim of the dissertation is presented.

In the core of the dissertation the development of the advanced methodology for the assessment of environmental impacts (EI) of refurbishments is presented. During the development of the thesis the decision was made that, due to the complexity of the current problems, not only one but several different methodologies should be developed to solve the current problems and that it should be possible to combine them.

The advanced methodology for the assessment of the embodied EI of refurbishments consists of two sub-methodologies that can be used together or independently. Firstly, a sub-methodology for remodelling the input environmental data is presented. The aim of the methodology is to provide time-corresponding data for the materials and components that were produced in the past or the future. The second is the sub-methodology for assessment of the environmental impacts and the residual value of refurbishment measures that also involves a division between life cycles. The focus of these methodologies are the embodied environmental impacts of refurbishments.

In the part "A methodology for the comparison of refurbishment measures" another methodology was developed. Since it is a comparative methodology, certain simplifications can be made. The methodology includes the assessment of the operational environmental impacts (calculated with dynamic thermal simulation tools) and embodied environmental impacts. The methodology is verified on the example of building envelope refurbishment.

The main findings of the works are then summarized in the final chapter. A proposal for future research and the contribution to the science are also provided.

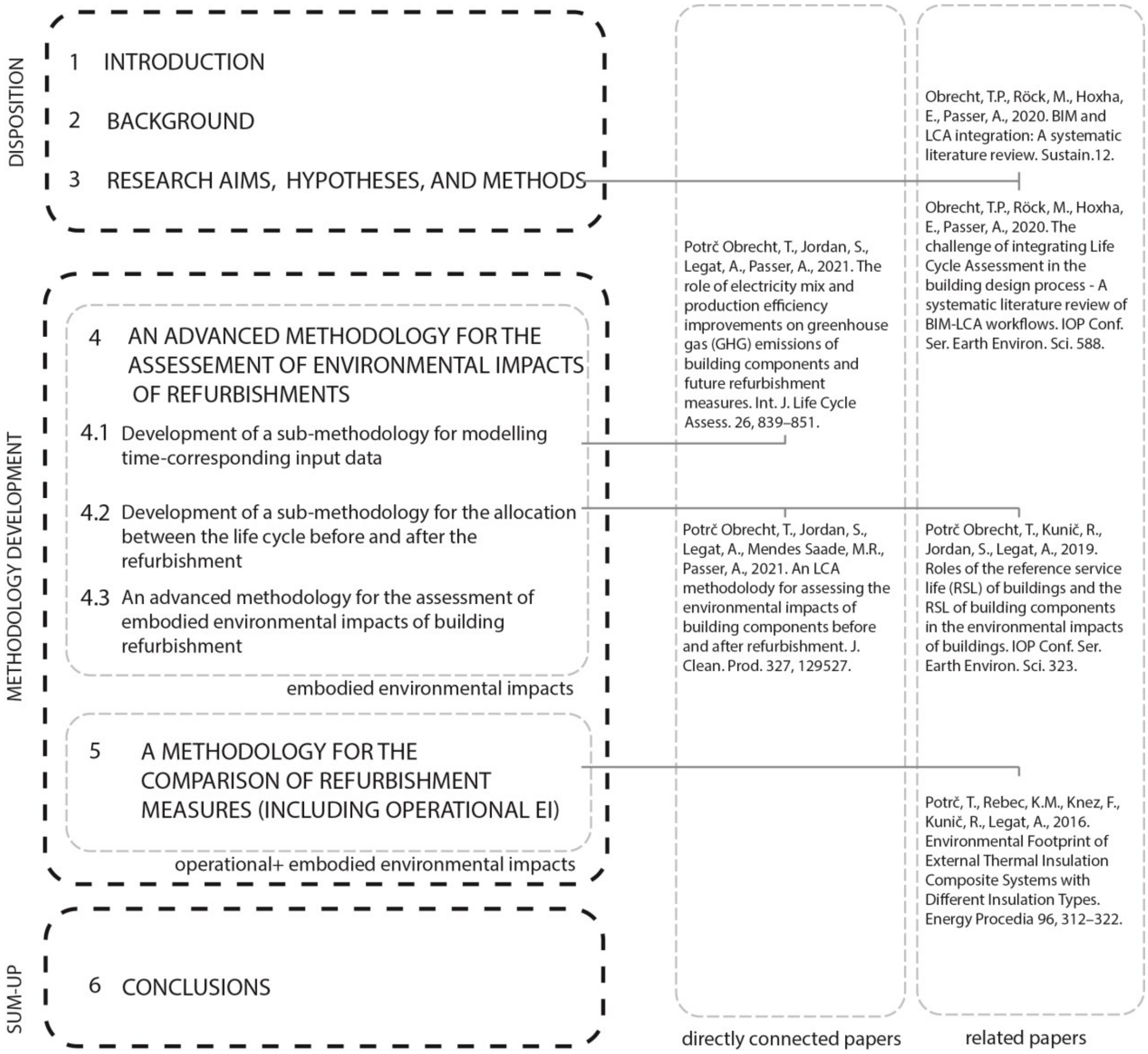

Figure 1: Structure of the thesis and the published papers
Slika 1: Struktura disertacije in objavljeni prispevki

2 THEORETICAL BACKGROUND

2.1 Life cycle assessment (LCA)

2.1.1 The history of LCA

The increased awareness of the potential impacts on the environment has increased the interest in the development of methods for measuring these impacts.

According to Buyle et al. (2013), the first environmental impact studies appeared between 1960 and 1970, and focused on comparing individual products at the production stage. One of the first studies was commissioned by The Coca-Cola Company as they wanted to examine the consumption of resources in relation to emissions and waste generated by various types of beverage packaging. At that time, the Midwest Research Institute used the term "Resource and Environmental Profile Analysis" for the assessment. They calculated the environmental impacts and consumption of materials from the "cradle to the grave" of the product. Despite some initial studies, interest in LCA died out and re-emerged around 1980. In 1984, the Swiss Federal Laboratories for Materials Testing and Research issued instructions to determine which data we need to carry out the LCA study, thus accelerating the implementation of LCA studies. Between 1970 and 1990, there were no uniform guidelines or a single theoretical basis for the production of LCA studies. The studies were not comparable to each other and were therefore not accepted by the experts.

Between 1990 and 2000, the field of LCA developed more rapidly. The first scientific articles on LCA began to appear. The Society of Environmental Toxicology and Chemistry (SETAC) has taken on the role of a leading organization that brings together LCA practitioners with users and scientists in this field, and constantly seeks to improve and harmonize the LCA methodology, frameworks and terminology. In 1994, the International Organization for Standardization (ISO) raised interest for the standardization of methods and processes. In 1997, it issued the ISO 14040 and ISO 14044 standards, which defined the general methodological framework of LCA research (ISO 14040, 2006). In the 21st century, the interest in LCA research has grown. The International Reference Life Cycle Data System Handbook (ILCD), which was released in 2010, further explained the requirements of the ISO 14040 series and made the methodology more comprehensive (European Commission - Joint Research Centre - Institute for Environment and and Sustainability, 2010). At the same time, the need for a common communication format increased and the Environmental Product Declarations (EPDs) were introduced (Passer and Maydl, 2006). EPDs are documents containing data about certain environmental parameters of an individual product in accordance with the SIST EN 15804 and ISO standards (ISO 14040, 2006). Users should be able to compare and choose between similar products according to the information in the EPDs (Passer et al., 2015).

In 2003, the European Commission issued the Integrated Product Policy (IPP), which attempts to stimulate each part of the product life cycle to improve their environmental performance. Hence, interest in LCA research, which is a method for assessing these impacts in the entire life cycle, increased. In alliance with the IPP document, the International Reference Life Cycle Data System Handbook (ILCD), a practical LCA guide that follows the ISO 14040 series guidelines, was developed. Additionally, the increasing interest in LCA was also a consequence of the newly developed framework for the EPDs. EPDs are defined as a Type III declaration that quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function (ISO 14025, 2006). The methodology is based on the LCA tool.
Much progress has been made in the construction sector in particular. The first reports about the assessment of environmental impacts with LCA were issued in 2003 by SETAC (SETAC-Europe et al., 2003). Based on this report, the ISO Commission and the European Commission for Standardization (CEN) issued specific standards that deal only with LCA of buildings. The ISO Technical Committee 59 "Building Construction" or its subcommittees (SC) 17 "Sustainability and building construction" have issued standards describing the framework for investigating the sustainability of buildings (EN 15978, 2021) and the implementation of the EPD (EN 15804:2012 + A2:2019, 2019). The European Technical Committee CEN TC 350 "Sustainability of construction works" has issued standards for assessing all three aspects of sustainability (economic, ecological and social aspects) for new and existing buildings and standards for easier adoption of EPDs into practice.

Recently the LCA methodology has become widely applied in almost all sectors (Passer and Maydl, 2006). In the construction sector, too, the number of studies, EPDs and projects has increased. Some countries have already developed national LCA methodologies and developed their own databases for LCA for assessing buildings (e.g. Belgium, Germany, Norway, etc.). However, one of the main problems of the studies remains that despite the standardization, the results are difficult to compare. In 2016, the International Energy Agency launched the IEA EBC Annex 72 project that aims to harmonize the methodology (IEA EBC, 2017) for the assessment of buildings' environmental impacts. In the project several issues were identified that still have to be resolved to increase the robustness and reliability of LCA studies for buildings (Röck et al. 2019; Frischknecht et al. 2019; Satola et al. 2021; Llatas, Soust-Verdaguer, and Passer 2020; Lützkendorf and Frischknecht 2020; Potrč Obrecht et al. 2020). Several of these issues are discussed and will be solved in this thesis.

2.1.2 LCA methodology

The LCA method is used to determine the EI of products and processes. It can assist in identifying opportunities to improve the environmental performance of products, inform decision makers about current dangers and possible opportunities for improvement and lately, it has been a good marketing advantage (European Commission - Joint Research Centre - Institute for Environment and and Sustainability, 2010; ISO 14040, 2006) The method systematically analyzes the EI of products and processes over their entire life cycle. In the 1990s, it was standardized with ISO 14040 series standards (ISO 14040, 2006). These standards define the research methodology, which is divided into four phases. The first phase (1) is to define the goal and extent of research that defines a functional unit of a product or process and limits the boundaries of the analyzed system; (2) in the second phase the information on material and energy flows in individual stages of the life cycle (this phase is called the Life Cycle Inventory (LCI)) is collected; (3) in the third phase, the accumulated material and energy flows are assigned to an environmental category and attributed to a characterization factor, to which the contribution of individual flows to the defined environmental category is calculated; (4) the fourth phase is the interpretation of the obtained results (Figure 2).

In the following subchapter the phases of the LCA defined by ISO 14044 will be explained in more detail.

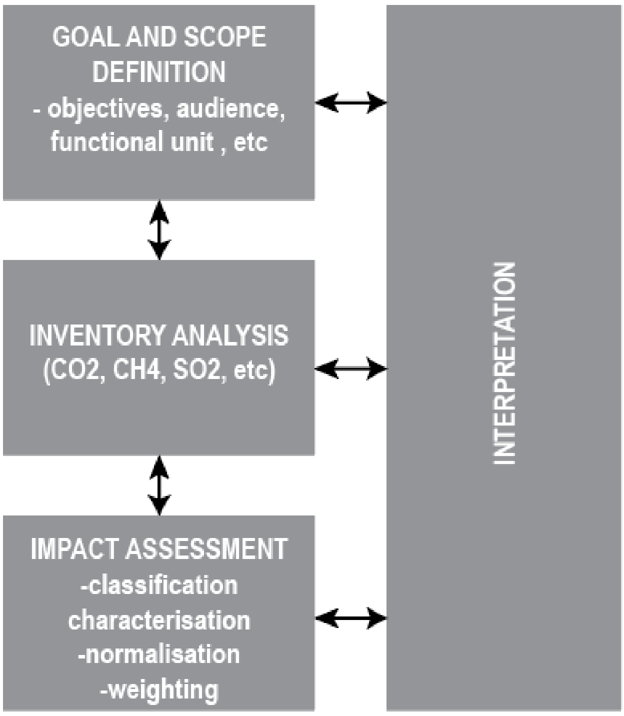

Figure 2: LCA methodology
Slika 2: LCA metodologija

The ILCD handbook suggests that the LCA is almost always an iterative process (European Commission - Joint Research Centre - Institute for Environment and and Sustainability, 2010). After defining the goal of the study, the scope has to be adjusted accordingly. During the data collection

(LCI phase) and subsequent impact assessment and interpretation more knowledge is gathered and typically, the initial scope also has to be harmonized accordingly. The iteration process is illustrated in Figure 3.

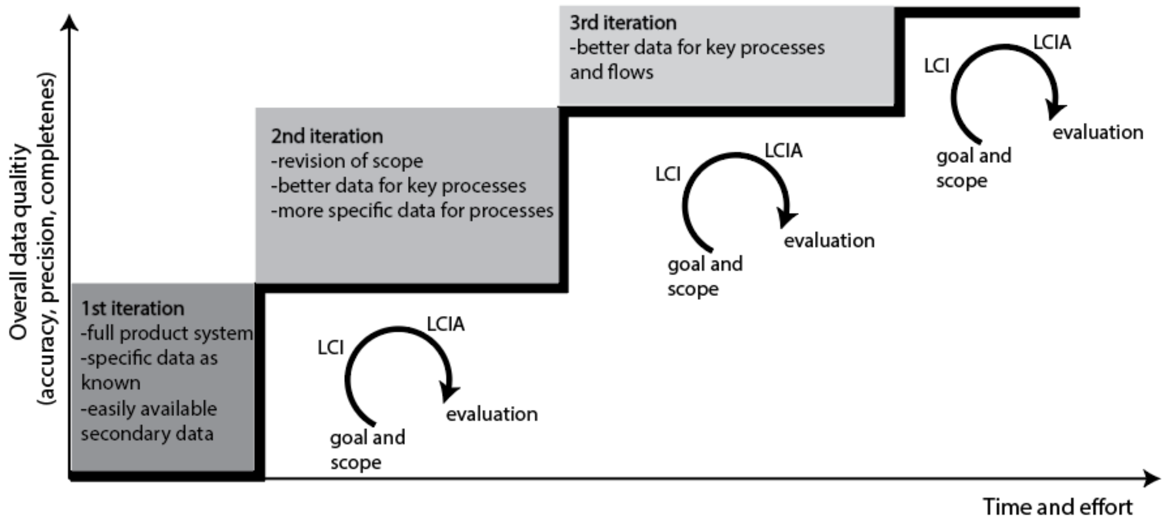

Figure 3: The iterative nature of the LCA study (adapted after the ILCD Handbook, 2010)
Slika 3: Iterativen process izvajanja LCA (prirejeno po ILCD Handbook, 2010)

Goal and scope definition

The requirements for the goal and study are defined in the ISO 14044 standard (ISO 14044, 2006). For the goal definition, it is important to clearly state the intended application of the study, the reasons for carrying out the study, the intended audience and whether the results will be available to the public.

The scope of the study should provide data about:

- the product to be studied,
- the functions of the product,
- the functional unit,
- the system boundaries,
- allocation procedures,
- LCIA methodology and types of impacts,
- interpretation to be used,
- data requirements,
- scenarios,
- value choices and optimal elements,
- limitations,
- data quality requirements,

- type of critical review, if any
- type of format of the report required for the study.

It is important to specify the functions of the system being studied. These should be aligned with the goal and the scope of the study. The functional study should be clearly defined and measurable. Its primary purpose is to provide a reference to which the input and output flows are normalized. Comparisons between products and processes should be made for the same functional units.

The system boundary determines which processes are included within the LCA study. The criteria for the system boundary selection should be explained. Any decisions to omit life cycle stages, processes, inputs or outputs is only permitted if it does not affect or change the conclusions of the study. Detailed criteria in which cases it is alloved to omit and processes or stages is presented in the EN 15804 standard. It is helpful to describe the system using flow diagrams showing the unit processes (the smallest element considered in the LCI analysis for which the input and the output data is defined) included. Ideally, the system boundary is chosen so that the unit processes are elementary flows (material or energy entering the system from the environment without previous human transformation). The criteria for the exclusion of certain flows, the so-called cut-off, shall be clearly described and its effect should be commented on in the study. The cut-off criteria are mostly based on mass or energy but it is also important that the cut-off flows do not have environmentally significant impacts.

In this phase we have to determine the relevant impacts categories and the characterization models used in the study. The data sources have to be determined as well as the requirements for the data quality.

This phase of the LCA study provides an initial plan for conducting the LCA study.

Life cycle inventory (LCI) analysis

The second phase of the LCA analysis is the LCI. Input and output for each unit process within the system boundary is collected. The ISO 14044 additionally suggests including information about the data sources and the quality of relevant data. The data can be classified as energy inputs, raw material inputs, ancillary inputs and other inputs. Often, we also classify the data as products, co-products and waste. All calculation procedures and assumptions should be stated and explained. In this phase the data should be checked and adjusted to the functional unit and system boundaries.

In this phase, the inputs and outputs and their impacts should be allocated to the different processes or products. Ideally, allocation should be avoided either by expanding the system boundaries or dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes. If this cannot be avoided, the inputs and the outputs should be divided between the products or processes based on physical characteristics. If this is also not possible, the allocation can be made based on other characteristics, such as economic value. The allocation procedures must be uniformly applied to similar inputs and outputs of the studied system.

The allocation principles are particularly relevant in the case of the recycling and reuse of products. In these situations, the inputs and outputs associated with the unit processes for extraction and processing of raw materials and final disposal of products are shared by more than one product system. Furthermore, the properties of materials may be changed in subsequent uses, particularly in the case of recycling. A distinction between open-loop and closed-loop allocation processes has to be made at this stage.

- Closed-loop allocation procedures apply to closed-loop product systems or to open-loop product systems where no changes occur in the inherent properties of the recycled material. This also applies to reuse cases.
- An open-loop allocation procedure is applicable in cases where the material is recycled into other product systems and if the inherent properties of the materials are changed.

A more detailed description of the allocation processes is given in the 4.2, where the allocation processes are aligned in the developed methodology.

Life cycle impact assessment (LCIA)

The third phase is LCIA. It should be in line with the previous two phases. The mandatory elements of this phase are:

- Selection of impact categories, category indicators and characterization models
- Classification (assignment of the LCI results to the selected impact categories)
- Characterization (calculation of category indicator results)

Studies mostly rely on existing impact categories, category indicators or characterization models.

After the relevant impact categories have been selected, the inventory established in the LCI phase should be assigned to them. Some of the results are assigned only to one impact category, while others can relate to more than one impact category.

The characterization step involves the conversion of the LCI results (separate flows identified during the LCI) to common units and the aggregation of them into the same impact category. For this step different characterization models are used (such as the Baseline model of 100 years of the IPCC based on IPCC 2013) which reflect the relationship between the LCI results and the category indicators. The characterisation models use different theoretical background studies to define the characterization factors. The characterization factor for each of the relevant inpurtc (defined in LCI) is than multiplied by the amount of the category indicator identified during the LCI. All of the category indicatros are then summed into the overall result of the impacts category. The category endpoint determines where the effects of the impacts are visible in the nature. For a better understanding of the terms and the process, an example is presented in Table 1.

Table 1: Explanation of the terms used for the characterization based on an example
Preglednica 1: Razlaga pojmov uporabljenih pri karakterizaciji na primeru

TERM	**Example**
Impact Category	Climate change
LCI results	Amount of greenhouse gas (CO_2, CO, CH_4, N_2O, etc.) per functional unit
Characterization model	Baseline model of 100 years of the Intergovernmental Panel on Climate Change (IPCC)
Category indicator	Infrared forcing (W/m^2)
Characterization factor	Global warming potential (GWP100 for each greenhouse gas)
Category indicator result	kg of CO_2-equivalent per functional unit
Category endpoint	Coral reefs, forests, crops
Environmental relevance	Infrared radiative forcing is a proxy for the potential effect on the climate, depending on the integrated atmospheric heat adsorption caused by emission and distribution over time of the heat absorption

Different LCIA methods exist which define the set of the observed impact categoris and which characterisation models are sued for the assessment of them. They can follow two different approaches. The first is problem-oriented, or “midpoint”. This approach aggreagtes the results without further weighting them. The other approach is damage-oriented, the so-called “end-point” approach (Buyle et al., 2013; Dong and Ng, 2014; Ortiz et al., 2009). A problem-oriented approach examines the environmental impacts associated with environmental impacts, acidification, nutrient saturation, the formation of photochemical ozone and toxins for humans. The more often applied methods are CML, TRACI, IMPACT +. In the dissertation the CML2001 - Jan. 2016 method is used (CML-IA Characterisation Factors, 2016). Because the problem-oriented or “midpoint” approach generally contains indicators for many different influential categories, these results are difficult to interpret (Dong and Ng, 2015).

A damage-oriented approach or end-point approach classifies and combines environmental impacts by assessing the harm to humans, the natural environment and raw materials. Basically, the main advantage is that it makes it easier to interpret results. Dong and Ng point out that, due to additional assumptions in predicting fate and damage, the damage-oriented approach is more uncertain than the midpoint approach. The Bare and Gloria study (2006) therefore suggests that the results obtained using the midpoint method are more suitable for scientific research, and underline that end-point methods can provide additional support in interpreting the results. The most often applied end-point methods are Eco-indicator 99 and Impact 2002 +.

There is also the distinction between attributional and consequential LCAs. The attributive LCA describes the environmental flows in the selected timeframe, while the consequential LCA describes how the environmental flows will change due to the influence of the decisions made (Buyle et al., 2013). For the goal of the thesis, the attributive approach was the appropriate choice.

Optionally, four phases can follow:

- Normalization,
- Grouping,
- Weighting,
- Data quality analysis.

These steps were mainly developed to enable an easier interpretation of the results. They allow expressing and aggregating the result up to a single score.

Interpretation

The fourth phase is an interpretation of the results (Buyle et al., 2013; Chau et al., 2015b; Ortiz et al., 2009; Sharma et al., 2011) It has several elements:

- The significant issues of the LCI and LCIA have to be identified
- The completeness, sensitivity and the consistency of the study have to be checked and commented on
- Additionally, conclusions, recommendations and limitations are given.

The results have to be interpreted according to the goal and the scope of the study. For the interpretation data from all previous phases of the LCA is required.

2.2 LCA of buildings

2.2.1 The history of LCA for buildings

Life cycle assessment was initially developed to assess products which have a far more comprehensible life cycle than buildings. In the construction industry, materials operation and demolition are varied and the range of EIs related to buildings seems to be enormous. A modern building is typically built of a number of different building materials, which consequently means they are much less standardized than most manufactured goods (Ramesh et al., 2010) When assessing a building, several assumptions have to be made which is rather uncertain due to the long lifespan of the building. Cabeza et al. (2014) state that construction-related LCAs face additional challenges, since the impacts are site-specific, the model is rather complex, the building scenario is unique, several assumptions have to be made and recycled materials are used. In addition to this, buildings provide an indoor environment that has impacts on the occupants' well-being, performance and behaviour. These factors make assessment of EI of buildings a challenging task.

Information about the EI during the whole life cycle of a building material or component is necessary for sustainable development. In 2003, the European Commission released the Integrated Policy Product (IPP). The document encouraged EPDs and ecodesign (Ortiz et al., 2009). Ecodesign looks at the relationship between the product and the environment and summarizes techniques to reduce the environmental impacts during the entire life cycle of a product. In this sense, EPDs can be seen as supportive information for ecodesign. They are used for external communication of the environmental impacts of the whole life cycle of the product (Passer et al., 2015). The methodology for the assessment of building products' EI and EPDs is determined by EN 15804 (EN 15804 2019). EN 15804 foresees the use of core product category rules (PCR) for construction products and services, ensuring that EPDs of comparable construction products are developed and verified in a harmonized way. Results are expressed in modules, which enable easy organization and expression of the environmental impacts throughout the life cycle of the products. To ensure consistency between the assessment at the product level (for example, building materials and building components) and at the building level, the same core indicators and similar modules are used for buildings in EN 15978 (EN 15978, 2021).

2.2.2 LCA methodology for buildings

The methodology for assessing environmental impacts of buildings with LCA is defined in EN 15978. The life cycle of the building is divided into different life cycle stages, namely the production stage, the construction stage, the use stage and the EoL stage. Additionally, there are benefits and loads that are beyond the life cycle of the building and include the reuse, recovery and recycling potential.

The methodology and the special characteristics of assessing the environmental impacts of a building as well as its components are interpreted in documents such as the EeB Guide for Buildings (Gantner et al., 2015). The special characteristics will be explained following the phases of the LCA:

- Goal and scope definition of LCA for buildings
- LCI of LCA for buildings
- LCIA of LCA for buildings
- Interpretation of LCA for buildings

Buildings have been extensively studied in recent times since they are associated with high environmental impacts. Anand and Amour and Rock et al. (Anand and Amor, 2017; Röck et al., 2019) identified that the major challenges that we are facing when performing an LCA on a building are comparison issues of LCA studies, differences in calculated and actual impacts, refurbishment analysis for whole buildings, system boundary selection procedure, standard data collection procedure, missing data, embodied energy indicator, deconstruction analysis, implementation of dynamic LCA, use of LCA in industry and differences in results from LCA integrated certification and LCA of buildings.

Goal and scope definition of LCA for buildings

The declaration of the goal of the study is following the recommendation of ISO 14044. This step requires special attention since it influences the study results and their applicability. It is suggested to follow the guideline of the International Reference Life Cycle Data System (ILCD) handbook: General Guide for Life Cycle Assessment -Detailed guidance (European Commission - Joint Research Centre - Institute for Environment and and Sustainability, 2010). The intended application, methods, assumptions and limitations should be declared. In addition, the reasons for the study should be given and the targets audience should be known. The goal of the study can be either to determine the environmental impacts of a system or to compare the EI on a building product, component or building to another. In this sense, the goal can determine whether the study is a comparative LCA. This can significantly influence the scope of the study, since in this case it is possible that only certain characteristics are compared against each other.

The EeB Guide also broadly predefines the scope of the study by clustering the studies into the study types: the basic screen LCA, the more precise simplified LCA and the complete LCA.

The screening LCA may serve as a quick initial overview of the environmental impacts. It typically focuses on the main contributors. It is meant to be used in the early design phases. Since it does not offer a comprehensive overview, it should be used for internal communication processes only.

The purpose of the simplified LCA is a quick assessment of a product or a building. It falls between the screening and the complete LCA. It focuses on major contributing inputs and provides more representative data than the screening LCA. It can be used for internal and external communication. However, for external communication an external review shall be conducted. The parameters and assumptions also have to be documented sufficiently. These studies are often used in building labelling schemes (e.g. DGNB (2015)) or when developing environmental fact sheets for products.

The complete LCA reflects the approach suggested in the ISO 14040 series of standards (ISO 14040, 2006; Yi et al., 2011). In accordance with EN 15978, the whole life cycle of the building shall be considered (production, use and EoL) as well as the impacts beyond the life cycle of the building, if relevant (module D). Special attention must be devoted to the scenarios of the use and the EoL stage. Buildings are very complex, containing several different products and, therefore, it may be very challenging to assess all of them.

The standards set different definitions for the functional unit. ISO 14040, ISO 14044 and EN 15804 define a functional unit; EN 15804 also defines a declared unit. EN 15978 defines a functional equivalent (Gantner et al., 2015). Generally, the terms functional unit and functional equivalent have rather negligible differences and can be used as synonyms.

At the building level, the functional equivalent is defined according to EN 15978. It includes the building type, relevant technical and functional requirements, the pattern of use and the required service life. Similarly, PEF states that the functional equivalent (unit) should give information about what, how much, how well and how long is studied. (Spirinckx et al., 2018)

An example of a functional unit is: an office building with a net floor area of 400 m^2 that is heated or cooled to a specific temperature (20–26 °C) and accommodates 200 workers (8 hours a day, 5 days a week and 48 weeks per year and has a service life of 50 years).

The reference study period (RSP) is the time period for which the time-dependent characteristics of an object are assessed (Gantner et al., 2015). In the baseline scenario the RSP is 50 years. However, different countries and studies use different RSP. Frequently used values are 50 years, 60 years and 100 years (Buyle et al., 2013; Lasvaux et al., 2019).

The system boundaries shall ideally include all stages of the life cycle. They divide the life cycle of the building on the production phase (comprising the stages of raw material extraction – A1, raw material transport – A2, production of construction materials – A3, their transport – A4 and their installation –

A5), the phase of use (including use – B1, maintenance – B2, repair – B3, replacement – B4, refurbishment – B5, operational energy use – B6 and operational water use – B7), the EoL phase of the building (comprising the deconstruction phase – C1, the transport of materials – C2, the waste treatment phase – C3 and the final disposal phase – C4) and the phase after the expiry of the building's lifetime – module D (it contains scenarios of reuse, recycling and energy recovery from obsolete materials). The stages of building and building products are declared with EN 15978 and EN 15804 standards. They are illustrated on the Figure 4. Special attention is placed on the distinction between the embodied and the operational environmental impacts (Röck et al., 2019).

The assessment can also focus on specific parts of the life cycle. For example:

- Cradle to gate (stages A1–A3)
- Cradle to grave (stages A1–C4)
- Cradle to cradle (stages A–D).

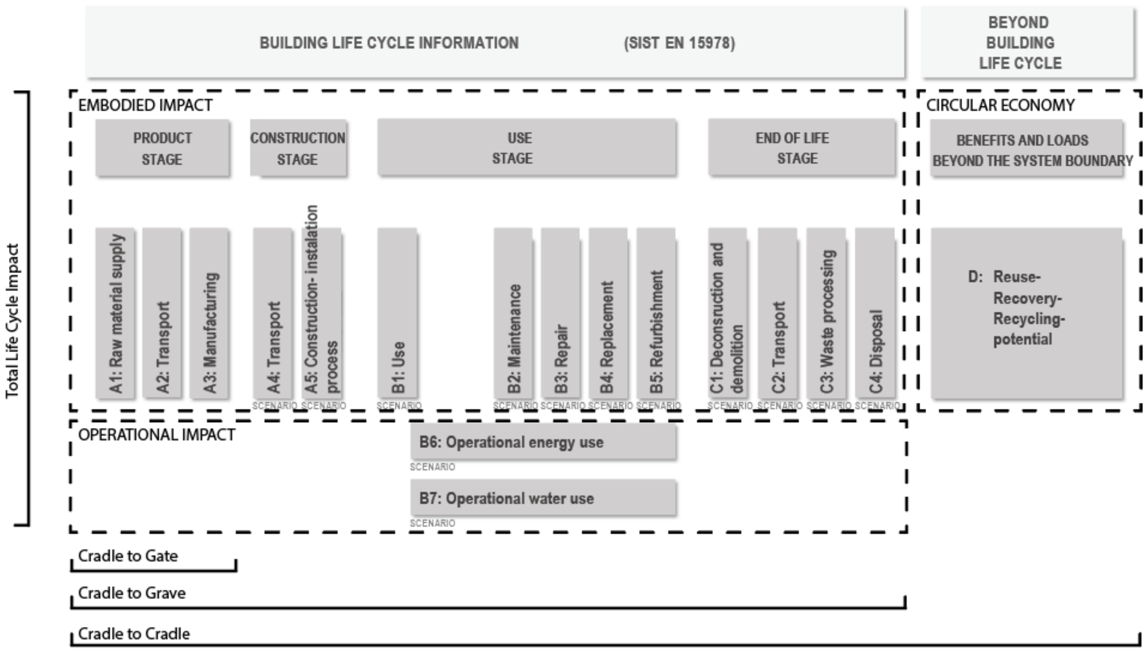

Figure 4: LCA modules according to EN 15978
Slika 4: LCA moduli povzeti po EN 15978

If the distribution cannot be avoided, it should be handled according to the relevant standards (ISO 14040, 2006); mass allocation is preferred. The allocation is frequently discussed in the cases of reuse, recycling and recovery or if energy is produced on site. It remains an open topic within the LCA community (Allacker et al., 2017; Cherubini et al., 2018; Ekvall, 2000; Ekvall and Tillman, 1997;

Frischknecht, 2010; Mirzaie et al., 2020) . Several approaches to allocation exist. These are explained in detail in chapter 4.2.2.

In practice the total inventory of the building is always unknown since buildings are very complex products containing several materials. The cut-off rules make it possible to assess the environmental impacts with the LCA without having to model 100 % of the system. If the LCA is conducted on the screening or simplified level, the practitioners should refer to the lists in the EeB Guide. For complete studies, the cut-off rules should be compliant with EN 15804 and 15978.

The life cycle of a building is very difficult to predict. While it is possible to have a relatively low uncertainty for the production phase, since the impacts of materials and the processes during these stages are known, the uncertainty increases in the use stage, EoL stage and for module D. For these stages scenarios and assumptions are used. Therefore, the uncertainty of these stages is relatively high. Much research has been dedicated to this topic and some countries have already developed a baseline scenario to reduce the uncertainties (Goulouti et al., 2020; Häfliger et al., 2017; Hoxha et al., 2017; Jung et al., 2013).

In this phase the environmental indicators and characterization models used in the LCIA subchapter also have to be declared. The quality requirement for the data should also be established and be compliant with the requirements in standards.

Life cycle inventory (LCI) of buildings

For the assessment of the inventory the practitioners rely on already established databases. Commonly used in the European context are Ecoinvent, Gabi, ELCD and ESUCO (Gantner et al., 2015). The databases can contain generic or product-specific data (EPDs). It is important that the data is derived from a single source since this assures that the data is modelled in a consistent way. In general, the use of different databases would not be a problem if the methodology and the cut-off rules applied were the same. LCA practitioners are often in a position where they have to decide whether it is more important to use consistent data or to use data that is more representative (geographically, time-dependent, technically similar, etc.) but is methodically inconsistent with other data (Gantner et al., 2015).

Life cycle Impact Assessment (LCIA)

This step includes the classification of the impacts to the environmental impacts studied and their characterization. According to EN 15978, the core environmental impacts are global warming potential (GWP), depletion potential of the stratospheric ozone layer (ODP), acidification potential of soil and water (AP), formation potential of tropospheric ozone (POCP), eutrophication potential (EP), abiotic depletion potential (ADP – elements) for non-fossil resources and abiotic depletion potential (ADP - fossil fuels) for fossil resources (EN 15978:2021; Gantner et al., 2015). The impacts are typically characterized at the midpoint or problem-oriented level. This approach generates a more complete picture of the environmental impacts. The other characterization approach is the endpoint or the damage-oriented approach. Here, the environmental categories are additionally grouped into general issues (e.g. human health, natural environment, etc.) or even weighted to a single-score result. Although they may be easier to understand and compare, they are also less transparent and difficult to interpret (Cabeza et al., 2014; Chau et al., 2015b; Pérez and Cabeza, 2017).

Mostly, the CML or ILCD characterization method is applied for buildings (Ortiz et al., 2009).

The LCIA is mostly performed in dedicated tools in which the LCI databases are already integrated. For product comparison Simapro and Gabi are used most often in the European context (Ortiz et al., 2009).

Interpretation

In the last step the results have to be interpreted accordingly.

Although normalization is an optional step of LCA studies, it can enable easier interpretation of the results. Often, the results are normalized per square metre of the building or per person. Similarly, the interpretation of the results can also be facilitated by weighting. For example, weighting factors from LCIA methods (such as Eco-indicator 99, IMPACT 2002+ and ReCiPe) that enable assessment on the midpoint and endpoint levels are also applied in the construction sector, although the CML and the ILCD methods are more common.

Uncertainty, sensitivity and scenario analyses should show the impact of certain decisions or the data quality on the final results (Gantner et al., 2015).

2.3 Refurbishment of buildings and LCA

2.3.1 The difference between terms refurbishment, maintenance, repair, and replacement

According to EN 15978, refurbishment is a separate phase within the life cycle of a building. Hereby, it is important that a clear distinction is made between modules B2 (Maintenance), B3 (Repair), B4 (Replacement) and B5 (Refurbishment) since in practice it is often difficult to assign the operation or inputs to one of these modules. In this dissertation the definitions given in standards EN 15804 and EN 15978 are used.

In this subchapter terminology is explained and a systematic literature review of papers dealing with LCA and refurbishment is conducted. Based on this review, the research gaps are defined and the hypotheses for the theism are made.

B2 – Maintenance

It includes all actions related to maintaining a product or a building part. It covers replacement or reparation of used, damaged or worn parts of the building (and not the entire functional unit) to maintain it in a state in which it can fulfil its functions. It applies to planned actions and also includes preventive and regular maintenance and cleaning operations. According to EN 15978, the actions should be a part of the "intended use" provided, along with the reference service life (RSL) definition. Regular and adequate maintenance should be provided to avoid premature replacement.

In practice it can include action such as regular cleaning or regular replacement of filters, etc.

B3 – Repair

It encompasses actions required to return the product or the building part to a condition in which it can fulfil its function. It includes corrective, responsive or reactive treatment of a product and replacement of broken components or parts because of damage. If the whole element must be exchanged, it should be assigned to module B4 – Replacement. The actions assigned to the Repair module fall outside the scope of the intended use that defines the RSL.

In practice these are actions such as the replacement of window panes or the repair of a broken technical part.

B4 – Replacement

It includes actions of replacement the whole construction element as well as the installation of new and identical construction elements according to EN 15804. It differs from modules B2 and B3 in that the entire component is replaced. Therefore, it is important how the building components and subcomponents are broken down. The RSL should be used to calculate the number of replacements.

In practice these are actions such as replacing a partition wall or a heating system.

B5 – Refurbishment

This module covers a set of repair, maintenance and replacement actions that are performed on a significant part of the whole building in accordance with EN 15804. It includes modifications that have an impact on several building components and affects building performance and functions.

Within the literature various terminologies can be found: retrofitting, refurbishment or even repair and restoration (Vilches et al., 2017).

The difference between the different measures is presented in Figure 5. The products have to be regularly maintained to ensure their performance. In case of failure, they need to be suitably repaired to fulfil their function. If this is not possible, they need to be replaced. Refurbishment, on the other hand, results in the increased performance of the product in the observed period.

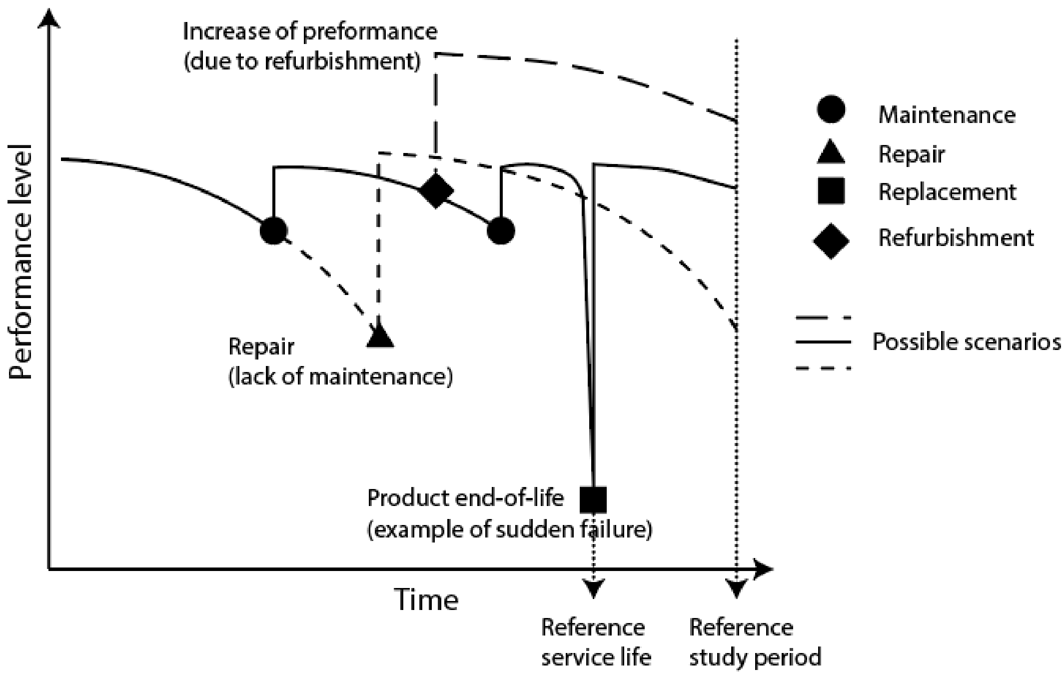

Figure 5: Example of performance over time depending on the maintenance actions (adapted after EN 15804)
Slika 5: Primer delovanja skozi čas glede na vzdrževalne ukrepe (povzeto po EN 15804)

The products may be replaced because of unforeseeable reasons or because they have lost their performance or because they have become obsolete. The later in the RSP it is, the more materials and products become obsolete and their performance is reduced, while the repair rate is unforeseeable and cannot be predicted. This is illustrated in Figure 6.

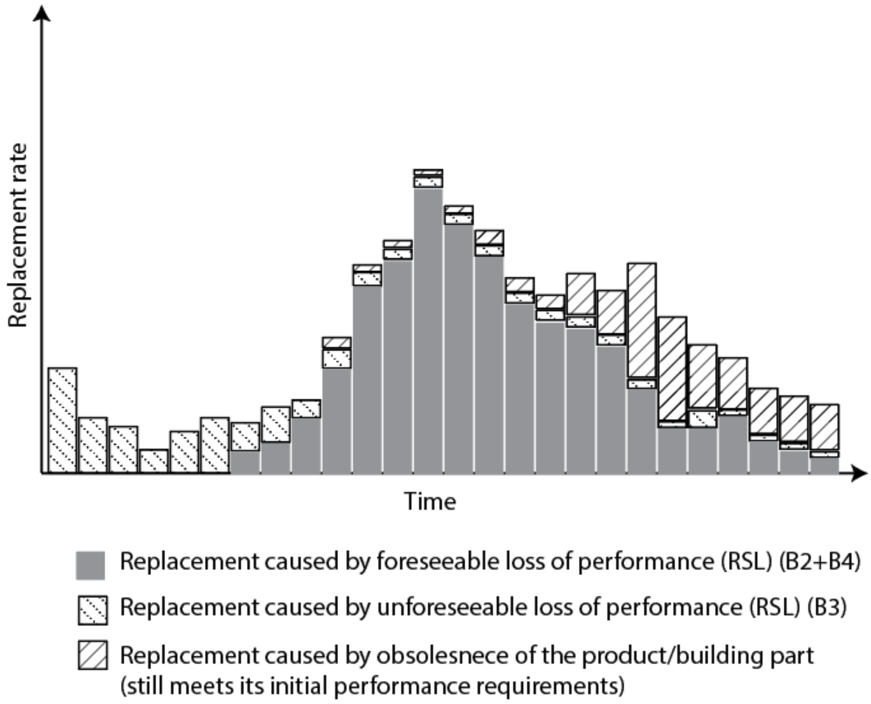

Figure 6: Replacement rate (adapted after EN 15804)
Slika 6: Pogostost zamenjave (povzeto po EN 15804)

2.3.2 Systematic literature review (SLR)

A systematic literature review of papers dealing with LCA and refurbishment is performed. Based on this review the research gaps are defined and the hypotheses for the thesis are made.

The methodology for the SLR is explained in chapter 3.2.4. The keywords for the search were “life cycle assessment” OR “LCA” AND “renovation” OR “refurbishment” OR “retrofitting” AND “building”. The databases searched were Science Direct, Scopus, Web of Science and Springer. The results were limited to the English language and peer-reviewed original and review articles. No time limits were set for the search.

The search protocol is illustrated in Figure 7. After the initial search a sample of 396 papers was collected. After the first filtering based on the title, the scope narrowed to a sample of 211 papers. After reading the abstracts, the sample was 126 papers and, in the end, after reading the whole papers, 94 relevant papers were further analyzed.

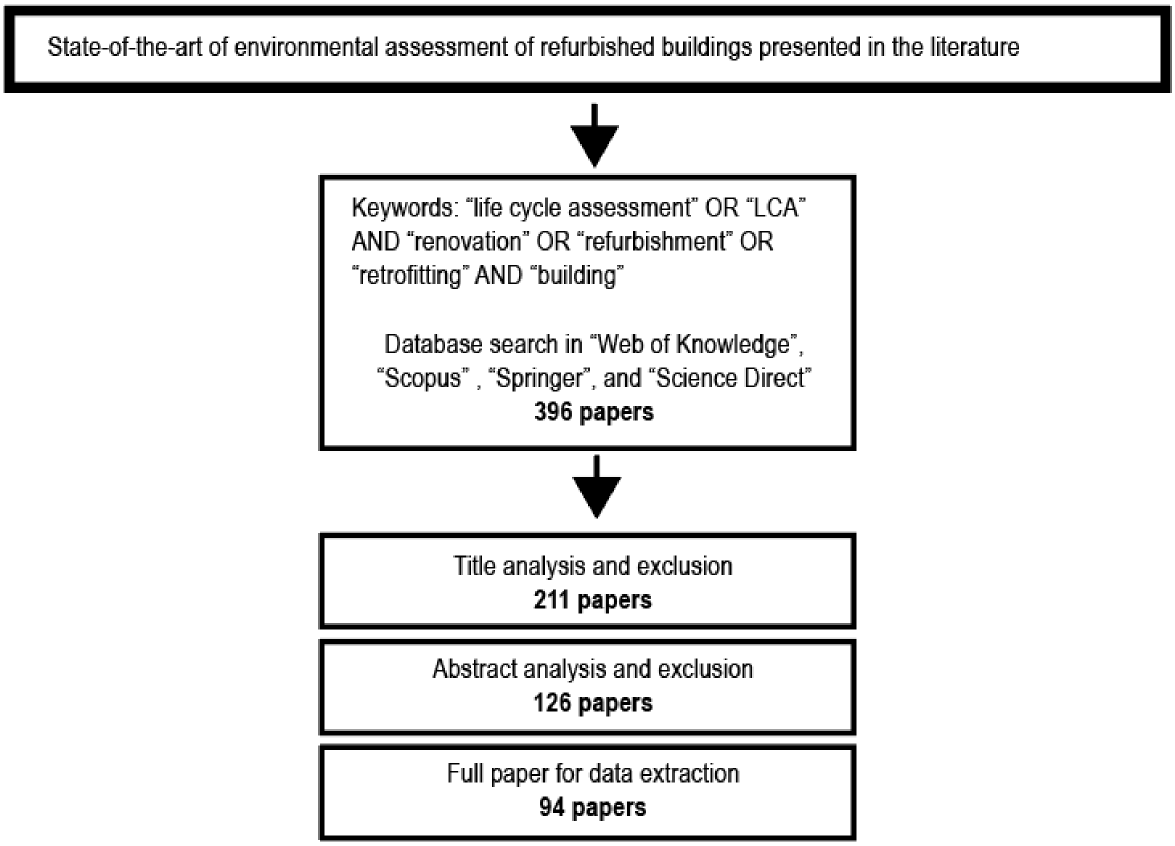

Figure 7: Search protocol for the systematic literature review
Slika 7: Protokol iskanja pri sistematskem pregledu literature

Information about the metadata (year, journal, title, authors), the types of building, which parts were renovated, and whether the study focuses on the embodied part or on the operational part of the life cycle was collected. The results of the analysis are summarized in APPENDIX A.

.

Based on the SLR, the following findings were made.

- The number of papers that evaluate the environmental impacts of refurbished buildings has been increasing since 2012. It is expected that this trend will continue as LCA is being applied more frequently in practice and refurbishment is encouraged (Figure 8).

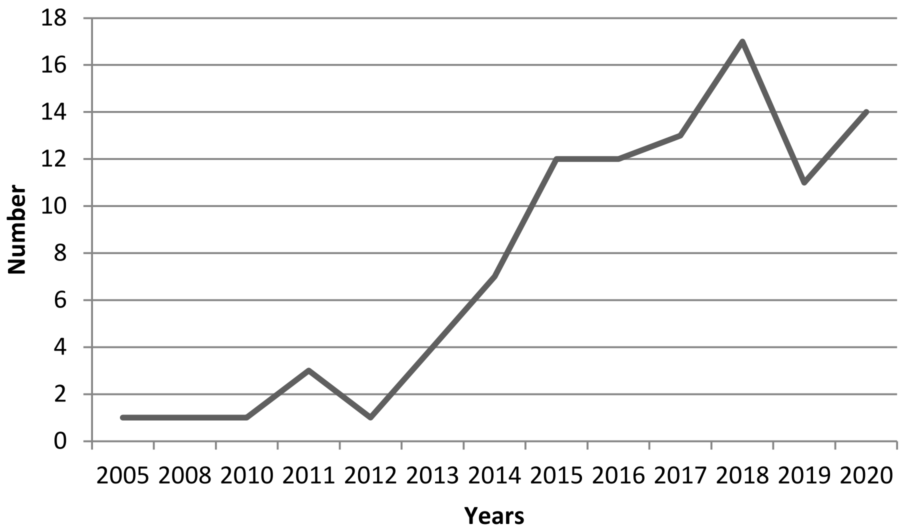

Figure 8: The number of papers dealing with the environmental impacts of refurbishments
Slika 8: Število člankov, ki se ukvarjajo z okoljskimi vplivi prenov

- In the studied papers most often the residential buildings were assessed (Figure 9). Office buildings and other building types were assessed only in a few cases. Residential building stock represents the largest share of the building stock and therefore the greatest potential for the reduction of environmental emissions of buildings (Passer et al., 2016).

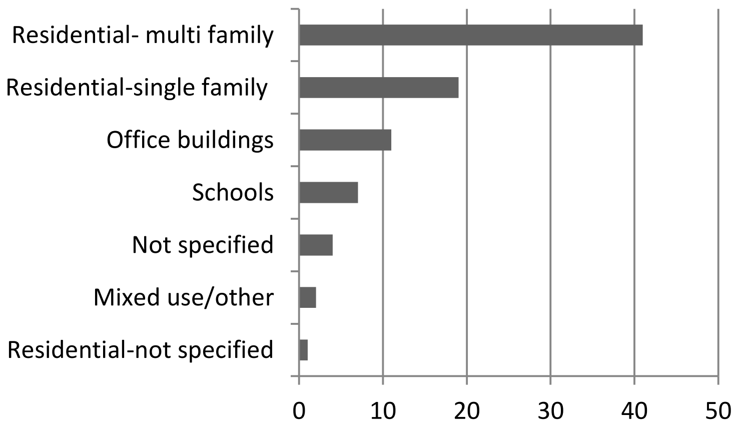

Figure 9: The building types identified in the SLR
Slika 9: Tipi stavb, obravnavani v SLR

- Mostly, buildings built between 1960 and 1980 were used as case studies for refurbishments. In this period, the majority of the residential building stock was rebuilt following World War II.

- Refurbishment is most often a combination of several improvements and varies from case to case. Prevailingly, the external envelope of the building is improved by adding insulation and by replacing the windows and doors (Ardente et al., 2011; Assiego de Larriva et al., 2014; Beccali et al., 2013; Brás and Gomes, 2015; Dodoo et al., 2014; Erlandsson and Levin, 2005; Famuyibo et al., 2013; Rodrigues and Freire, 2014; Stazi et al., 2012). Window replacement, HVAC replacement, and installation of photovoltaic panels are also frequently discussed (Ardente et al., 2011; Assiego de Larriva et al., 2014; Beccali et al., 2013; Dodoo et al., 2014; Nicolae and George-Vlad, 2015; Stazi et al., 2012). Ballarini et al. (2014) in their study suggest that building models selected as reference buildings for a given period and location in different European studies should be used to assess the contribution of refurbishment to improving energy efficiency and reducing environmental impacts. When evaluating the environmental impacts of buildings, it makes sense to analyze how long it takes for the environmental impacts caused by the refurbishment to be recovered due to the greater energy efficiency of the building. The so-called environmental neutrality of the building envelope refurbishment is defined in the study of Kunič (2011) as the time period in which the environmental parameter (e.g. CO_2 footprint and other environmental indicators) associated with losses through the building envelope is equalized. The second most often applied refurbishment measure is the replacement of heating, ventilation and cooling devices in the building, followed by the improvement of the roof (Figure 10).

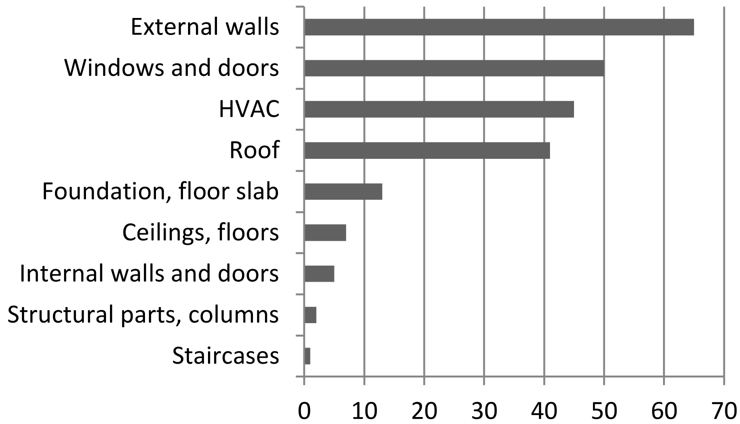

Figure 10: The scope of the refurbishment
Slika 10: Obseg prenove

- Mostly, the studies assessed embodied and operational environmental impacts. However, in some studies the focus was only on the embodied environmental emissions of the refurbishment measures (Bari et al., 2020; Cappelletti et al., 2015; Favi et al., 2018; Fregonara et al., 2016; Mangan and Oral, 2015; Moschetti and Brattebø, 2017; Napolano et al., 2015; Oregi et al., 2017a; Rodriguez et al., 2020; Salgado et al., 2020). Due to the scope of the SLR, those studies focusing only on the operational part of the life cycle were excluded.

- Many of the papers assessed the payback period of the refurbishment actions. In some cases only the economic payback time of the refurbishment measures were assessed (Almeida and Ferreira, 2017; Conci et al., 2019; Mateus et al., 2019; Montana et al., 2020; Nydahl et al., 2019; Rodrigues et al., 2018). The payback times were calculated using different methodologies. Most often, the net present value was used for the calculation of payback times. In many cases payback times were calculated for the economic aspects as well as for the environmental indicators (Ghose et al., 2017a; Mateus et al., 2019). On the other hand, some of the studies only focused on the payback time of environmental impacts, mostly CO_2 emissions.

- Only in two of the observed cases were the payback times calculated with consideration of the future changes of the energy mixes. In Passer et al. (2016), a sensitivity analysis was conducted which observed how the payback time would change if the energy mixes became renewable in the future. Similarly, Ghose et al., observed how the CO_2 emissions of the buildings would change if the electricity mix were improved in the future (Ghose et al., 2020).

- The operational energy use is calculated with dynamic energy simulation tools in some cases (Bull et al., 2014; Oregi et al., 2020; Rocchi et al., 2018; Rodrigues and Freire, 2014; Schwartz et al., 2016; Sierra-Pérez et al., 2018; Tadeu et al., 2015), but the dynamic energy simulation connected with the assessment of the environmental payback of refurbishment measures has never been performed for the Central European region. The majority of them are performed for the Southern European region, while Bull et al. (2014) focus on the climate of the United Kingdom.

- The assessment of the environmental impacts of the refurbishment measures is often coupled with life cycle cost (LCC) analysis. In 28 of papers a LCC analysis was also performed.

- GWP and primary energy are the most often assessed indicators in LCA. GWP is assessed in every study except those of Oregi et al. (2015) and Dodoo et al. (2010), where the focus is only on primary energy.

- The prevailing database used is Ecoinvent. Surprisingly, there are few studies that use EPDs as the source of data (Ramírez-Villegas et al., 2019; Sedláková et al., 2020; Volf et al., 2018). In some studies national databases are also used, for example the Swiss KBOB (Lasvaux et al., 2015a), the Bath ICE (McGrath et al., 2013; Schwartz et al., 2018), Oekobaudat (Kovacic et al., 2015; Montana et al., 2020) or others.

- The observed RSL varies significantly and makes the different case studies difficult to compare. In most cases, the 50-year RSL is used, but other RSL, such as 30, 60 and 100 years were also used.

- Only in two cases were materials and components that were present prior to the refurbishment included in the calculation methodology. Conci et al. (2019) have calibrated the embodied energy of the building construction and services according to the changes in the energy efficiency of the manufacturing process in the past and the future. They have estimated a 30 % rise in manufacturing efficiency between the original construction year of 1952 and the refurbishment year 2020, and estimated a 30 % rise in manufacturing efficiency in the next 100 years. These estimates are used as coefficients in the evaluation of the GWP impact of past and future energy embodied in building construction and building services. Hasik et al. (2019), on the other hand, pointed out that when comparing new construction against the refurbishment of an old building, the environmental impacts of the deconstruction or the demolition should also be included. Hence, information about the exiting building has to be known.

- None of the papers deals with residual value, which is defined as the sum of the non-amortized environmental impacts of the building observed at a specific point in time (SIA, 2020). The residual value can be an important source of information about the potential refurbishment measures.

2.4 Chapter summary

At the beginning of the chapter, the LCA methodology in general and its application for building is explained.

The term refurbishment is distinguished from the terms maintenance, repair and replacement.

The systematic literature review shows that the refurbishment is treated as the beginning of the new life cycle. The recognition of an allocation need is, however, seldom observed in published studies.

Several authors suggest calculating the impacts with time-corresponding data. Mostly, this is emphasized for the calculation of operational energy use (Kono et al., 2017; Roux et al., 2016), but the embodied impacts of materials are also changing due to technological improvements in production, the increased energy efficiency of production, improvement of the electricity or energy sources used for production, etc. In the SLR only two studies were observed, namely Passer et al. (Passer et al., 2016) and Ghose et al. (Ghose et al., 2020), that consider that the environmental impacts are subjected to change over time.

It was also observed that no information about the environmental impact of refurbishment measures has been gathered for the national context of Slovenia. Recommendations about the best possible refurbishment scenario from the environmental point of view would be beneficial for the investors as well as for the producers of insulation materials.

Based on the observations, the research aims and the dissertation hypotheses were formed, which are presented in the following chapter.

3 RESEARCH AIMS, HYPOTHESES AND METHODS

3.1 Research aims

The refurbishment of the existing building stock is one of the most important task in order to reduce the environmental emissions associated with buildings. In ornder to evaluate the reduction of the environmetal emissions due to the refurbishment an accurate and robust LCA methodology is needed. Therefore, the main research question of the thesis is:

What is the appropriate methodology to assess the environmental impacts of building refurbishments considering the entire life cycle?

Based on the analysis of the systematic literature review it was concluded that current methodology for evaluating the environmental impacts of the building does not deal with phases prior to the refurbishment of the building. In other words, it does not evaluate the entire lifetime of the building. This practice is still in line with EN 15978, which states that "if a building is refurbished and the refurbishment was not taken into account at the outset, i.e. in any previous assessment, a new assessment should be carried out, particularly where the refurbishment changes the functional equivalent". The environmental impacts of the refurbishment materials and processes are thus addressed in modules A1 to A5 (the production stage of the building) of the life cycle after the refurbishment. While the European standard does not clearly mention how the practitioner should address the materials and components that shall remain after refurbishment, according to ISO 14044 the reuse of previously adopted materials in a new product system (i.e. in a new building's life cycle) calls for an allocation procedure. ISO 14040 emphasizes that allocation should be avoided either by dividing the unit process into two or more independent sub-processes or by expanding the scope of the study to include the additional functions related to the co-products (ISO 14040, 2006). If avoiding allocation is not possible, division between two life cycles shall take place (Allacker et al., 2017; Frischknecht, 2010).

If allocation between two life cycles is the appropriate approach for the determined goals, the information about the associated environmental impacts of the materials and components of the life cycle before the refurbishment is often missing. The assumptions about the environmental emissions of the past or the future can be made with current data, they can be very different due to the changes over time. Therefore, it would be useful to remodel the current data in order to be accurate for the observed point in time (time-corresponding). With these issues in mind, the first two hypotheses were structured:

HYPOTHESIS 1

To evaluate the environmental impact categories (GWP, ODP, AP, EP, ADP – elements, ADP – fossil, POCP) of a building refurbishment, the entire life cycle of the building, including the pre-refurbishment phases, must be considered in the LCA analysis. The current methodology for evaluating the environmental impacts of building refurbishment is comparative and does not evaluate the entire life of the building but only the phase after renovation. Consequently, this leads to difficulties in evaluating the environmental impacts of the EoL phase and beyond the EoL phase of the building, as the analysis of these phases should also take into account materials installed in the past. The current methodology makes it more difficult to compare the environmental impacts of refurbishment with replacement new construction. It is also not possible to estimate how much the environmental impacts are affected by premature renovation where installed materials have not fully utilized their intended reference life.

HYPOTHESIS 2

When calculating the environmental impacts of the refurbishment of existing buildings and including the whole life cycle, data on the environmental impacts of related modern materials can be used for already installed materials. Studies of embodied energy of materials suggest that the impacts of materials in buildings with high energy consumption are relatively small and thus it is sufficient to use data for current materials with a similar production method, since the difference will not be noticeable. It is concluded that the situation is similar for environmental impact categories.

While the previous two hypotheses focus on the embodied environmental impacts of materials, the third observation is that there is a lack of studies that deal with the environmental impacts of refurbishments for the Central European climate zone, which is evaluated under realistic climatic conditions that are changing over the day and year .

In addition, a systematic approach to the refurbishment, in our case of envelope refurbishment, would provide additional insights into the environmental impact of the refurbishment for the Central European climate zone, which is evaluated under realisticly changingclimatic conditions. Therefore, there is a need for a new advanced methodology that would enable an adequate assessment of the environmental impacts.

Another hypothesis was therefore added to the thesis:

HYPOTHESIS 3

Due to the different heat accumulation in the building due to different insulation materials and installation methods of the insulation materials, the effects of refurbishment of the envelope of multi-apartment buildings are differently reflected in selected environmental impact categories

(GWP, ODP, AP, EP, ADP – elements, ADP – fossil, POCP). Due to the different heat accumulation in the building due to different materials and thermal insulation installation methods, there are differences in energy consumption during the use phase. Also, the environmental impacts of the built-in materials are different and consequently, the payback time of the environmental impacts of the refurbishment measures is different.

The main aim of the doctoral dissertation is to facilitate the assessment of environmental impacts for refurbishment measures. A new advanced methodology was developed that allocates the impacts between the life cycle before and after the refurbishment. It consists of two sub-methodologies that can also be used separately. The first methodology is used for remodelling data in order to make them time-corresponding. The second methodology is for the assessment of the environmental impacts and the residual value of components and materials before and after a refurbishment. The focus of this part is on the embodied environmental impacts.

Since a research gap in the comparative assessment of the refurbishment measures was also identified, another aim of the dissertation was to develop a methodology that can be used for the comparison of the EI of refurbishment measures and also includes operational EI. The methodology is applied to the case of building envelope refurbishments. Different, commonly used insulation materials were compared with each other and recommendations connected with the environmental impacts of the refurbishment measures are made based on this comparison.

3.2 Research methods

3.2.1 Life cycle assessment (LCA)

LCA is an analytical and calculation method to quantify the environmental impacts of the selected case studies. A detailed description of the methodology can be found in chapter 2.1. In each of the subchapters the application of the LCA is presented. Each subchapter also presents the scope of the research, the functional unit and the characterization factors. A more detailed description of methodology used can be found in the chapter 4.

3.2.2 Case study

The case study approach is an empirical research method that investigates contemporary phenomena within a real-life context (McCorcle and Bell, 1986). The method allows to contribute towards scientific development through generalization of findings on an individual case. In the case of the building, it is challenging to draw general conclusions from individual cases due to the unique characteristics of buildings. To mitigate this issue, the chosen case study is a reference building and is representative for the majority of the buildings of a certain period.

Ballarini et al. (2014) propose in their study that building models that have been selected as reference buildings for a specific period and location in various European studies should be used to assess the contribution of refurbishment to improving energy efficiency and reducing environmental impacts. Based on the research task of the European Commission, within the framework of the TABULA project (Ballarini et al., 2014; Mastrucci et al., 2017), reference buildings for individual periods and building types were determined.

The case study in this dissertation is a reference building, representing a typical residential building from the period between 1971 and 1980. According to Slovenia's long-term renovation strategy, this kind of building has the greatest potential for the mitigation of GHG emissions with refurbishment measures ("Long - term strategy for energy renovation of buildings until 2050," 2021). The building was selected in the international TABULA project (Ballarini et al., 2014; Mastrucci et al., 2017) and is presented in Table 2 and Figure 11. A more detailed description of the reference buidling is in APPENDIX B

Table 2: Component list for the reference building
Preglednica 2: Popis elementov referenčne stavbe

REFERENCE BUILDING	
Component	**Area [m^2]**
Foundation slab	506.5
Exterior walls	1241.9
Windows	267.9
Slabs	2532.5
Inner walls	4216
Roof	646.6

Figure 11: Illustration of the reference building – a typical residential building from the period 1971–1980
Slika 11: Ilustracija referenčne stavbe- tipična stanovanjska stavba v obdobju med 1971-1980

In the dissertation components of the reference buidling were used to demonstrate the separate methodologies developed in the thesis. For the verification and demonstration of the advanced methodology for the building refurbishment individual building components were used (walls, windows, foundations, roof). A simplified model of one storey was used for the calculation of the energy demand reduction due to the refurbsihment measures

3.2.3 Sensitivity analysis

The sensitivity of a model shows to what degree the variation of an input parameter or a modelling choice leads to variation of the LCA results. It helps to identify the key parameters and modelling choices that have a high influence on the results. Different approaches for sensitivity evaluations exist. Rosenbaum (2018) differentiates between two different approaches for analyzing parameter sensitivity. Global sensitivity analysis investigates how much each input parameter contributes to the output variance, while the local sensitivity analysis investigates the effect of a particular change in input by varying one input at a time. Scenario analysis can be used for evaluating the influence of modelling choices on the LCA results by assessing different possible scenarios.

In the dissertation the focus is on the sensitivity analysis. The sensitivity of the methodologies to the changes of chosen parameters is discussed.

3.2.4 Systematic literature review (SLR)

A systematic literature review (SLR) is a structured procedure for identifying relevant sources in order to obtain a comprehensive overview of the literature published for a specific research question. Based on the research question, relevant keywords are identified, and the search is performed in the defined databases. The obtained results are the filtered (1) based on the title, (2) based on the abstract and (3) after reading the full paper (Wohlin, 2014).

The systematic literature review has proven to be a very helpful tool when performing an analysis of the existing workflows that connect building information modelling (BIM) with LCA (Potrč Obrecht et al., 2020). The study was performed within the IEA Annex 72 expert group and should help to establish a comparable methodology and supporting workflows for the LCA.

In the thesis, the systematic literature review was used to obtain a detailed insight into the current state-of-the-art of the field of LCA and refurbishment. Based on the predefined keywords a list of papers was composed. The analysis of these papers is presented in chapter 2.3.2.

3.3 Chapter summary

Based on the finding of the SLR the research aims were formed. The research aims are concentrated into three hypotheses.

The first hypothesis is about the importance of inclusion of the phases prior the refurbishment in the assessment of the EI. This hypothesis is answered in the chapter 4.2 were a new methodology for the allocation between the lifecycle before and after the refurbishment is developed and discussed. The second hypothesis is about the importance of remodelling the input data of already installed materials when assessing the EI of refurbishments. This is answered in the chapter 4.1 where a new methodology for the remodelling of input data is presented and discussed. The methodologies developed in the chapters 4.1 and 4.2 are combined into an advanced methodology for the assessment of embodied environmental impacts of building refurbishment. The development of the advanced methodology was the main aim of the thesis.

The third hypothesis discussing the impacts of heat accumulation due to different insulation materials and installation methods of the insulation materials on the EI of the façade refurbishment measures. This hypothesis is answered in the chapter 4.3 where the newly developed methodology for the comparison of the refurbishment measures is verified on the case study of the façade refurbishment.

The methods used in the study (LCA, case study, sensitivity analysis and the systematic literature review) are described and explained.

4 AN ADVANCED METHODOLOGY FOR THE ASSESSMENT OF EMBODIED ENVIRONMENTAL IMPACTS OF BUILDING REFURBISHMENT

4.1 Development of a sub-methodology for modelling time-corresponding input data

4.1.1 Introduction

The advanced methodology for the assessment of embodied environmental impacts of building refurbishment is a combination of two sub-methodologies: the sub-methodology for modelling time-corresponding input data and the sub-methodology for the allocation between the life cycle before and after the refurbishment. The content of chapter 4.1 was published in the Journal of LCA (Potrč Obrecht, Jordan, Legat, and Passer 2021).

To calculate the residual embodied EI of existing buildings/materials or components, data for the construction materials that were manufactured in the past is needed. However, at that time, no data about the environmental impacts for the production of individual building materials was collected. The first official LCI databases started in the late 1990s and no data is available before this period (Martínez-Rocamora et al., 2016). Although some processes might have changed over time, it is assumed that the general principles for the production of the building materials stayed the same for several decades, with the result that the current datasets can also be remodelled to obtain an approximation of the embodied environmental impacts of the materials produced at an earlier date. For a more precise modelling of environmental emissions in the past, including the production change, accurate data is needed which is almost impossible to obtain.

In this part the influence of the change of production over time on environmental impacts by using the example of the timely accurate electricity mix (the proportion of total electricity generated by each source in a specific region, country, continent or worldwide) and assuming an increase in production efficiency over time is shown. Following some principles of a dynamic LCA, which is an approach that includes dynamic process modelling in the context of temporal and spatial variations in the surrounding industrial and environmental systems (Collinge et al., 2013; Su et al., 2017), the electricity mix in the already-existing LCA datasets (e.g. in databases like Ecoinvent) can be remodelled to correspond with the electricity mix used at the time of production of the selected materials. The electricity mix is a combination of different sources and technologies of electricity generation that are constantly developing over time (Barros et al., 2020). Kono et al. (2017) suggested that in some cases it is even sensible to use hourly GHG emissions factors to quantify the GWP accurately. Studies have shown that the energy or electricity mix chosen in an LCA study usually has a strong influence on the LCA results, and due to the long lifespan of the building, the parameter is subjected to changes during this period (Barros et al., 2020; Roux et al., 2016). Therefore, the remodelling of the datasets contributes to a more realistic determination of the environmental impacts produced in the past and thereby also to a more reliable determination of the residual value of the buildings. To the best of our knowledge, however, this issue has never been investigated in any previous research work and is a novel approach in this field.

Including the information about the processes and materials before the refurbishment also helps to determine the residual value of a building or a component correctly. Its determination supports the evaluation of the refurbishment in comparison with the alternative scenario “demolition and new construction”. According to Severin (2018) and Guida et al. (2015), the residual value is the sum of the non-amortized environmental impacts embodied in building materials observed at a specific point in time. When observing a building at a specific point in time during its life cycle, some materials are already amortized and some still have a large residual impact, because either they have a long RSL or they were recently exchanged (Grant, Ries, and Kibert 2014; Potrč Obrecht et al. 2019; Rauf and Crawford 2015; Grant and Ries 2013), as illustrated in Figure 12. With the “residual-value” approach an insight into whether the materials have fulfilled their function (e.g. building component 2) or if their lifespan has ended prematurely (e.g. building components 1 and 3) can be obtained. This information is important for planning future refurbishment measures, so it must be calculated correctly. Nevertheless, there is a lack of scientific literature dealing with the residual environmental impact of buildings and its effect on refurbishment decisions.

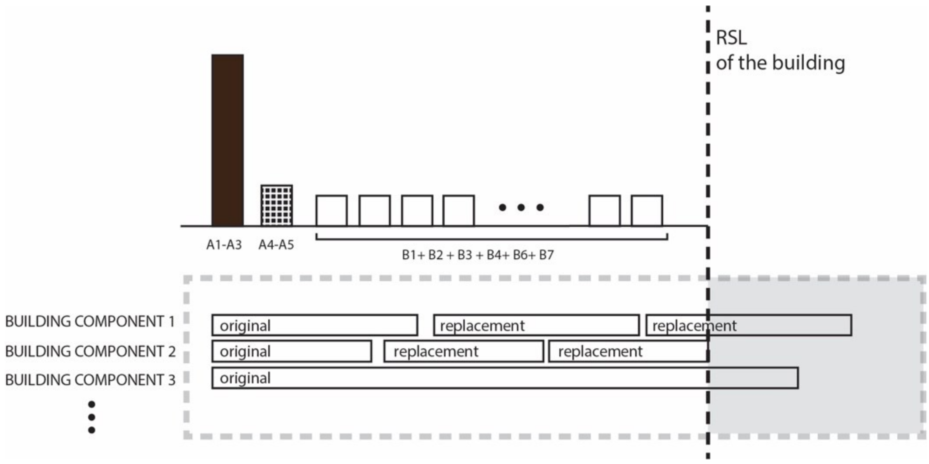

Figure 12: Residual value of a building (shaded grey) (Potrč Obrecht et al., 2019)
Slika 12: Preostala vrednost stavbe (obarvano sivo) (Potrč Obrecht et al., 2019)

The objective of this chapter is to compare the environmental impacts of selected building materials and components that were modelled with the electricity mix and the assumed past efficiency. In addition, the predicted future electricity mixes were also assessed to test whether the relevance of using the accurate electricity mix will increase or decrease in the future. The LCI datasets were adapted in such a way that they give an approximation of the production procedure using the electricity mixes that were used at a specific time in the past. A case-study building located in Central Europe (Slovenia) was selected to verify the methodology. A temporal differentiation was introduced, which is not normally applied in a traditional LCA. The scenarios for the electricity mix and the production efficiency were based on the collected data and the assumptions.

Additionally, the extent to which the modification of the electricity mix and the production efficiency influence the residual value of the building was tested. The calculation of the residual value for the building is often used to determine the refurbishment measures and to observe which elements are discarded prematurely during the refurbishment process. The aim is to find out whether the modification of the electricity mix has a strong impact on the residual value of the building and its components and can therefore have an influence on decisions about the refurbishment measures.

4.1.2 Methodology description

A new approach to the modelling was developed for the testing objectives. The approach involves three phases, as presented in Figure 13. In phase 1, the electricity mix must be remodelled for the selected periods. In phase 2, the LCI datasets were remodelled using the electricity mixes obtained in the previous phase. At this point, cut-off criteria were applied to avoid the remodelling of the sub-materials that do not make a significant contribution to the end-results. In phase 3, the residual value of the building is calculated using the remodelled datasets.

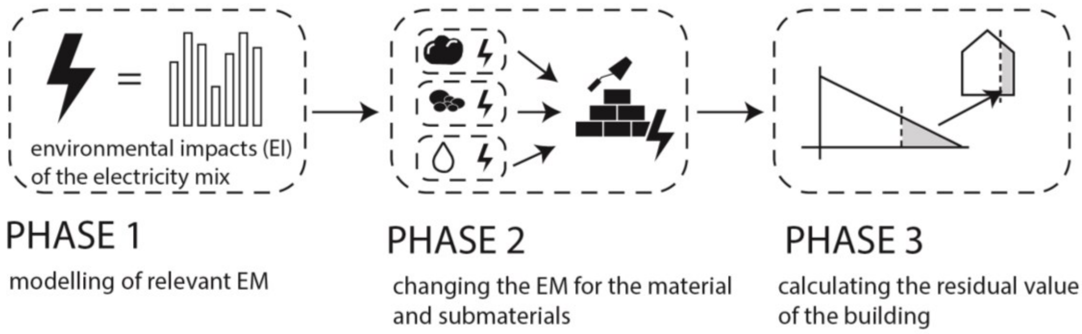

Figure 13: New, three-phase approach to remodelling the existing datasets and calculating the residual value of a building with the time-corresponding electricity mixes

Slika 13: Nov, trifazni pristop k preoblikovanju obstoječih podatkovnih nizov in izračunu preostale vrednosti stavbe s časovno ustreznimi proizvodnjami električne energije po energentih

The results are presented and discussed for the GWP impact category since the focus on one impact category facilitates the explanantion of the methodology. In the discussion part we have also evaluated how other impact categories will be affected by the change of the electricity mix over time. The database used in the study is Ecoinvent 3.5 (Wernet et al., 2016). The characterization factors used for the calculation were CML 2001 – January 2016 (Heijungs et al., 2013). The novel approach is illustrated on the selected case study which is presented in 3.2.2. The scope of the study is focused on the embodied impact of the production phase, i.e. phases A1–A3, covering the raw-material supply, transport, and manufacturing according to EN 15978 (EN 15978, 2021). The functional unit (FU) is defined as the whole building, with an RSL of 60 years (Fořt et al., 2018).

Electricity mix remodelling

The electricity mixes of individual countries change continuously, in general following the national strategies and technological developments. For example, they must now comply with the global energy and climate targets set out in the European Green Deal strategy (EC, 2020), the main goal of which is for Europe to become the first climate-neutral continent, following the goals of the Paris Agreement (UN, 2016). For this reason, the environmental emissions from the electricity mixes are in constant state of change.

As a first step, the electricity mixes for the past were remodelled based on the data obtained from Slovenian Statistical Office (SI-STAT, 2022), while the prediction for the future electricity mix was obtained from two sources: the Energy Concept of Slovenia (ECS) (Slovenian Ministry of Infrastructure, 2017) and the National Energy and Climate Plans (NECP) (European Commission, 2020). The environmental emissions for the average electricity mixes in every decade between 1970 and 2050 were then calculated. The results of these calculations are shown in Figure 14.

As presented in Figure 14, Slovenia's electricity mix in 2020 is still heavily dependent on nuclear, thermal (coal-generated) and hydro energy. Prior to 1970, the year when the Slovenian nuclear power plant was built, the electricity requirement was supplied solely by hydro and thermal power plants. The long-term strategy, in line with international policies, is to decrease the use of fossil fuels and to increase the share of renewables and low-carbon energy sources.

Two possible future developments for the electricity mix are presented. The first scenario, the ECS, makes the assumption that the nuclear power plant will be active until 2043 and that fossil fuels will have been abandoned by 2040. The electricity supplied by these two sources will be replaced partly by renewable energy sources and partly by the use of natural gas. As shown in Figure 14, in first period the GHG emissions will decrease only slowly, because of the abundance of fossil fuels, while after 2040 emissions will increase, when the electricity from the nuclear plant is partly substituted by energy from natural gas, which typically has larger emissions. The second scenario, that of the NECPs, proposes a decarbonization of the electricity mix by building a new nuclear power plant and increasing the share of renewable-electricity production. The GHG emissions will then be decreasing steadily during the observed period. However, it must be emphasized that due to the electricity generation from nuclear power, the GHG emissions from the electricity mix will be decreasing, although the use of nuclear power remains controversial (Wang et al., 2019). These problems exceed the scope of this study.

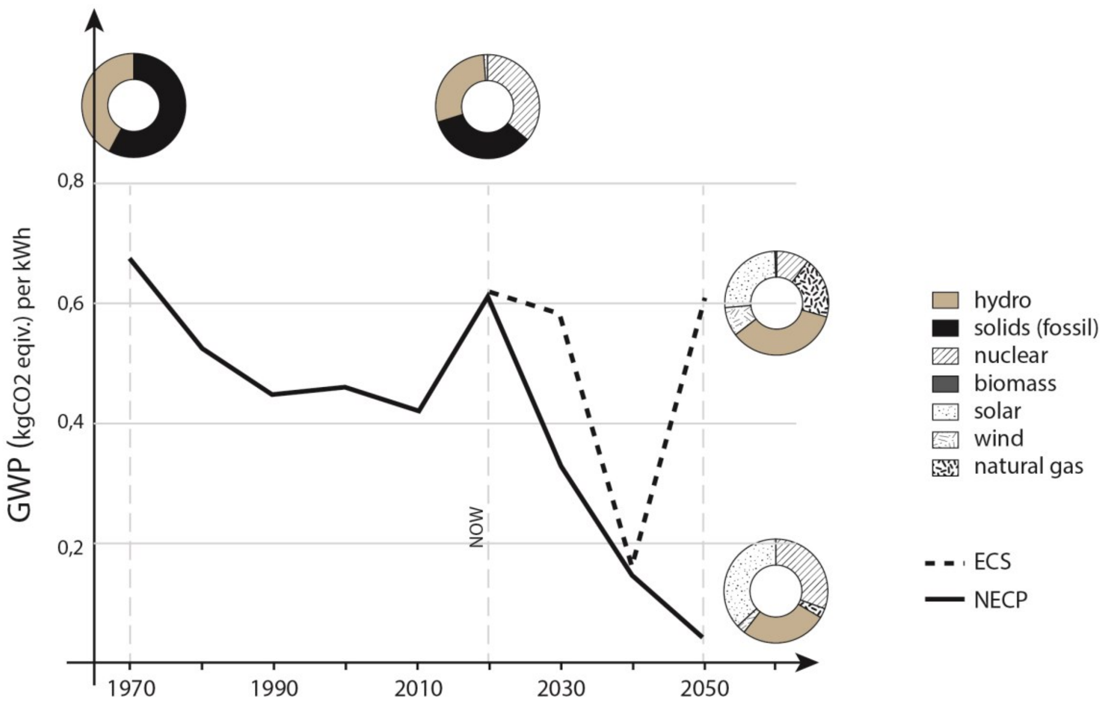

Figure 14: The composition of the electricity mixes over time and the corresponding GWP emission
Slika 14: Sestava proizvodnje električne energije skozi čas in njihove emisije toplogrednih plinov

Remodelling of the datasets

In the second phase, some of the existing LCI datasets of building materials were remodelled. The most common databases use the unit process (u-so) or the aggregated (agg) approach for modelling their datasets (Gervasio and Dimova, 2018). The first of these makes it possible to trace the processes down to the raw-material extraction and gives a very accurate insight into which processes contribute the most to the final environmental emissions. The downside of this is that the models are very large and difficult to manage. The aggregated databases, on the other hand, are small and very easy to use, but they do not provide a detailed insight into the upstream processes. Furthermore, they are unable to provide the option of being changed at any point, as most of the data are accessible only to the database operators. Since the task of this phase is to remodel the datasets, the unit process dataset had to be used. Therefore, the Ecoinvent database 3.5 (Ecoinvent integrated in Gabi) was used in this study (Wernet et al., 2016). Its database contains the unit process datasets that make possible the remodelling. The remodelling and calculating of the results were performed in Gabi (Gabi, 2022).

The remodelling process is illustrated in Figure 15. In step 1, the electricity mix of the original process dataset alone was replaced with the electricity mix of the period when the component/material was produced. It is assumed that the country's electricity mix is representative, although it has to be pointed out that in practice the component could be produced with a regional mix that is different, or that the component could be produced in other countries. However, this is beyond the scope of the study. In step 2, the electricity mix of the original processes dataset is further subdivided into sub-processes, and in each of the processes and sub-processes the electricity mix was replaced with the electricity mix of the period in which the component/material was produced. The third step (STEP 3) follows the principle of the previous two, but in addition the production efficiency is modified. A 0.5 % production efficiency increase in electricity consumption per year is assumed (as in Van De Moortel (2019)) since no actual data about the efficiency increase of individual production processes were found for the observed region. This means that the production process is assumed to have been less efficient in the past and thus required a higher electricity input. On the other hand, production in the future is expected to be even more efficient than at present and less energy will be needed. For the calculation of the efficiency increase the interest rate methodology was applied using the equation 1:

$$G_{\mathrm{n}} = G_0 + \mathrm{n}\cdot (G_0 \cdot p)/100 \qquad (1)$$

where G_o are the initial impacts calculated for the current conditions, p is the interest rate and n is the time horizon in years. The cut-off criteria were applied to remodel the existing datasets. The electricity mix was modified in those sub-materials that make up more than 1 % of the entire mass of the initial material and that include the electricity mix as one of the inputs.

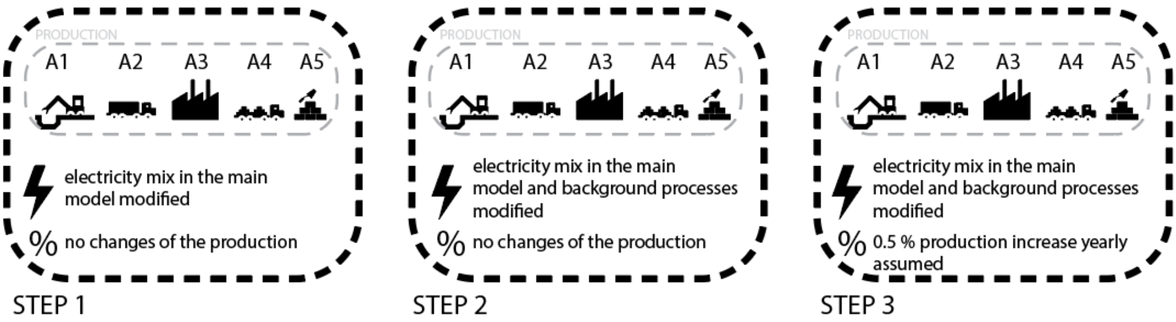

Figure 15: Stepwise remodelling of the existing datasets
Slika 15: Postopno preoblikovanje obstoječih podatkov

Residual value calculation

The residual value is the sum of the not-yet-amortized, embodied energy, environmental emissions evaluated in a specific moment in the production phase, whereas the embodied energy includes the production phases (modules A1–A5), maintenance (B4) and the EoL phases (modules C1–C4) according to EN 15804 (EN 15804:2012 + A2:2019, 2019). The building materials and components are amortized within their RSL and the building should be amortized within the observed reference study period (RSP). The definitions of the building RSP and the RSL of the components are thus of great importance for defining the residual value of a building. These values can vary depending on the database of their source (Rauf and Crawford, 2015). They are influenced by different parameters, e.g. the indoor and outdoor environments, the predicted maintenance, and the design of the product (Dixit, 2019; Grant et al., 2014; Grant and Ries, 2013).

In the presented case study, the residual-value calculation is simplified, because the aim of the study was to evaluate how the electricity-mix modification can influence the residual value of the building and to see if the differences can influence the decisions made about the future refurbishment measures. Only the production phases (A1 to A3 according to EN 15978) were used for the calculation of the residual value. The RSP of the building is 60 years. For the determination of the RSL of the individual components, the German BNB database was used. According to this database, none of the major components need to be replaced within the RSP of the building since their RSL is higher than 50 years and therefore it was assumed that their amortization time is the same as the RSP (Bbsr, 2011). This assumption raises the question about the importance of the RSL database choice, that is also discussed in the next chapter, The regular repainting of the walls has a negligible impact on the GHG emissions and was, therefore, not included.

4.1.3 Validation of the methodology on a case study

This section presents the results of the GHG emissions and residual values for our case study, i.e. the apartment building dating from 1970. The first subsection shows the remodelling approach for the individual components and this is illustrated using the exterior wall as an example. This approach was also performed on all the other components of the building. The results for the other components are available in the APPENDIX C. The purpose is to illustrate how the environmental impacts change when the electricity mixes from the production time of the existing materials are used for the calculation. Furthermore, datasets are also remodelled with future energy mixes, with the aim of investigating how the influence of the electricity mix will behave over time. In the next step, the difference in the results is shown for all the remaining components of the building. Finally, based on the previous results, the residual value of the building before refurbishment was calculated using different electricity mixes and the difference in the results was then analyzed.

Remodelling of the exterior wall

The exterior wall of our building (Figure 16) is composed of the structural part, which is built from concrete blocks with adhesive mortar in the joints and a finishing layer (see Table 3). Base plaster is used on the inside, with a water-based paint, and there is a cover coat on the outside.

Table 3: Exterior wall composition and basic data of the components
Preglednica 3: Sestava zunanje stene in osnovni podatki o komponentah

EXTERIOR WALL 1m^2			
	Thickness [m]	**Volume [m^3]**	**Mass [kg]**
Cover coat (OUT)	0.015	0.029	28
Concrete brick	0.29	0.275	440
Adhesive mortar	/	0.015	30.45
Base plaster	0.015	0.015	24
Alkyd paint (IN)	/	/	0.28

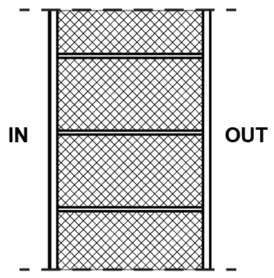

Figure 16: Cross-section of the exterior wall
Slika 16: Prerez zunanje stene

Each individual dataset used in the exterior wall of the case study was remodelled according to the described methodology. When observing the results (see Table 4 and Figure 17) after step 1 for the actual electricity mix (2020), it would appear that the contribution of the electricity mix to the total GHG emissions is relatively small in the case of some materials. For the concrete block, paint and adhesive mortar, this value is between 0.7 and 1.1 %. The GHG emissions of the electricity mix are higher in the cases of the base plaster and the cover coat, at 5.2 and 12.9 %, respectively. In step 1, however, the electricity mixes are modified only in the main process and not all the sub-processes are included in the main process. Although this approach is often applied in practice, it does not give realistic results, since it neglects the contribution of the electricity mix in the subprocesses that can substantially contribute to the final result. In step 2, after the sub-datasets have been remodelled according to the substitution criterion, the relative contribution of the electricity mix increases, as illustrated in Figure 17, since now the GHG emissions of the electricity mix of the sub-databases were also isolated and exchanged with the reference-year electricity mix. The relative contribution of the electricity to the total GHG emissions is 67.3 and 80.9 % higher for the cover coat and base plaster, respectively. For the paint, adhesive mortar and concrete block, these contributions are even 4.4 to 9.4 times higher than in step 1. They contribute from 4.8 to 21.5 % to the total GWP emissions.

The objective of the study was to see if the remodelling of the datasets with the electricity mixes used in the past can influence the result. After the substitution of the current electricity mix with the 1970 electricity mix, the relative contribution of the electricity mix to the total GWP emission increases. The relative contribution after step 2 is between 7.5 and 31.4 %, which is on average 54.0 % more than in 2020. If the production efficiency is also considered (step 3), the relative contribution of the electricity mix is between 9.1 and 36.4 %. The total emissions increase by between 3.2 and 14.1 % after step 2 and between 5.1 and 23.1 % after step 3, as illustrated in Figure 17. The increase in the total emissions is higher if the electricity mix of a single material contributes a lot to the total emissions. Therefore, the increase of the total emission is the lowest in the case of paint and the highest in the case of the cover coat.

In addition, the datasets were also remodelled with future electricity mixes (scenario ECS and NECPs) to compare how they contribute to changes in the total emissions in the future. The ECS scenario foresees an electricity mix that is similar to the current electricity mix. The relative share of the electricity mix in the total emissions is, on average, 15.0 % lower for individual materials after step 2 and 25.0 % lower if the production efficiency is also included (step 3). The total emissions decrease by between 0.8 and 2.9 % for step 2 and between 1.4 and 5.7 % for step 3. In the case of the scenario 2050 NECP, which foresees an almost completely decarbonized electricity mix in the future, the contribution of the electricity mix to the total emissions decreases substantially. The relative share of the electricity mix towards the total emissions is, on average, 90.0 % lower for individual materials (between 0.4 and 2.4 %) after step 2 and 91.5 % lower (between 0.4 and 2.1 %) if the production efficiency is also included (step 3). The total emissions decrease by between 4.0 and 19.5 % for step 2 and 4.1 and 19.8 % for step 3.

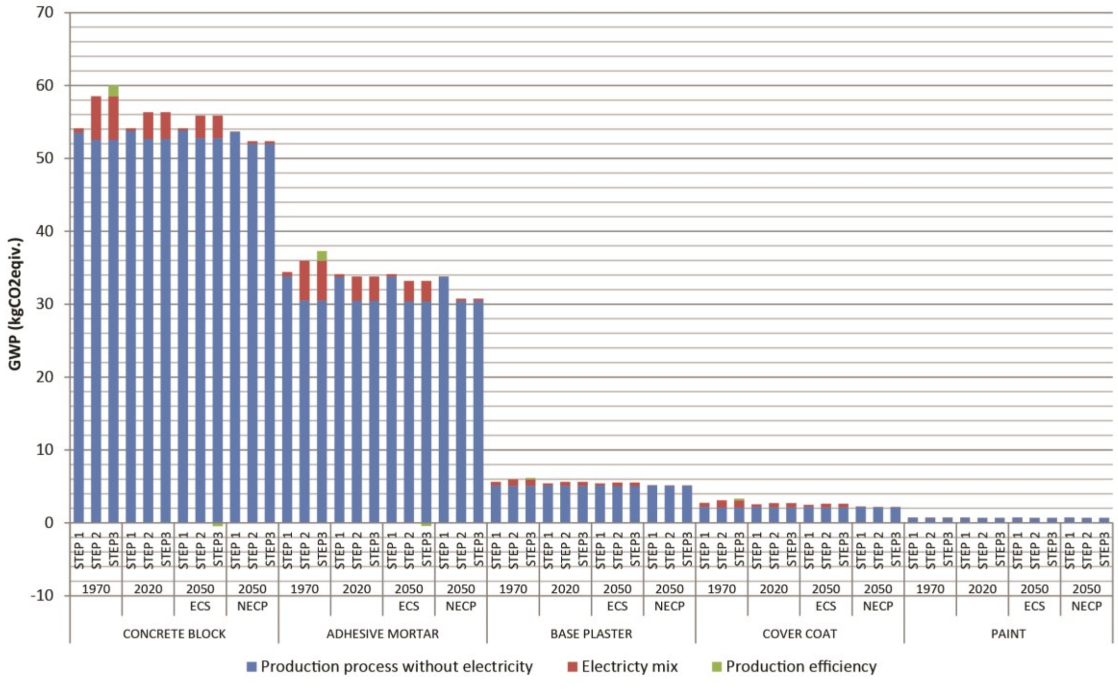

Figure 17: Calculated GHG emissions of 1 m^2 of exterior wall from materials according to the new remodelling approach

Slika 17: Emisije toplogrednih plinov za materiale 1 m^2 zunanje stene, izračunane po novi metodologiji

Table 4: Relative contribution of the electricity mix towards the total GWP emission of materials calculated with electricity mixes for different periods and corresponding production efficiencies
Preglednica 4: Relativni prispevek električne energije k skupnim GWP emisijam materialov, izračunanih z ustreznimi energenti za različna obdobja in ustrezno proizvodno učinkovitostjo

	1970			2020			2050 ECS			2050 NECP		
	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3
Concrete block	1.1%	10.2%	12.4%	0.7%	6.5%	6.5%	0.6%	5.5%	4.7%	0.1%	0.6%	0.5%
Adhesive mortar	1.7%	15.1%	18.2%	1.0%	9.8%	9.8%	0.9%	8.5%	7.3%	0.1%	1.0%	0.8%
Base plaster	8.2%	14.5%	17.5%	5.2%	9.4%	9.4%	4.4%	8.1%	7.0%	0.5%	0.9%	0.8%
Cover coat	19.5%	31.4%	36.4%	12.8%	21.5%	21.5%	11.1%	19.0%	16.7%	1.3%	2.4%	2.1%
Paint	1.7%	7.5%	9.2%	1.1%	4.7%	4.7%	0.9%	3.9%	3.3%	0.1%	0.4%	0.4%

Construction components

The calculation procedure according to the new methodology was subsequently performed for other construction components of the building. The detailed results for each component can be found in APPENDIX C. If all the building components are considered, the results after step 1 for the actual electricity mix (2020) show (see Table 5 and Figure 18) that the contribution of the electricity mix to the total GHG emissions is between 0.7 % in the case of the foundation up to 9.8 % in the case of the roof. After further modification of the electricity mix of all the relevant sub-datasets that apply, according to the declared substitution rules (STEP 2), the contribution of the electricity mix to the total emissions grows from 8.0 to 13.9 %.

Furthermore, if we are substituting the electricity mix with the energy mix of 1970, the relative contribution of the electricity mix increases by 50 % on average. In the first step (step 1), the relative share of the GHG emissions caused by the electricity mix is in the range between 1.1 % and 2.9 % for the foundation, exterior walls and inner walls. In the case of the windows and roof, the contribution of the electricity mix to the total GHG emissions is higher, i.e. 8.6 and 15.2 %. With the engagement of the procedure in step 2, the relative contribution of the electricity mix to the total emissions rises from 12.7 to 20.8 %. In addition, with the introduction of the production efficiency (step 3), the relative contribution of the electricity mix rises to values between 15.1 and 24.8 %. As illustrated in Figure 8, the total emissions in step 2 increase between 5.0 and 9.0 %. If an additional decrease of the production efficiency is considered (step 3), the total emissions increase to between 8.3 and 14.7 %. Again, the increase of the total emissions is higher if the electricity mix contributes in a greater amount to the total emissions. The changes in the total GWP emission are not significant, but they should not be neglected in the case they are used for calculating the residual value of a material or a component.

The relative contribution of the electricity mix to the total emissions is reduced when the modified electricity mix has a lower environmental impact compared to the current electricity mix. This is the case for the two presented future scenarios. In the 2050 ECP scenario, the relative contribution of the electricity mix to the total GHG emissions is like the case of the current electricity mix. In step 2 the relative share in the total emissions is on average 14.0 % lower (between 12.5 and 20.8 %). If an additional increase of the production efficiency is considered, the relative contribution decreases by 25.7 % (the relative share between 15.1 and 24.8 %). The decrease of the total GHG emissions is between 1.2 and 2.2 % for step 2. If the increase of the production efficiency is considered, the total emissions decrease between 2.3 and 3.9 %. For the 2050 NECPs scenario, the decrease of the environmental emissions associated with the electrify mix is considerably higher.

In step 2, the relative share of the total emissions is between 0.8 and 2.1 %. If a further increase of the production efficiency is considered, the relative contribution is even lower, between 0.7 and 1.8 % to the total GWP emissions. In this case the electricity mix is almost decarbonized; therefore, it also does not contribute a lot to the total emissions. The decrease in GWP emission lies between 7.8 and 12.5 % for step 2 and between 8.0 and 12.7 % for step 3.

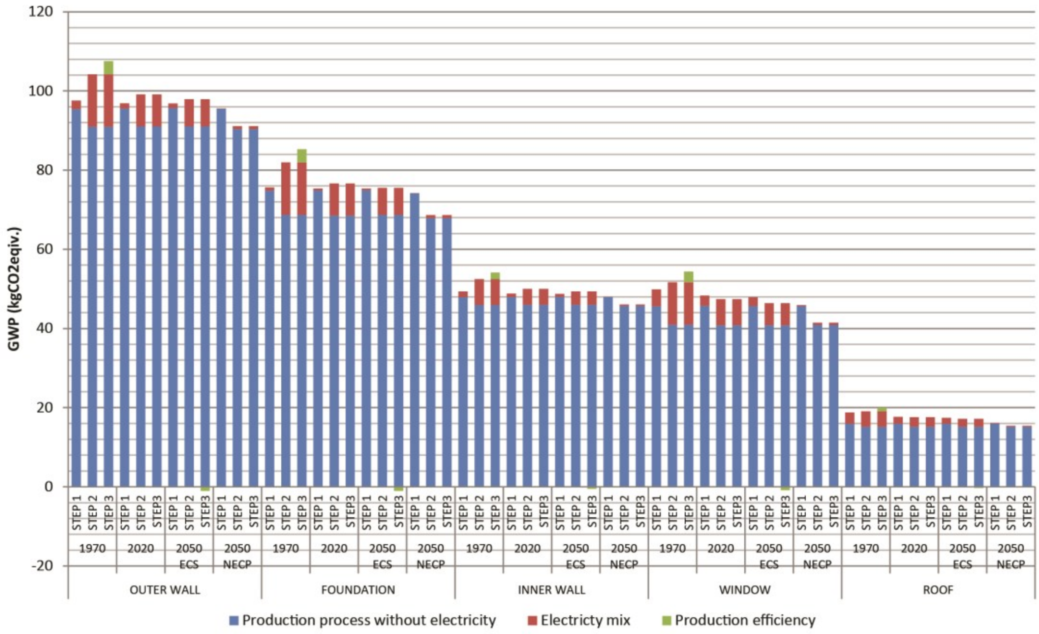

Figure 18: GHG emissions for 1 m^2 of all construction components of the building
Slika 18: Emisije toplogrednih plinov, izračunane za 1 m^2 vseh gradbenih komponent stavbe

Table 5: Relative contribution of the electricity mix to the total GWP emission of components calculated with electricity mixes for different periods and corresponding production efficiencies
Preglednica 5: Relativni prispevek električne energije k skupnim GWP emisijam komponent, izračunanih z ustreznimi energenti za različna obdobja in ustrezno proizvodno učinkovitostjo

	1970			2020			2050 ECS			2050 NECP		
	STEP 1	STEP 2	STEP 3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3
EXTERIOR WALL	2.3%	12.7%	15.4%	1.4%	8.2%	8.2%	1.2%	7.0%	6.0%	0.1%	0.8%	0.7%
FOUNDATION/FLOOR	1.1%	16.2%	19.4%	0.7%	10.5%	10.5%	0.6%	9.1%	7.8%	0.1%	1.1%	0.9%
INNER WALL	2.9%	12.5%	15.1%	1.8%	8.0%	8.0%	1.5%	6.9%	5.9%	0.2%	0.8%	0.7%
WINDOW	8.6%	20.8%	24.8%	5.4%	13.9%	13.9%	4.6%	12.0%	10.4%	0.7%	2.1%	1.8%
ROOF	15.2%	20.2%	24.1%	9.8%	13.4%	13.4%	8.5%	11.6%	10.0%	1.0%	1.4%	1.2%

Residual value of the building

In the continuation of the dissertation, the results for the residual value are presented, calculated for our case study of the selected building using different data for the electricity mixes. The results, illustrated in Figure 19, show that for the selected case study, the residual value is 9.7 % higher if the time-corresponding datasets for the electricity mix are used instead of the electricity mix from today. Assuming that the production of electricity in 1970 was more efficient (would resemble the 2050 ECS and 2050 NECP electricty mixes), this would mean that the residual value observed at a certain point in time would be lower. If calculating with the 2050 ECS electricity mix, the residual value is 2.5 % lower, while in the case of an almost-decarbonized electricity mix (2050 NECP) the residual value would be 9.8 % lower. When we are dealing with residual value, the relative differences in impacts are the same. The absolute differences of the impacts calculated with different electricity mixes, however, are decreasing the more we approach the end of the RSL. Therefore, the differences in the results are greater if the residual value is high and become less important when we are approaching the end of the RSL of the component or the building.

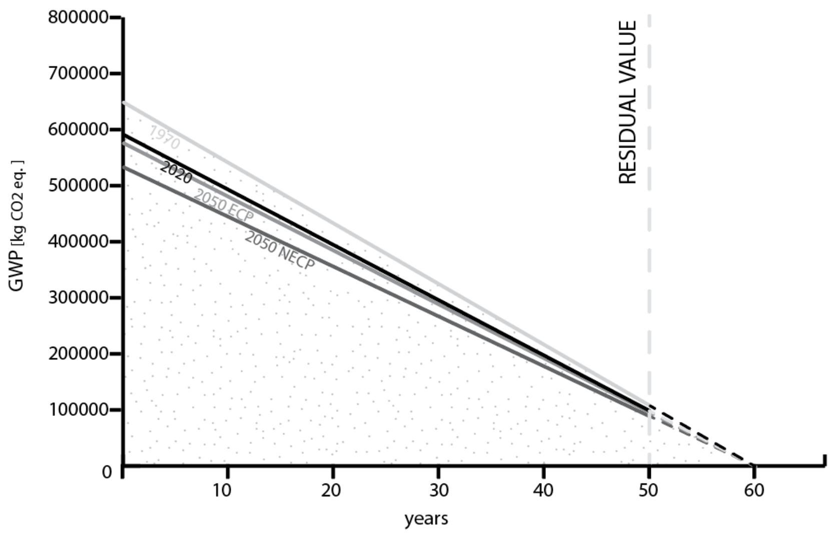

Figure 19: Residual values of our case study, the selected building, calculated with different electricity mixes
Slika 19: Preostale vrednosti našega študijskega primera izbrane stavbe, izračunane z različnimi sestavami električne energije

4.1.4 Discussion

The contribution of the electricity mix to the total emissions of materials and components can be falsely interpreted as minor if just the contribution of the electricity mix of the final process (the main datasets) is observed (Roux et al., 2016). It is important that the electricity mixes are also considered in all the sub-processes (sub-datasets) to obtain a realistic impression about the impact of the electricity mix on the total environmental emissions. Technically, this means that the existing datasets must be provided with a structure that enables the modification and adjustment of certain inputs. In this sense, the u-so way of modelling as used, for example, in Ecoinvent, has a clear advantage over the datasets modelled as aggregated (agg) datasets. Although the calculation with aggregated datasets is faster and the files are smaller, this method does not provide a clear insight for the inputs and thus also for the remodelling of the datasets (Gervasio and Dimova, 2018).

In the presented study the contribution of the electricity mix to the total emissions was as high as 20 %. It is, therefore, a very important parameter when calculating the total environmental emissions of the materials and components, as also shown in other studies (Kiss and Szalay, 2020; Pomponi and Moncaster, 2016; Roux et al., 2016). This parameter, however, is subject to major changes over time. It was observed that in many cases the electricity mix for the future is modified time-dependently, but remodelling the data for the past, as presented in our case, is an innovation. The environmental impacts of electricity mixes have generally been greater in the past than they are today. In the study it is assumed that the production processes remained similar and that only the electricity mix and the efficiency of the electricity use have changed over time, so, consequently, the environmental impacts of the materials and components manufactured in the past were also greater and the relative contribution of the electricity mix on the total emissions was also higher at that time. In the presented case the total emissions for individual building components were between 5.0 and 9.0 % higher if the current electricity mix was substituted with the electricity mix of 1970. If the production efficiency decrease were also to be considered, the difference in total emissions is between 8.3 and 14.7 %. In the presented study assumptions were made in order to replicate the reality, while at the same time they introduce uncertainty into the calculation, as also discussed by Van De Moortel et al. (2019).

On the other hand, the current regulation is streaming towards decarbonization and minimization of the environmental footprint of the electricity mix in the future (EC, 2020). The environmental emissions of the future electricity mixes will be reduced and will become more or less negligible, which opens up further areas of investigation (Kiss and Szalay, 2020; Pomponi and Moncaster, 2016; Roux et al., 2016). This was also observed in the presented study for the GWP category. It is assumed that the future electricity mixes perform better in all the environmental categories recommended by EN 15804. The exception is the abiotic depletion of elements that could become a major burden in the future in the case of the increased share of photovoltaic generated electricity (Turconi et al., 2013). This assumption, however, is based on calculations with current datasets that reflect the technological state of the art. This problem could be resolved with greener technologies in the future. Establishing what the meaningful differences between the compared electricity mixes should be in order that replacing them will be worthwhile is a research task for the future.

The differences in results can be substantial, as presented here, and it is thus recommended that the remodelling of the datasets is performed if it is intended to use the data for the calculation of the former impacts of the manufacturing of existing buildings and also plan future refurbishment measures based on it. In the study of Kohler et al. (2010) it is indicated that the residual value is an indicator of building ageing and can therefore be used as a criterion for building preservation or demolishment. It can also be used as benchmark for when to start the refurbishment. In addition to this, the residual value gives information about the amortization of the materials or components and this can be used for a decision about their preservation and reuse or their discarding. The findings showed that the relative differences in the results for the phases A1–A3 were also up to 10.0 %. The absolute differences in the results are dependent on the amortization time. Consequently, an imprecise determination of the residual value could lead to premature refurbishments, demolition and discarding building materials or components too early if the decision were made only based on the residual value and if the electricity mix of the reference year of the construction had had a higher impact than the current electricity mix. It also makes a difference whether the product is near the end of the depreciation period, since the absolute differences are relatively small towards the end of the amortization period and therefore the modification of the electricity mix does not influence the results to any great extent, compared to the beginning of the amortization period. The scope of the study is the production phase, however, and it does not include the embodied impacts of the maintenance activities. If these impacts were to be included, the substituted materials would be at different levels of amortization and therefore the absolute differences could be influenced by the electricity mix. These aspects can also be part of future research.

4.1.5 Summary

The present study confirmed that the electricity mixes used in the production of buildings can significantly influence the calculated values for the environmental indicators of buildings in need of refurbishment. Our results from calculations in the case of an apartment building showed that the contribution of emissions from the electricity mixes of different time periods could be as high as 20 % in the context of individual materials. It must be emphasized that the contribution of the electricity mix to the total emissions will need to be evaluated along the entire chain of datasets and sub-datasets, since the modification of the electricity mix only in the original dataset (and not in sub-datasets) could lead to a false estimation. It is assumed that the embodied environmental emissions of the past are even higher because the production was less efficient and therefore more electricity was needed for the production of the materials. Individual changes in production efficiency are usually the internal data of the manufacturer and this is not commonly disclosed or is not even known or recorded, thus only the general value (i.e. 0.5 % per year) could be used in the calculations. In the presented case it is shown that the total emissions of individual materials and components can increase by 5.0 and 14.7 % or decrease by between 1.2 and 12.7 %, depending on the emissions of the used electricity mix and the projected change of the production efficiency.

In addition, it was established that the time-dependent modifications in the electricity mix can also have a strong impact on the residual value of any building. The relative difference in the presented case was in the range of 10.0 %, but the absolute values decreased towards the end of the amortization periods for individual materials and components. Decisions about the potential refurbishment or demolishing of a building, time of maintenance actions or the handling of individual materials and components based on the residual value require a precise and realistic calculation with the correct data at the point of time. The differences in results are not negligible and can potentially lead to premature and incorrect actions (e.g. the building being renovated too early, which elements are worth preserving from the environmental perspective).

An analysis of the results obtained in the present study revealed that parameters which are usually subject to a major change during the service life of the building need to be included in life cycle calculations with the correct data at the point of time. This means that all time-dependent data sets related to the electricity mix and productivity efficiency are used correctly in the assessment (for individual time periods). This was clearly illustrated in the calculation of the residual value of the selected building before the refurbishment. In doing so, however, these analyses also provide valuable insights that can be applied for a variety of purposes for each product with a long life span. Ideally, the dynamic inventory data should also be coupled with dynamic characterization factors to obtain a fully dynamic LCA, but the dynamic characterization factors for different environmental categories are still under development and this issue should thus be a part of future research.

4.2 Development of a methodology for the allocation between the life cycle before and after the refurbishment

4.2.1 Introduction

In this part, the sub-methodology for the allocation between the life cycle before and after the refurbishment is developed and verified. The content of Chapter 4.2 was published in the Journal of Cleaner Production (Potrč Obrecht, Jordan, Legat, Ruschi Mendes Saade and Passer 2021).

The refurbishment of a building should be assessed in module B5 according to the EN 15978 standard (EN 15978, 2021). This includes:

- production of new building components,
- transportation of the new building components (including production of any materials lost during transportation),
- construction as part of the refurbishment process (including production of any material lost during refurbishment),
- waste management of the refurbishment process and
- the EoL stage of replaced building components.

However, several studies (Corrado and Ballarini, 2016; Ferreira et al., 2013; Häkkinen, 2012; Häkkinen et al., 2016; Oregi et al., 2017b, 2015a; Passer et al., 2016; Vilches et al., 2017) indicate that the environmental impacts of a building's refurbishment are not addressed as phase B5 of the whole life cycle, but are treated as the beginning of a new life cycle of a building (Anand and Amor, 2017). This practice is still in line with EN 15978, which states that "if a building is refurbished and the refurbishment was not taken into account at the outset, i.e. in any previous assessment, a new assessment should be carried out, particularly where the refurbishment changes the functional equivalent (…)". The environmental impacts of the refurbishment materials and processes are thus addressed in modules A1 to A5 (the production stage of the building) of the life cycle after the refurbishment. While the European standard does not clearly mention how the practitioner should address the materials and components that shall remain after refurbishment, according to ISO 14044 the reuse of previously adopted materials in a new product system (i.e. in a new building's life cycle) calls for an allocation procedure. ISO 14040 emphasizes that allocation should be avoided either by dividing the unit process into two or more independable sub-processes or by expanding the scope of the study to include the additional functions related to the co-products (ISO 14040, 2006). If avoiding allocation is not possible, the division between two life cycles shall take place. The recognition of an allocation need is, however, seldom observed in published studies.

Since LCA is a relatively new method, the majority of buildings have not yet been assessed, so in almost all cases refurbishment is accounted for in a new life cycle (Vilches et al., 2017). This will probably change in the future, especially if the LCA method becomes mandatory for buildings. However, if the refurbishment implies a change of the building's functional equivalent, one will still consider the refurbishment as the start of a new life cycle.

The current modelling practice does not consider the entire life cycle of the building that will undergo extensive refurbishment, but only the parts after the refurbishment (Agostino et al., 2017; Anand and Amor, 2017; Dascalaki et al., 2016; Häkkinen, 2012; Häkkinen et al., 2016; Jagarajan et al., 2017; Oregi et al., 2015a; Passer et al., 2016; Pomponi et al., 2015; Weiler et al., 2017). The exclusion of materials and components used prior to the refurbishment is, according to the requirements outlined in ISO 14044, scientifically questionable. If only the materials substituted during the refurbishment are considered in an LCA study, we produce a gap at the end of the building's new life cycle where all the materials (the material reused during the refurbishment and the newly added materials) are "discarded", an issue already observed in the study of Vilches et al. (2017). Additionally, no information about what impacts have already been considered in the past bears the risk that some of the impacts are double-counted. For example, a material has already been rewarded as burden-free at the beginning because it consists of recycled content. If we do not have this information in the later stages, we can also assign it the benefits of recycling it at its end of life, thus the benefit of recycling is assigned twice to the same material (Frischknecht, 2010).

To bridge the gap between the common building refurbishment LCA practice and the international standard's requirements, practitioners must consider how to distribute the flows between previous and new life cycles (Allacker et al., 2017; Ekvall, 2000; Ekvall and Tillman, 1997; Frischknecht, 2010; Kim et al., 1997; Mirzaie et al., 2020)). The distribution of the environmental impacts is only a theoretical methodological approach since in the real world the EI are caused and emitted at one point of the time and no allocation in time is possible. There are several approaches to allocate the environmental burdens and benefits between two product systems (Allacker et al., 2017). In this paper the (1) the recycled content approach, (2) the module D approach, (3) avoided impact burden approach, (4) 50:50 approach and (5) the PEF approach are investigated. The allocation approaches are presented in subchapter 4.2.2. It is important to mention that the approaches are mainly discussed for the recycling of the materials or products. In the case of refurbishment, the situation is similar to recycling except that mostly the materials and components are being reused. Compared to recycling, this means that no additional recycling processes and their related environmental impacts are caused.

The selection of the allocation method influences the environmental impacts of separate materials and hereby also the residual value of the building. According to the definition of SIA 2032:2020, the residual value is the sum of the not yet amortized environmental emissions of embodied energy evaluated at a specific moment in the life cycle, whereas embodied energy includes the production stage (modules A1–A5), maintenance (B4) and the end-of life stages (modules C1–C4) according to EN 15804. In the ideal case, the RSL of the building materials and components should be amortized within the RSP of the building and at this point, the building should be either refurbished or demolished. This is seldom the case. In practice, at the end of the RSP, the building materials are often not amortized and the building is demolished, whereas some materials are still intact (Vilches et al., 2017). Therefore, the environmental residual value of the components should be assessed. The residual value can be an important source of information to define which materials can still be reused and how to refurbish the building to minimize its environmental impact. However, the residual value may vary depending on the calculation methodology and the input data (e.g. LCI database used, RSL database, etc.) (Kohler et al., 2010; Severin, 2018).

The solution to the presented problems is a newly developed methodology for the assessment of the environmental impacts and the residual value of components and materials before and after a refurbishment. The methodology builds on the LCA methodology and the SIA 2032 standard that is used to evaluate the residual value. This methodology is upgraded by the allocation approaches of the impacts between the life cycle before and after the refurbishment. For the allocation of the impacts, different existing allocation approaches can be used, which are chosen based on the scope and goal of the study. The connection of the various methodologies into a new methodology is innovative and allows a reliable estimation of the environmental impacts and the residual value at a certain moment in time. This information facilitates decisions about the further use of different components and materials.

The following subsections describe the outline of this research. First, the four-step methodology for the assessment of the environmental impacts and the residual value of refurbished buildings is described in detail in subsection 4.2.2. Finally, subsection 4.2.3 describes the validation of the methodology on two case studies (two different building components of a multi-family building).

4.2.2 Methodology description

The newly developed calculation approach to measure the refurbishment measures' environmental impact and residual value has four steps (Figure 20). In step 1, the inputs and outputs of the building's life cycle before and after its refurbishment are determined. For each life cycle it must be indicated which inputs are virgin materials and which consist of recycled materials. Similarly, this step also defines which materials are disposed of at the end of the life cycle, which materials are recycled and which are reused (e.g. reuse of the structural components after the refurbishment). The scope of the study should be chosen so that it shows the relationship between the first and the second life cycles. This step establishes a logical background for the calculations performed in step 2.

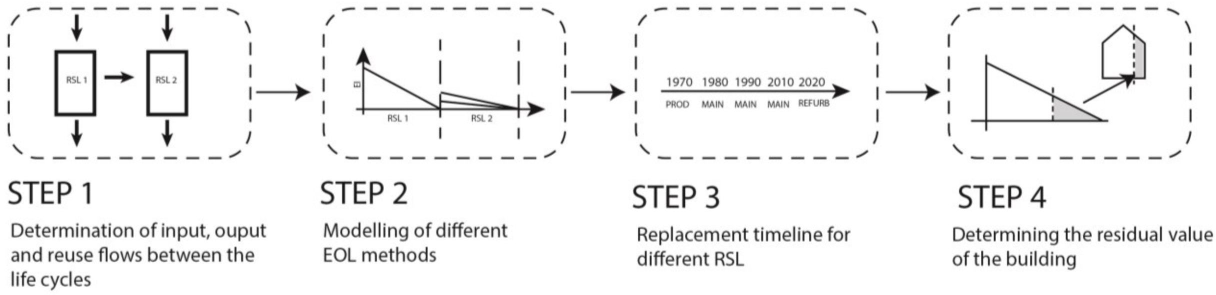

Figure 20: Methodology for the assessment of environmental impacts and the residual value of components and materials before and after a refurbishment in four steps
Slika 20: Metodologija za oceno vplivov na okolje in preostale vrednosti komponent in materialov pred in po prenovi v štirih korakih

Step 2 is the most time consuming. The environmental impacts of the materials, components or buildings are calculated and distributed between the life cycle before the refurbishment and the life cycle after the refurbishment using the chosen allocation method. The connection between the first and second life cycles and the choice of the allocation schemes is an important topic, especially when materials are reused or recycled. The allocation approaches between the life cycles of a building lead to very different results (Allacker et al., 2017).

The cut-off (also called the 100:0 or the recycled content) approach considers that the environmental impacts of the production phase for a product are attributed to the first use of this product and follow the "polluter pays" principle (Gervasio and Dimova, 2018). The second use of the product only bears the environmental impact of collection and the preparation of the product for its subsequent use. In some cases, the collection is also attributed to the first use of the product. However, the materials that are used for a second time do not bear any environmental load from the primary production process (Allacker et al., 2017; Frischknecht, 2010; Gervasio and Dimova, 2018). The cut-off approach with module D tries to introduce the circularity stimulus to the previous approach by the introduction of module D. This is the phase beyond the system boundary of the building's life cycle that includes possible benefits or loads due to recycling, reuse and energy recovery. However, in module D the difference in quality of the material before and after the recycling process is not assessed. The avoided burden approach (also called the End-of-Life approach or 0:100) considers the benefits of the potential recycling or reuse and accredits it in the first life cycle. The 50:50 approach divides the burdens and benefits equally between the first and second life cycles. It allocates 50 % of the benefits of using recycled materials in the production stage and 50 % of the benefits of recycling at the EoL stage to the observed life cycle. It can be seen as a compromise between the recycled content and the avoided burden approach. The Product Environmental Footprint (PEF) approach builds on the 50:50 approach and introduces two factors: one to take into account the downcycling of materials, and the other to introduce the market demand for recycled products (Gervasio and Dimova, 2018). However, these factors are sometimes difficult to determine due to a lack of data (Spirinckx et al., 2018). A graphical presentation of the approaches is shown in Figure 21.

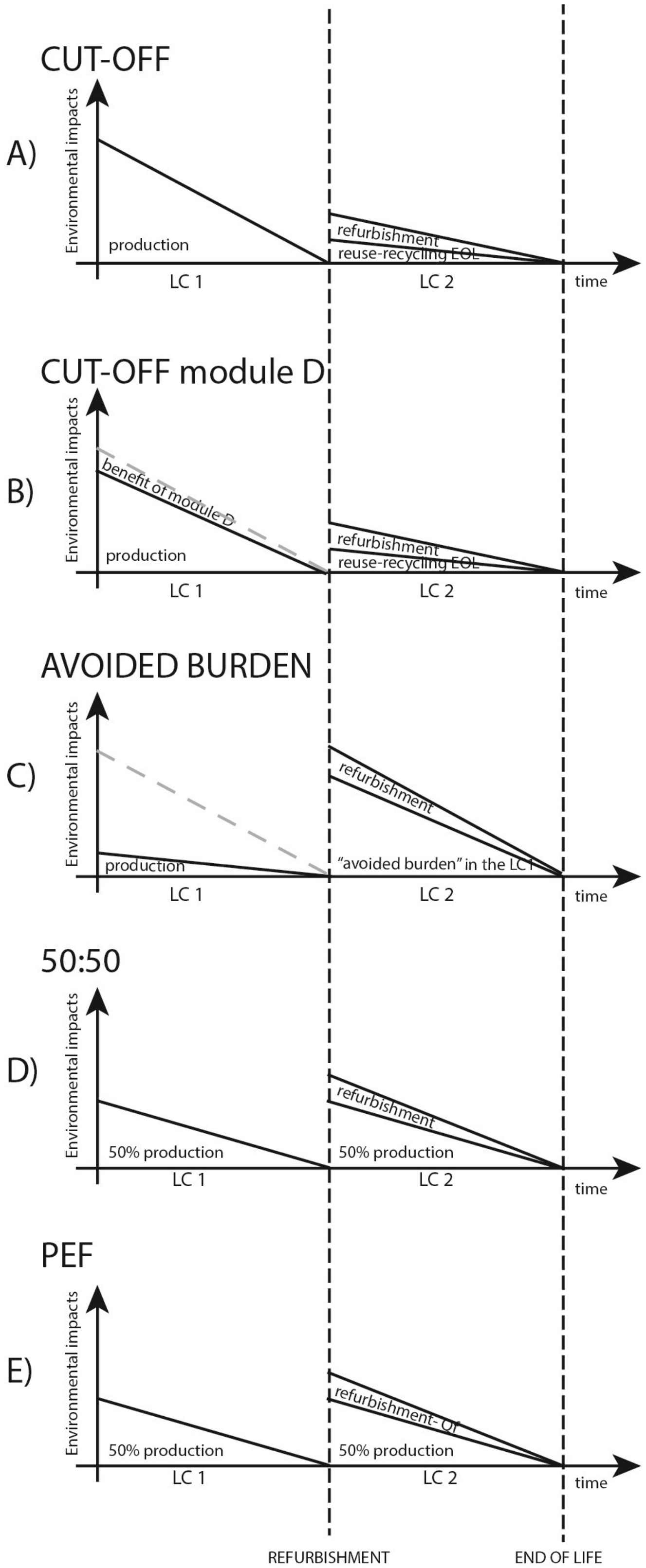

Figure 21: Graphical representation of the allocation approaches
Slika 21: Grafični prikaz različnih postopkov alokacije

The ISO standards do not dictate which to adopt, relying on the practitioner's judgement to determine their appropriateness. The results of this step are the absolute environmental values of separate life cycles, and these are an input for the calculation of the residual value. For the materials that are replaced or kept during the following life cycle, additional information is needed for the calculation of the residual value, which is provided in the next step. The formulas for the allocation are derived from Gervasio and Dimova (2018), and Allacker et al. (2017). To facilitate the interpretation of results, the total environmental impact for each allocation approach was further subdivided into the subcategories proposed in Table 1: A, production; C, EoL; and D, beyond the building life cycle. These subcategories are divided into parts that represent impact virgin (environmental impact of the virgin materials), impact recycled content (impact related to the use of recycled materials), impact disposal (environmental impact of disposal), impact EoL (environmental impact of EoL), recycling impact (environmental impact of the recycling) and credit module D (environmental impact avoided because of the benefits of reuse, recycling, incineration with waste recovery). The formulas used for the calculation are presented in Table 6.

Table 6: Formulas for calculating the EI of separate life cycle modules according EN 15978 for the different allocation approaches
Preglednica 6: Formule za izračun okoljkih vplivov posameznih modulov življenjskega cikla po EN 15978 za različne postopke alokacije

	Formulas				
Modules EN 15978	**A - production**		**C - EoL**	**D - beyond the building life cycle**	
Allocation approach	**EI virgin**	**EI rec content**	**EI disposal**	**EI EoL rec**	**EI, rec, open loop (credit module D)**
CUT-OFF	(1-R1)Ev	R1*Erec	(1-R2)*Ed	0	0
CUT-OFF +D	(1-R1)Ev	R1*Erec	(1-R2)*Ed	(R2-R1) *Erec,eol	-(R2-R1)*E*v
AVOIDED BURDEN	Ev	0	(1-R2)*Ed	R2* Erec,eol	-R2* E*v
50:50	(1-R1/2)Ev	R1/2*Erec	(1-R2/2)*Ed	R2/2*Erec,eol	-R2/2* E*v
PEF	(1-R1/2)Ev	R1/2*Erec	(1- R1/2- R2/2)*Ed	R2/2*Erec,eol	-R2/2* E*v*(Qprod,out/Qprod,in)

Where:

- Ev = emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material;
- E*v = emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials;
- Erec = emissions and resources consumed (per unit of analysis) arising from the production process of the recycled material, including collection, sorting and transportation processes;
- ErecEoL = emissions and resources consumed (per unit of analysis) arising from the recycling process at the EoL, including collection, sorting, transportation and recycled material production processes;
- Ed = emissions and resources consumed (per unit of analysis) arising from disposal of waste material (e.g. landfilling, incineration and pyrolysis);
- R1 = recycled content of the materials;
- R2 = recycling share at the end of the life cycle;
- Qprod,out/Qprod,in = difference in the quality of the primary Qprod,in and secondary materials Qprod,out

In step 3, a timeline with the replacement times and maintenance actions for each component or material is established according to the selected RSL. Materials and building components have different RSLs and are amortized at different times of the observed reference study period (RSP) of a building. For the determination of the RSL various sources can be used (Grant and Ries, 2013). Often, they are acquired from RSL databases. Generally, the data for various materials or components differ from one database to another. In a previous study it was found that due to different replacement rates, the environmental impact can vary significantly (Potrč Obrecht et al., 2019). In the developed methodology, this step provides the information about the replacement rate and maintenance procedures and consequently, also about the remaining RSL of the building materials and components.

Finally, in step 4 the data from the two previous steps are used to calculate the residual value of the material, a component or a building. The environmental values calculated in step 2 are linearly distributed accordingly to their remaining RSL (which was determined in step 3). The residual value is calculated following the approach presented in SIA 2032 (Severin, 2018). As already mentioned, the residual value of a material, component or building is the sum of the not-yet-amortized environmental emissions of embodied energy evaluated at a specific moment in time, whereas the embodied energy includes the production stage (modules A1–A5), maintenance (B4) and the EoL stages (modules C1–C4) according to EN 15804 (EN 15804:2012 + A2:2019, 2019; Severin, 2018). The residual value of a material component of a building can be determined at any point during the observed life cycle period. The equation 2 for the calculation of the residual value is based on SIA 2032: 2020:

$$RV = \sum_i EI_i - \frac{EI_i}{y_{RSL}} y_{USE} \tag{2}$$

where

- RV = residual value
- EI = environmental impact of the production and EoL phases of the material
- y_{RSL} = estimated RSL in years
- y_{USE} = years in use

4.2.3 Validation of the methodology on a case study

The application and verification of the methodology is presented on two selected components of a typical Slovenian multi-residential building from around 1980- the same as used in the study in the previous chapter. The components were deliberately selected so that they differ greatly in both composition and refurbishment measures. The first component is the floor between the storeys (Table 7 and Figure 22). The component was selected because it contains a material that already has recycled content in the first life cycle (the reinforcing steel).

Table 7: LCI talne plošče
Preglednica 7: LCI of the floor

FLOOR 1m²		
	Thickness [cm]	**Mass [kg]**
Sawn wood	1.5	8.40
Screed	5	110.00
EPS	3	0.60
Reinforced concrete	15	360.00
Base plaster	1.5	24.00
Alkyd paint	/	0.28

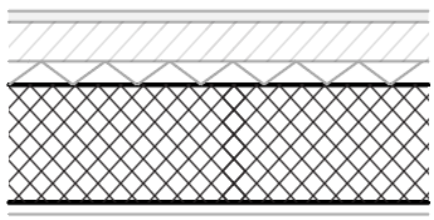

Figure 22: Floor
Slika 22: Medetažna plošča

The second component selected for the illustration of the methodology is the exterior wall (Table 8 and Figure 23). In this case, material thermal insulation was added during the refurbishment.

Table 8: LCI of the wall
Preglednica 8: LCI zunanje stene

EXTERIOR WALL 1m2		
	Thickness [cm]	**Mass [kg]**
Cover coat (OUT)	1.5	28.00
Rock wool	30	30.00
Concrete brick	29	440.00
Adhesive mortar	/	30.45
Base plaster	0.015	24.00
Alkyd paint (IN)	/	0.28

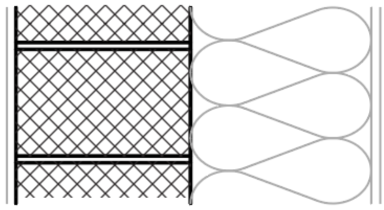

Figure 23: Exterior wall
Slika 23: Zunanja stena

A sensitivity analysis was performed along with the validation, to show the dependence of the residual value from the following parameters (Figure 24):

- the EOL modelling approaches,
- the RSL databases.

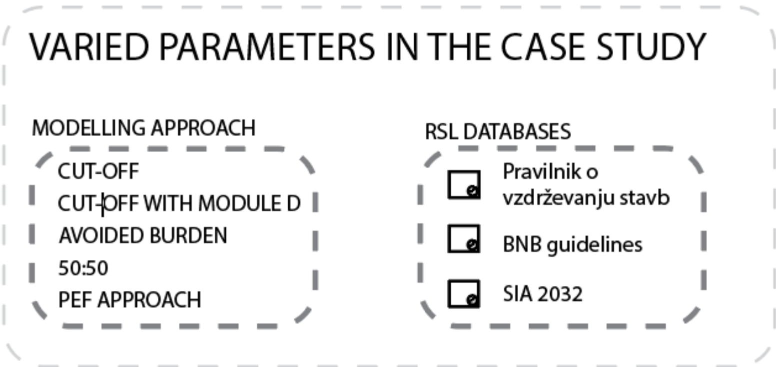

Figure 24: Varied parameters in the case study
Slika 24: Spremenljivi parametri v študiji

After defining the flows (inputs, outputs and reuse) between the life cycle before and after the refurbishment (step 1), the environmental impacts of the individual materials were assessed and allocated between the life cycles by using five often-used allocation approaches, namely cut-off, cut-off with module D, avoided burden, 50:50 and PEF (step 2). To facilitate interpretation of the results, the total environmental impact for each allocation approach was further subdivided into the subcategories proposed in Table 6.

In step 3, three different databases containing data about RSL of building components and materials were compared. The first database is Rules on standards for the maintenance of apartment buildings and apartments and is used in Slovenia (SLO) (Rules on standards for the maintenance of apartment buildings and apartments, 2004), the second database is derived from Bewertungsystem für Nachhaltinges Bauen (BNB) (Bbsr, 2011) and is often used in Germany, and the third database is from SIA2032: 2020 (SIA) (Severin, 2018) used in Switzerland. The comparison will show how the residual value of buildings can vary depending on the RSL database used for the study.

In step 4, the residual value was calculated for each life cycle (the LC1 before the refurbishment and the LC2 after the refurbishment) after two arbitrary selected periods. Each of the life cycles has an RSP of 60 years and the first calculation of the residual value is after 30 years (on half of the observed RSP) and the second calculation is made after 50 years (10 years before the end of the RSP) of the individual life cycle.

The methodology can be applied to every material, component or building and can be used for every environmental impact category. In the study the results for the GWP impact category are presented since it is the most prominent indicator. The results are explained on this impacts categories since the focus is on a clear presentation of the methology and not as much on the results itself. The database used in the study is Ecoinvent 3.5 (Werner et al., 2016). The characterization factors used for the calculation are derived from IPCC 2013 (CML-IA Characterisation Factors, 2016).

Step 1

Initially, in step 1, the basic flows between the first and second life cycles were determined.–The material flows between the first and second life cycles are illustrated for the floor in Figure 25 and the exterior wall in Figure 26. The figures show which virgin materials were used, their recycled content, which materials are recycled or reused, and also how individual materials were treated at the end of its lifecycle (recycling, reuse, landfill or incineration).

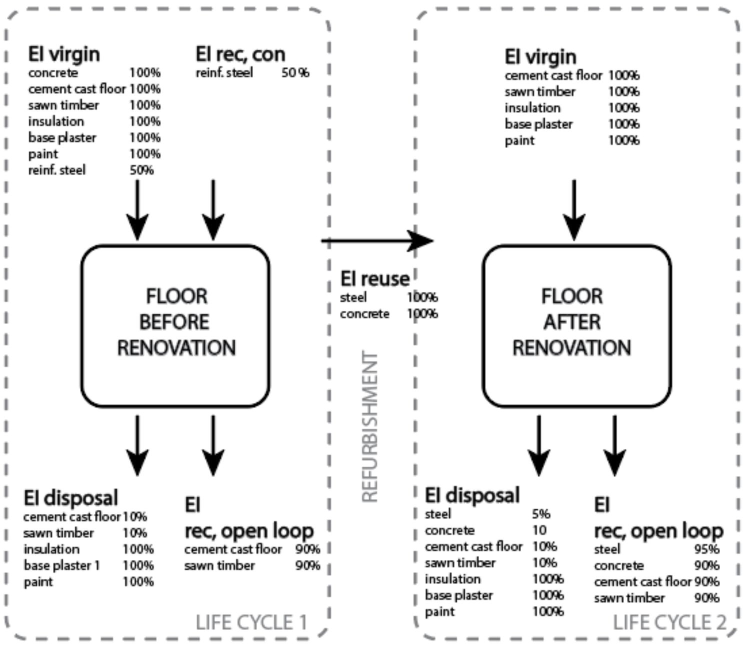

Figure 25: Step 1 – Distribution of the environmental impacts (EI) between the life cycle before the refurbishment (LC1) and life cycle after the refurbishment (LC2) of the floor
Slika 25: Korak 1 - porazdelitev vplivov na okolje (EI) med življenjskim ciklusom pred prenovo (LC1) in življenjskim ciklom po prenovi (LC2) za medetažno ploščo

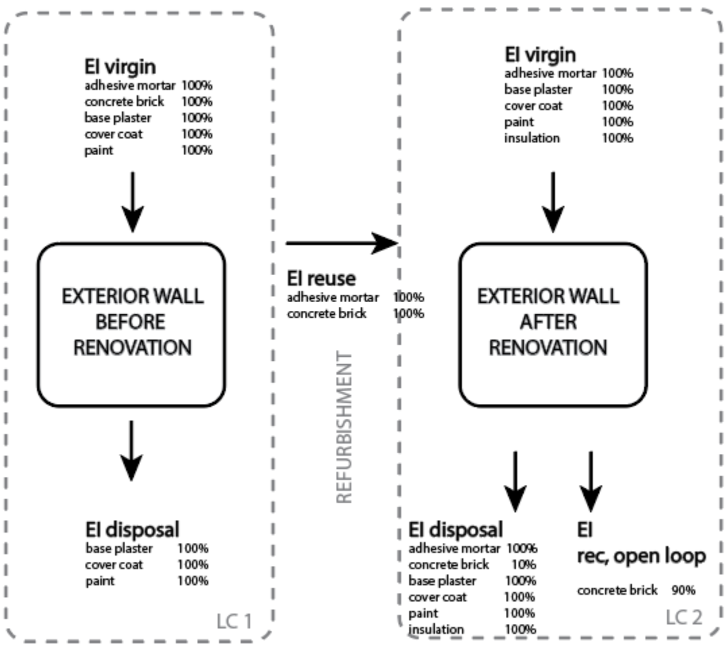

Figure 26: Step 1 – Distribution of the environmental impacts (EI) between the life cycle before the refurbishment (LC1) and life cycle after the refurbishment (LC2) of the wall
Slika 26: Korak 1 - porazdelitev vplivov na okolje (EI) med življenjskim ciklusom pred prenovo (LC1) in življenjskim ciklom po prenovi (LC2) za zunanjo steno

Step 2

The GWPs for the floor were calculated with five different allocation methods (cut-off, cut-off with module D, avoided burden, 50:50 and PEF) for the first life cycle of the building component (LC1) and the life cycle after the refurbishment (LC2). They are illustrated in Figure 27. All the inputs needed for the figure are presented in APPENDIX D. The differences between LC1 and LC2 only emerge for materials that are reused after the refurbishment, i.e. the reinforcing steel and the concrete. In the cut-off approach no credits for reuse were assigned, as in the case of the cut-off with module D. In the avoided burden approach the credits are the same as the negative value of the virgin impact, while in the 50:50 and PEF approaches they are halved when compared to the previous two approaches. In the second life cycle the credits are given because the reinforced steel and the concrete are recycled at the end. In the case of steel, 95 % is recycled for steel production. The recycled concrete is used instead of gravel; in other words it is downcycled. Therefore, the credits gained for the recycling of concrete are also minimal.

For thermal insulation, base plaster and paint, which are completely disposed of at the EoL, no allocation exists so the impacts are the same in LC1 and LC 2, since the same amounts are used in both life cycles. They also receive no credits, because they are disposed of at the EoL. For the cast cement floor and sawn timber, which are recycled at the EoL, the impacts in LC1 and LC2 are the same because everything is handled within the observed life cycle, and hence there is no allocation between the life cycles.

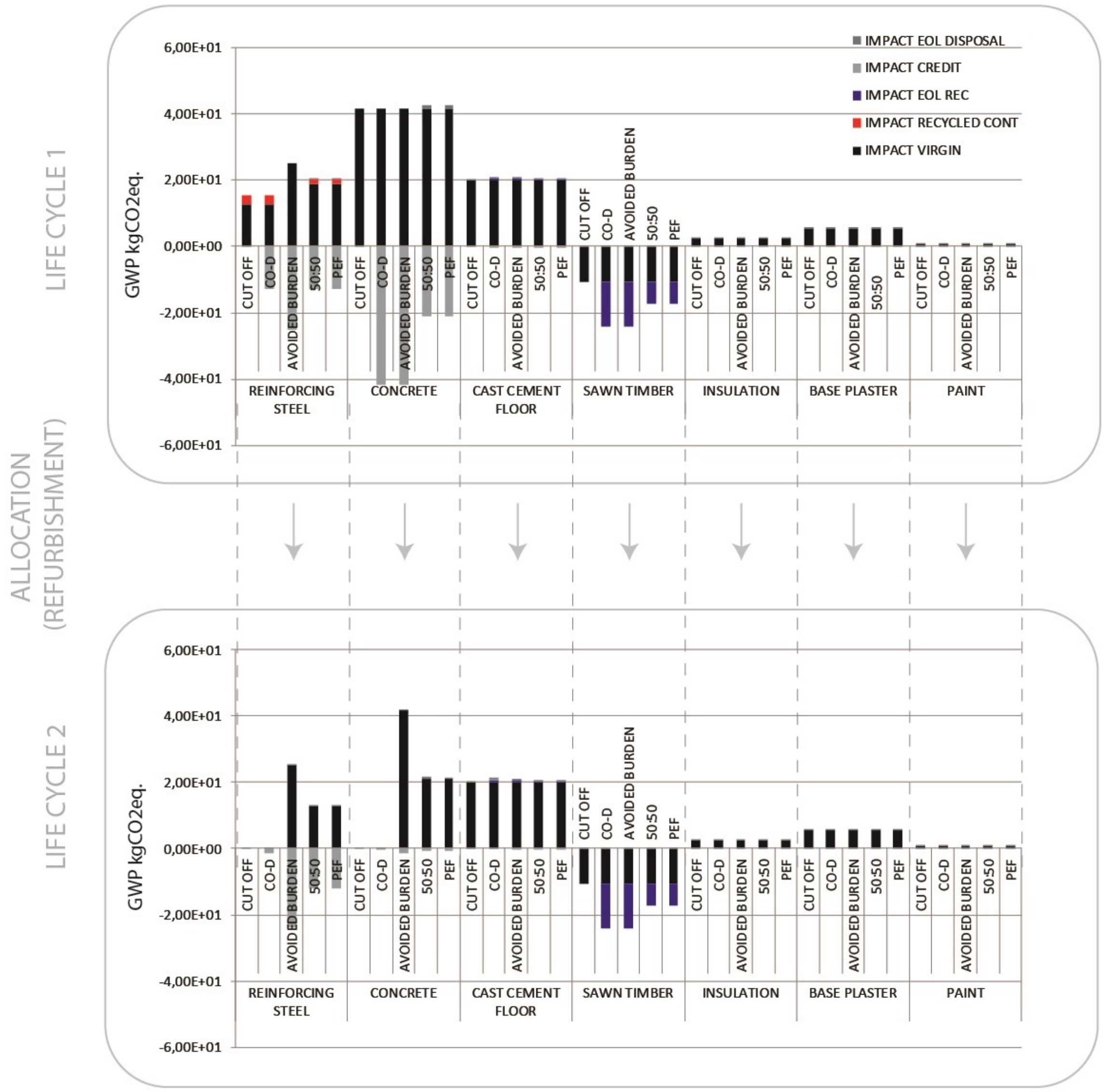

Figure 27: Step 2 – GWP results for different allocation approaches before the refurbishment (LC1) and after the refurbishment (LC2) for the floor
Slika 27: Korak 2 – rezultati GWP za različne postopke alokacije pred obnovo (LC1) in po prenovi (LC2) za talno ploščo

The application of the methodology on the exterior wall provided similar insights (Figure 28). The differences are noticeable for the materials which are reused in LC2 after the refurbishment, i.e. adhesive mortar and concrete bricks. Again, in the first life cycle those two materials get credit for being reused in all the allocation approaches, except for the cut-off approach. On the other hand, the differences are minor for the materials used only in one life cycle. These materials have a similar impact for different allocation approaches in both life cycles. The only difference between the approaches is in how they treat the recycling at the end of each life cycle. This means that the results for different allocation approaches differ from each other, but are the same in the life cycle before and after the refurbishment. It is also important to notice that in LC2 thermal insulation was added. This material addition influences the residual value calculation.

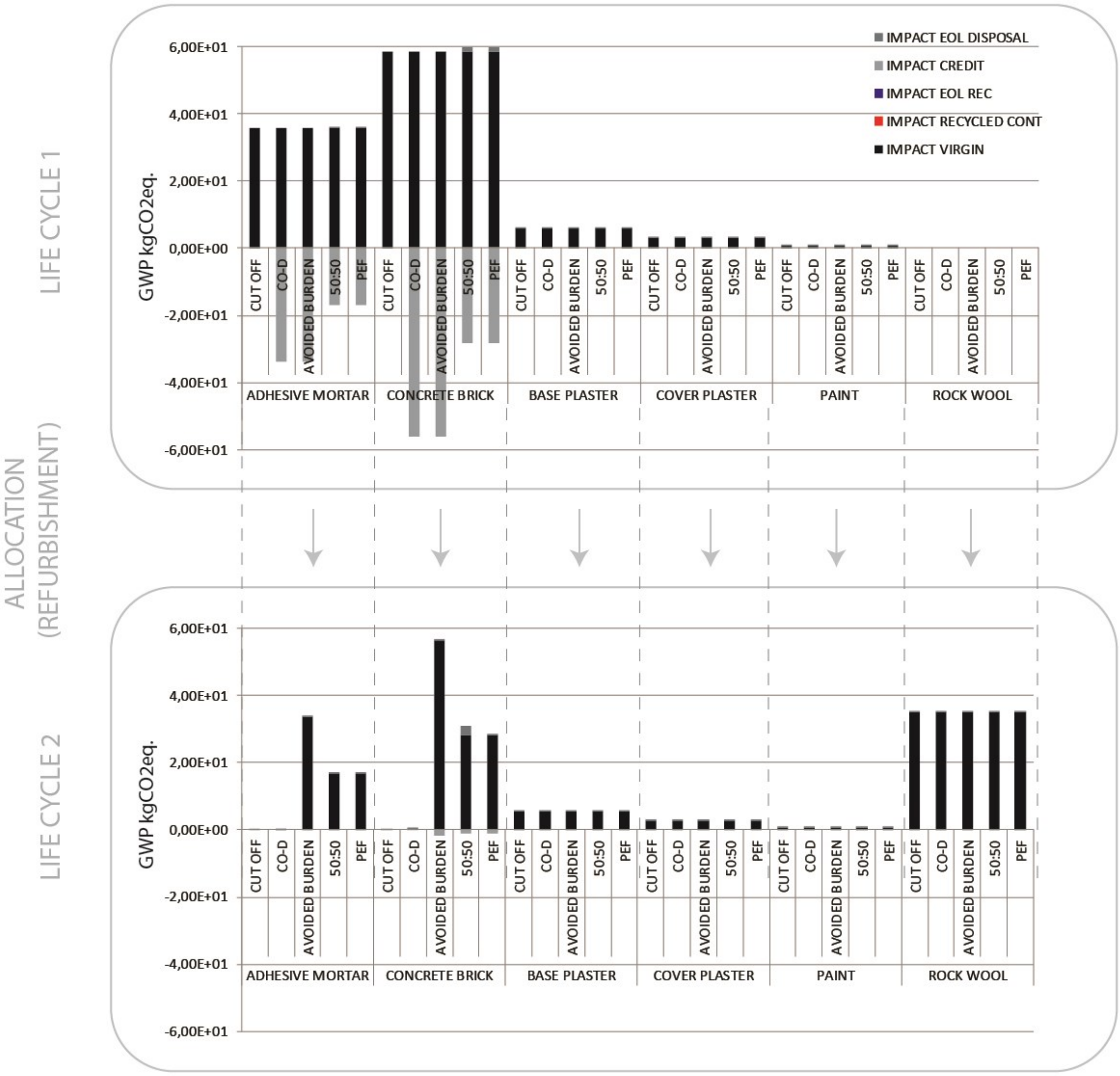

Figure 28: Step 2 – GWP results for different allocation approaches before the refurbishment (LC1) and after the refurbishment (LC2) for the external wall

Slika 28: Korak 2 – rezultati GWP za različne pristope alokacije pred obnovo (LC1) in po prenovi (LC2) za zunanjo steno

Step 3

For each component, maintenance and replacement scenarios were established according to three different RSL databases: SLO, BNB and SIA. In the case of the floor, it is necessary to regularly repaint the ceiling and also replace the floors once during the period of the life cycle, which is 60 years. In the case of the floor replacement, the EoL of the previous floor is included. In the refurbishment phase everything except the concrete and the reinforcing steel was replaced (Figure 29).

The exterior wall has to be regularly repainted on the inside and the cover coat has to be replaced once in the observed period according to the data in the three different databases. When the cover coat was replaced in the first cycle (before the refurbishment), the impact of the disposal of the old cover coat is also included in the environmental impacts of this action. During the refurbishment, thermal insulation is added to the exterior wall. In LC2 the walls were regularly repainted and after a certain period the base plaster on the inside was exchanged. When replacing the base plaster, the impacts of the disposal of the old base plaster were also taken into account. Additionally, the exchange of the thermal insulation requires that the cover coat is replaced. The impacts of the disposal of the old thermal insulation and the cover coats were also considered.

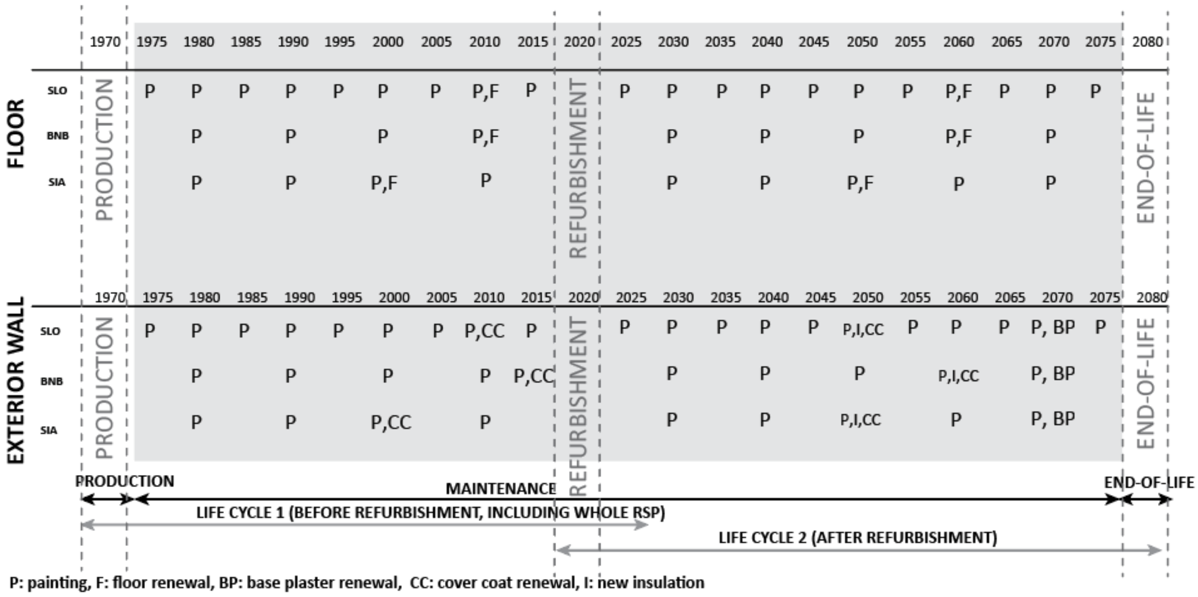

Figure 29: Step 3- The maintenance and replacement timeline for the floor and the exterior wall
Slika 29: Korak 3- Načrt vzdrževanja in zamenjav materialov in komponent za ploščo in zunanjo steno

Step 4

The results of the residual value calculation are illustrated in Figure 30. Generally, the residual value is higher after 30 years than after 50 years. In the cut-off approach, the residual value should be lower in LC2, because some materials were reused during the refurbishment. For example, in the case of the floor, the concrete and the reinforcing steel are reused, while in the case of the exterior wall the bricks are reused. However, in the case of the wall, the thermal insulation is added and consequently the impacts are sometimes higher in LC2. In the case of the cut-off with module D, the residual values are lower for each RSL database, compared to the previous approach. This is because the benefits of module D for recycling or reusing the materials at the EoL are also included in the calculation of the overall impacts. On the other hand, the avoided- burden approach has higher impacts in LC2. As for the wall, the impacts are considerably higher because additional thermal insulation was added. If we compare the results of the 50:50 and the PEF approaches, they are similar for the separate RSL databases. For the floor they are also similar for LC1 and LC2.

Generally, the residual value in LC1 is the lowest in the case of the avoided burden approach, where the impacts are shifted to the life cycle after the refurbishment. This approach clearly rewards the recycling and reuse at the EoL. Also, the cut-off with module D has small residual values in the first LC, because the materials are credited for recycling and reuse at the EoL. In the 50:50 and PEF approaches these credits are distributed between LC1 and LC2. Therefore, the residual values are higher than those obtained with the cut-off with module D. The highest residual values were observed in the case of the cut-off approach.

In LC2 it is important to note that in the case of the exterior wall the residual values are higher because a new material, namely the thermal insulation, was added during the refurbishment. Otherwise, the impacts would be similar for both life cycles in the case of the 50:50 and PEF approaches, smaller in the case of the cut-off and cut-off with module D approaches and higher in the case of the avoided burden approach.

The differences in the results caused by using different RSLs, namely, the SLO, BNB and SIA databases, are difficult to compare. In the case of the floor, the RSLs are similar for the SLO and BNB database, while the use of the SIA RSL values results in smaller residual values. In the case of the wall, the residual values are the highest if we use the SLO database, and the lowest if we use the BNB database. On the other hand, when looking at the residual value after 50 years for the LC2, the residual value is higher if the BNB database is used. This proves that the results can be very different depending on which database we use and therefore it is very important to include data about the RSL and the maintenance of different materials in the study to ensure transparency and reproducibility.

Due to the different environmental impacts for production, reuse, recycling and disposal of each material, it is impossible to make direct comparisons between allocation approaches. Therefore, only general conclusions about the choice of the allocation approaches and RSL databases can be made.

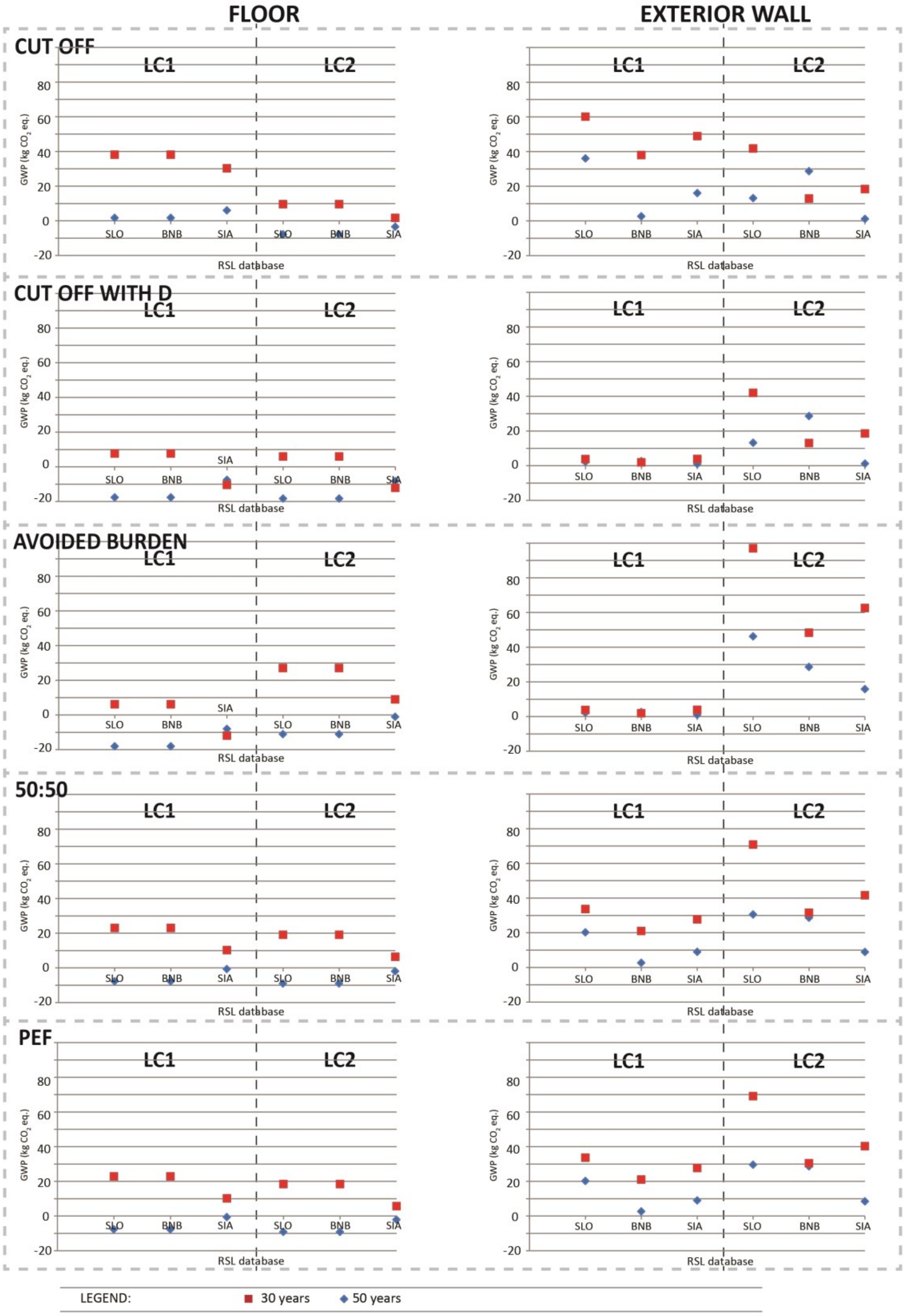

Figure 30: Step 4 - Residual value of the floor and the exterior wall calculated with different allocation approaches after 30 and 50 years of the observed RSP for the life cycles before (LC1) and after the refurbishment (LC 2)

Slika 30: Korak 4 - Preostala vrednost za talno ploščo in zunanjo steno, izračunana z različnimi postopki alokacije po 30 in 50 letih opazovanega RSP za življenjski cikel pred (LC1) in po prenovi (LC2)

4.2.4 Discussion

Today's approach to calculating the environmental impacts of refurbishments focuses only on the life cycle after the refurbishment. Consequently, an allocation of the impacts is not possible and there is a gap in the information for the materials that remain in the building after the refurbishment. On the other hand, neglecting the life cycle before the refurbishment could lead to incorrect conclusions. The proposed methodology helps to allocate the environmental impacts according to the scope, and it reduces the information uncertainties related to the life cycle before the refurbishment.

The allocation of environmental impacts before and after the refurbishment is seldom discussed in the literature (Allacker et al., 2017, 2014). On the other hand, the discussions about the allocation approaches are far more often at the level of products (Frischknecht, 2010). This is most likely due to the products' shorter service lives, which makes the need for allocation more understandable than at the building level, where the service periods are relatively long. The newly developed calculation methodology for environmental impacts and residual value before and after a building's refurbishment enables a more comprehensive determination of the results, since no previous environmental exchanges are ignored. In an LCA of building refurbishment, the previous life cycle is usually ignored, and consequently, as previously discussed, the benefits of refurbishment could be overestimated. The EI can be distributed between primary and secondary product systems in various ways and double counting should be avoided (Allacker et al., 2014; Eberhardt et al., 2020; Frischknecht, 2010; Schrijvers et al., 2016; Weidema, 2000). Different allocation methods have been developed and each of them has its own theoretical background as well as strengths and weaknesses. Some of the approaches promote the use of recycled materials (e.g. cut-off), some promote recycling at the EoL (e.g. avoided burden approach) or try to distribute the impacts across both life cycles (e.g. 50:50 and PEF) (Allacker et al., 2017; Gervasio and Dimova, 2018). The cut-off approach is most commonly used, since it is easy to apply and reduces the uncertainties connected to future recycling and reuse scenarios. On the other hand, it does not promote the use of materials with recycling potential within the system. Its credits can be reported independently in module D, which summarizes the benefits and the burdens of recycling, reuse and incineration. This module was optional in the previous version of the EN 15804:2012+ A1:2013, but has become mandatory in the latest version EN 15804:2012 + A2:2019 2019. With the amendment of EN 15804, it has become more comparable with the PEF approach and should promote the circular use of materials, which is also in line with the UN's sustainable development goals (United Nations, 2019). Since the idea of a circular economy is not promoted by all the allocation approaches equally, it is assumed that the PEF method and the cut-off method with module D, which include the aspects of circularity, will prevail over the other methods.

The allocation approaches should be aligned with the goal and scope of the study. In this sense, an attempt to summarize the positive and negatives aspects of the allocation approaches was made (Table 9). Their individual contributions to a circular economy were also indicated.

Table 9: Positive and negative aspects of the individual allocation approaches and their ability to contribute to the circular economy
Preglednica 9: Pozitivni in negativni vidiki posameznih postopkov alokacije in njihova sposobnost prispevanja k krožnemu gospodarstvu

Allocation approach	Positive	Negative	Circular economy
Cut-off	• Rewards the use of recycled materials • Easy application • Reduces uncertainty associated with future recycling	• Neglects all benefits of creating recycled materials at the EoL	no
Cut-off with module D	• Rewards the use of recycled materials • Rewards the creating recyclable materials in module D	• The quality of the secondary materials is not taken into account	yes
Avoided burden	• Rewards the creating recyclable materials	• Neglects the benefits of using recycled materials	no
50:50	• Rewards the use of recycled materials and creating of recyclable materials		yes
PEF	• Rewards the use of recycled materials and creating of recyclable materialsIntroduces factors for the quality differences between primary and secondary materials	• The quality factors are not available	yes

For a proper impact allocation between the life cycles, it is crucial to define the scope and the boundaries of the life cycles before and after the refurbishment. In this study, the scope and the relations between the life cycles before and after a refurbishment were determined (e.g. Figure 25 and Figure 26) (Oregi et al., 2017a). In these figures it is indicated which inputs and outputs are related to which life cycle and which of the materials are reused or recycled at their EoL. Therefore, basically, a clear definition of the scope should prevent errors by allocating the impacts and the possibility of double counting.

It was also found out that the calculation of some of the allocation methods requires specific input information, such as the difference in the quality of the virgin and the recycled material or the impact of virgin materials that will be replaced by the recycled materials, etc. This information is generally difficult to find in the literature and therefore presents a great challenge when the allocation of the impacts is modelled (Eberhardt et al., 2020). Often the information is available only for closed-loop recycling (the material is recycled into the same material with the same quality, e.g. steel), but generally the information is lacking for open-loop recycling (the recycled materials are used for other purposes, e.g. crushed concrete is replacing gravel). Also, the question arises whether the recycling always happens within the same materials pool or if in the recycling process virgin materials are also used, which consequently widens the material pool and causes material depletion. To calculate the environmental impacts, these data should be provided. This data gap is a potential area for future research.

During the study, impacts related to the EoL (module C) and phases beyond the life cycle of the building according to EN15978 (EN 15978, 2021) (module D – -reuse, recovery, recycling, energy export) were assessed. Reporting these impacts became mandatory for EPDs in 2019 according to EN 150804:2012+A2:2019, which also proves the increasing importance of the circular economy in the construction sector. Gathering the information about the EoL processes and the reuse, recycling and recovering processes is very challenging and introduces great uncertainties into the LCA (Ng and Chau, 2015). It was observed that several authors have the same experience (Spirinckx et al., 2018). The EPDs are ordered by manufacturers, which have information and control relating to the production process, but generally they do not have any control over what happens to their product during the construction, use and the EoL stages. Therefore, generic data for the disposal and the recovery process are often used (Lasvaux et al., 2015b). Recently, a guidance document with basic principles and recommendations for describing the dismantling, post-use, and disposal stages of construction products were developed (Agency, 2020). It proposes the establishment of documents where the manufactures of the construction products and the disposal practitioners (recyclers, waste management companies, etc.) exchange information, determine the recycling and recovery prerequisites or conditions, etc. These documents should provide realistic and comparable life cycle assessment data for modules C and D for buildings and so close the current information gap in this area.

Since the choice of the different RSL databases can have a major influence on the results when observing the entire life cycle of a building, it is very important that each study indicates which RSLs were used for the calculation or refer to the selected RSL database (Potrč Obrecht et al., 2019). It was noticed that the RSL for the same materials can be very different in selected RSL databases, even though the geographical circumstances are similar. Further research has to be devoted to this field to test the uncertainties and differences that result from these parameters (Goulouti et al., 2020; Hoxha et al., 2017).

4.2.5 Summary

Today, the environmental impacts of a building's refurbishment are not addressed as the phase B5 of the whole life cycle, but are calculated as the new life cycle of a building. This is in line with the current standard if no assessment has been carried out prior to the refurbishment or if the functional equivalent changes during the refurbishment. Since the majority of buildings have not yet been assessed, this actually applies for almost all cases. Consequently, the impacts have to be correctly distributed among the life cycles before and after the refurbishment. Therefore, a new methodology has been developed to assess the environmental impacts and the residual value of buildings, which also includes the allocation of the impacts between the life cycles before and after the refurbishment, as well as the maintenance scenarios according to the RSL. This approach has not been applied before and enables a more correct distribution of the environmental impacts between the life cycles.

The allocation approach and the RSL are the variable parameters of the methodology. The sensitivity analysis of the allocation approaches showed that differences between the assessed environmental impacts and residual values emerge if materials with recycled content are used or if the materials are being recycled or reused at the end of their life cycle. For materials with no recycled content and for those disposed of at the end of the observed life cycle, there is no significant difference caused by the selection of the allocation approach. The results indicated that greater differences between the allocation approaches were visible in the second life cycle after the refurbishment, where larger shares of reused and recycled components were present. The sensitivity study also confirmed that the choice of the RSL database has a significant influence on the maintenance scenarios (replacement rates) and leads to different residual values of the materials and components, and consequently also of buildings. For this reason, it is crucial to indicate which RSL database is used in the estimation procedure.

Due to the ambitious targets set by European governments to reduce the built environment's contribution to climate change, the refurbishment of buildings and also the recycling and reuse of materials are strongly encouraged and will become everyday practice. Hence, the application of the developed methodology will become progressively necessary. In this sense, it is believed that the developed approach will not only improve environmental impact assessments and contribute to the circular economy of the construction sector, but it will bring scientific consistency to the future estimation of refurbishment measures. It is expected that this research will encourage professionals to avoid the negligence of previous environmental flows, relying on the very nature of LCA: a strong methodological framework able to consider broad scopes and connections between different product systems.

4.3 An advanced methodology for the assessment of embodied environmental impacts of building refurbishment (including the methodology for modelling time-corresponding input data and allocation between the life cycle before and after the refurbishment)

4.3.1 Introduction

The sub-methodologies that were introduced in the previous two chapters highlight that the use of time-accurate datasets and the allocation of the impacts between the life cycle before and after the refurbishment can have a big influence on the final results.

The environmental emissions of the production processes are not static but change over time. For example, the electricity mix is changing on an hourly basis so some of the research studies propose using the hourly electricity mix for the assessment of the environmental emissions (Barros et al., 2020; Kono et al., 2017). The energy or electricity mix can have a strong influence on the results (Potrč Obrecht et al., 2021; Roux et al., 2016). Therefore, it should be encouraged that the datasets of the materials used should also be modelled with energy or electricity mixes that correspond with the time of production. In the chapter 4.1, it was found out that the relative share of the electricity mix GHG emission towards the total value was as high as 20 % for separate building components. Therefore, a methodology for the time-corresponding remodelling of datasets was developed. The main assumptions are that the production process remains the same and that the electricity used for the production changes over time. Therefore, the methodology is not applicable for new innovative products or for products where there was a major change in the production process. The main conclusion was that if this electricity mix is replaced with an electricity mix having greater environmental emissions, the relative contribution of the electricity mix to the total emissions can be even higher. When, by contrast, the modified electricity mix is almost decarbonized, the relative contribution to the total emissions may well be reduced to a point where it becomes negligible. The modification of the electricity mix can also influence the residual value of a building. In the observed case, the differences due to different electricity mixes were in the range of 10 %.

On the other hand, the methodology for the assessment of the embodied EI and the residual value of the materials before and after the refurbishment measures revealed that the choice of the allocation approach is mostly neglected even though it can have a big influence on the results. The differences between the different allocation approaches emerge if materials with recycled content are used or if the materials are being recycled or reused at the end of their life cycle. If only virgin materials are used, differences between the allocation approaches do not appear. In order to assess the environmental impacts as precisely as possible, the two proposed methodologies can be combined.

The aim of this part is to show how the combination of the two methodologies is applied in practice and how this influences the results.

4.3.2 Methodology description

The methodology is a combination of the methodologies that were presented in the previous chapters and is presented in Figure 31.

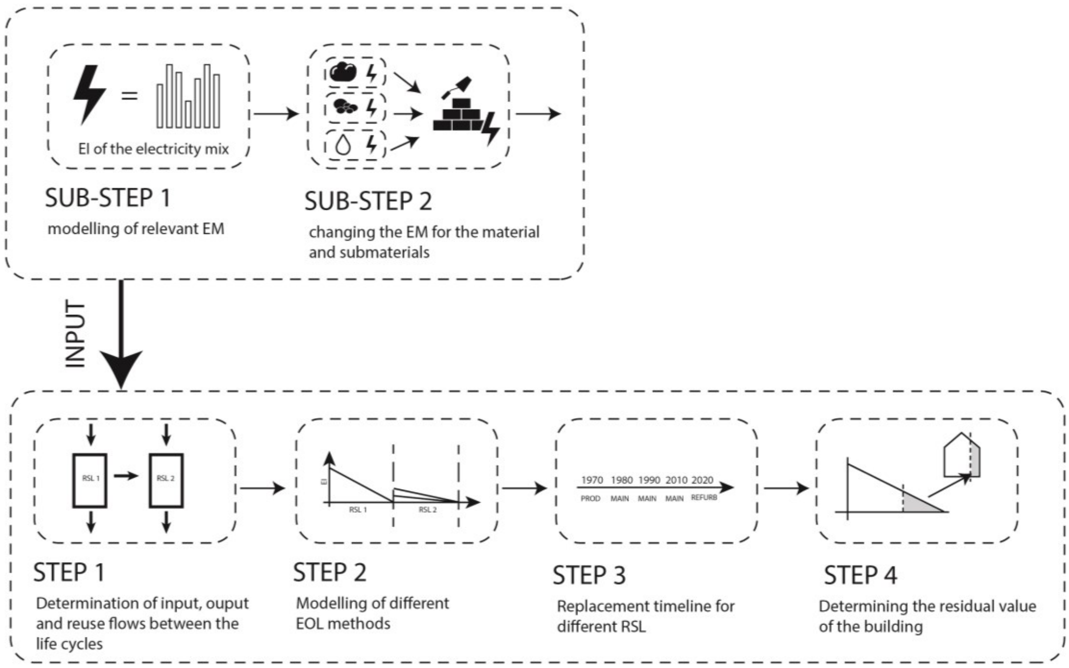

Figure 31: Combination of the methodology for the time-accurate determination of materials manufactured in the past and the methodology for the allocation between the life cycle before and after the refurbishment into a single methodology
Slika 31: Kombinacija dveh metodologij, metodologije za časovno natančno določanje materialov, izdelanih v preteklosti, in metodologije za alokacijo okoljskih vplivov med življenjskim ciklom pred in po prenovi, v enotno metodologijo

The input data is remodelled in two sub-steps. In sub-step 1 the electricity mixes have to be remodelled for the selected time period. In the second sub-step, the LCI of the datasets have to be remodelled using the electricity mixes obtained in the previous phase. At this point, cut-off criteria were applied to avoid the remodelling of sub-materials that do not make a significant contribution to the end results. A detailed explanation of these sub-steps can be found in chapter 4.1.2

In the first step, the input, output and reuse flows between the life cycles before and after the refurbishment are determined. In the second step, the environmental impacts are assessed using the chosen allocation approach (i.e. the cut-off, cut-off with module D, avoided burden, 50:50 and the product environmental footprint (PEF)). In the third step, a maintenance scenario is implemented according to the selected reference service life (RSL) database. The environmental impacts of the maintenance scenarios are also calculated with time-corresponding data (calculated with the procedure described in the sub-steps). In the fourth step, the residual value is estimated. A detailed explanation of these steps can be found in chapter 4.2.2.

This approach is presented on 1 m^2 of exterior wall of the same case study of a multi-residential building that was used in the chapters 4.1 and 4.2. The results of the electricity remodelling can be found in subchapter 4.1.2. A comparison between the materials with the current materials and the materials with the exchange electricity mix is presented.

In the second part, the difference in the results after the allocation of the impacts is presented. Steps 1–3 are the same as in chapter 4.2.2. Only the SLO RSL database is used (Rules on standards for the maintenance of apartment buildings and apartments, 2004). The results of the last step are presented in this part.

4.3.3 Validation of the methodology on a case study

The environmental impacts of the first life cycle can be calculated with the static data or semi-dynamic (time-corresponding) data. Table 10 indicates how the environmental emissions would change if the environmental emission of the material were calculated with time-corresponding data (semi-dynamically). The detailed EI for the exterior wall modelled with the 1970 electricity mix is presented in APPENDIX E.

In this case, the environmental emissions of the current electricity mix were exchanged with the EI of the electricity mixes for the 1970, the year in which the case study building was built. The 1970 electricity mix has higher emissions and consequently, the materials produced with this mix also have higher emissions.

Table 10 shows that the individual materials have from 3.2 to 14.1 % higher GWP impacts if they are calculated with the 1970 electricity mix instead of the current electricity mix. Furthermore, 1 m^2 of the exterior wall has 5.1% higher emission than if it were calculated with the current electricity mix.

Table 10: The difference between the GWP impact of the materials for 1 m^2 of exterior wall calculated for different years

Preglednica 10: Razlika med izračunanimi GWP vplivi za posamezne materiale 1 m^2 zunanje stene za različna leta

	CONCRETE BLOCK		ADHESIVE MORTAR		BASE PLASTER		COVER COAT		PAINT		**EXTEROR WALL**	
year	1970	2020	1970	2020	1970	2020	1970	2020	1970	2020	**1970**	**2020**
GWP (kg CO_2 eqiv.)	58.5	56.3	35.9	33.8	6.0	5.6	3.1	2.7	0.7	0.7	**104.2**	**99.1**
Relative (%)	103.9	100.0	106.3	100.0%	106.0	100.0	114.1	100.0	103.2	100.0	**105.1**	**100.0**

Table 11and Figure 32 show how the residual value changes if time-corresponding data is used. In the life cycle before the refurbishment the EI are generally higher if time-corresponding data is used for the assessment. The differences between the different allocation methods are small since mostly virgin materials were used at the beginning. The only difference emerges in the case of the 50:50 and PEF allocation methods because of the benefits of reusing the mortar and bricks. After 30 years, the residual value is about 4 % higher, while after 50 years the residual value is 2.7 % higher.

After the refurbishment the residual values calculated with time-corresponding data are smaller since the replaced materials have lower EI because they are produced with environmentally friendlier electricity mixes. In the second life cycle the differences between the different allocation approaches are bigger since the EI of the reused materials (mortar and brick) are allocated in a different way. After 30 years, the residual value is 10 % lower for the cut-off and cut-off with module D approaches, 4% lower for the avoided burden approach and 6 % lower for the 50:50 and PEF approaches.

Table 11: The difference between the use of static and time-corresponding data for the assessment of the residual GWP EI after 30 and 50 years for the life cycle before (LC1) and after refurbishment (LC2)
Preglednica 11: Razlika med uporabo trenutnih in časovno ustreznih podatkov pri oceni preostale GWP vrednosti po 30 in 50 letih za življenjski cikel pred (LC1) in po prenovi (LC2)

			EXTERIOR WALL			
			LC1		LC2	
			30 years	50 years	30 years	50 years
GWP (kg CO2 eq)	CUT-OFF	static	60.1	36.0	41.7	13.1
		time-corresponding	62.5	37.0	37.6	9.6
	CO-D	static	60.1	36.0	41.7	13.1
		time-corresponding	62.5	37.0	37.6	9.6
	AVOIDED	static	60.1	36.0	98.1	46.8
		time-corresponding	62.5	37.0	93.9	43.4
	50:50	static	61.8	37.0	71.3	30.8
		time-corresponding	64.2	38.0	67.2	27.4
	PEF	static	61.8	37.0	69.6	29.8
		time-corresponding	64.2	38.0	65.5	26.3

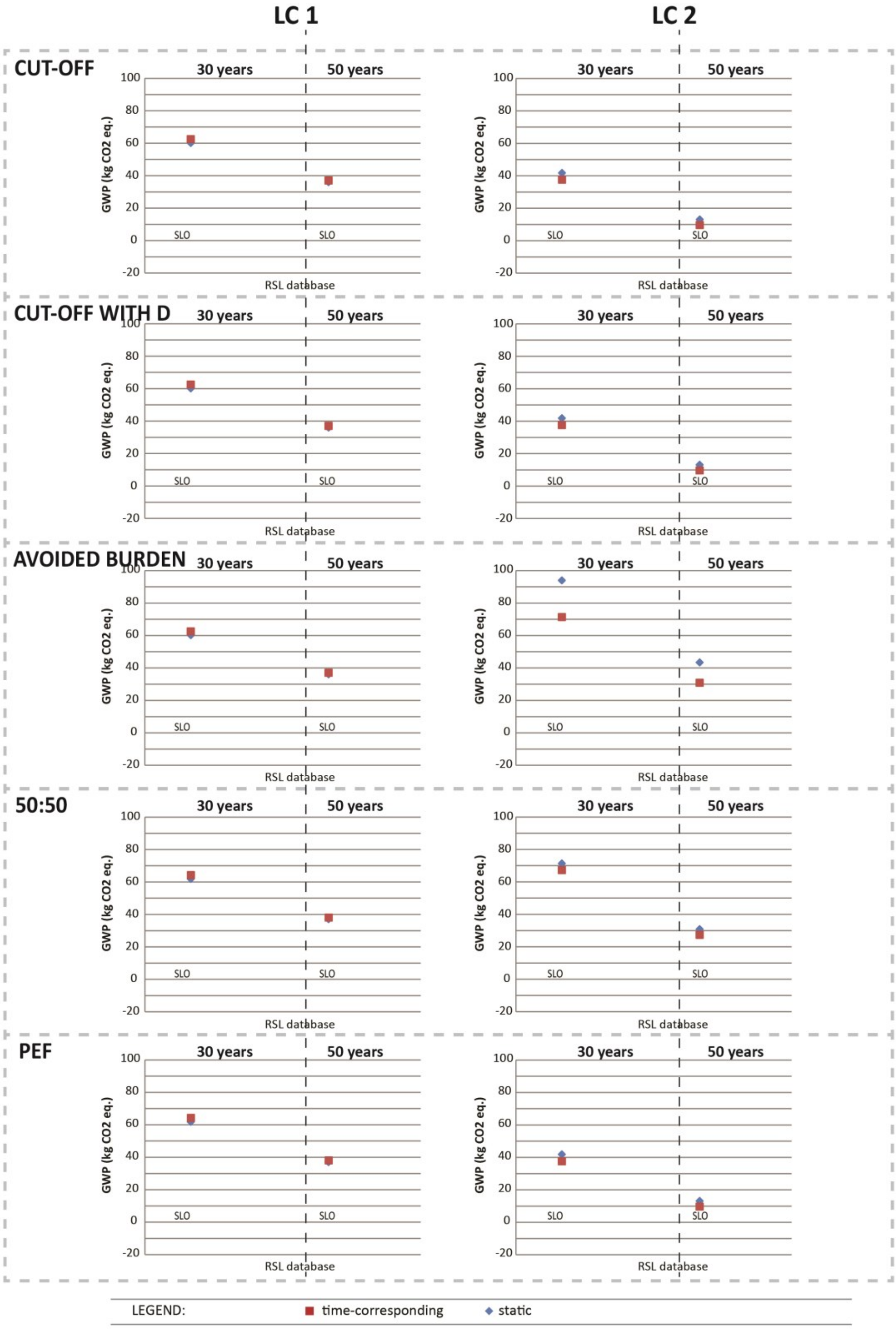

Figure 32: The difference between the use of static and time-corresponding data for the assessment of the residual GWP EI after 30 and 50 years for the life cycle before (LC1) and after refurbishment (LC2)
Slika 32: Razlika med uporabo trenutnih in časovno ustreznih podatkov pri oceni preostale GWP vrednosti po 30 in 50 letih za življenjski cikel pred (LC1) in po prenovi (LC2)

4.3.4 Discussion

The assessment of the EI with time-corresponding data can lead to great differences in results. In the presented sub-methodology, the focus was on the use of time-corresponding electricity mixes. In the study of Obrecht et al. (Potrč Obrecht et al., 2021) it was found out that the contribution of the electricity mix to the overall EI of materials can be as high as 20 %. Thus, the change of the electricity mix over time can have a great impact on the total EI of materials and therefore it is advised that precise and time-corresponding electricity mixes are used in the calculations. It is assumed that the differences in results would be even higher if the electricity mix were modelled on an hourly, monthly or seasonal basis. However, the remodelling of the input data is a demanding process which requires a lot of input information and work.

The division of the impacts of the life cycle before and after the refurbishment has also proven to be a challenging task. It is seldom discussed for buildings since the service life of buildings is very long. Each of the allocation approaches has its strengths and weaknesses (see Table 9) and therefore the choice of the right allocation approach depends on the scope of the study. However, since only the PEF and the cut-off with module D approaches promote the idea of circular economy, it is likely that they will prevail in the future.

The use of time-corresponding data leads to differences in results on such a scale that it should not be neglected. The use of time-corresponding input data in the methodology for the assessment of the EI and residual value before and after the refurbishment has proven to be a very demanding and time-consuming task. A lot of work and information is required. The development of a tool that would reduce this work would be welcome. The presented methodology can act as a framework for this tool.

The input data for the life cycle before the refurbishment can be made based on realistic data, while the EI for the life cycle after the refurbishment is mostly based on scenarios and predictions. This increases the uncertainty of the results for the life cycle after the refurbishment. However, since the European countries are obliged to plan and report the development of electricity mixes, it is assumed that this reduces the uncertainty at least on the conceptual level.

4.3.5 Summary

The use of time-corresponding input data for the assessment of EI and the residual value for the life cycle before and after the refurbishment would increase the representativeness of the results. Therefore, the methodology for modelling time-corresponding input data and the methodology for assessment of EI and the residual value including allocation between the life cycle before and after the refurbishment were combined. In the presented case of the exterior wall the differences were in the range from 4 to 11 %. For the life cycle before the refurbishment, the EI and the residual value are generally higher if time-corresponding data is used, because the EI of the electricity mix are higher, while for the life cycle after the refurbishment they are generally lower. The differences in the results are on a scale that should not be neglected. However, since this entails a lot of input information and work, it would be welcome if a tool were made available. The presented work can be used as a framework for the development of such tool.

4.4 Chapter summary

An advanced methodology for the assessment of the embodied impacts of refurbishment was developed as a combination of methodologies that can also be used separately. The first methodology is used for remodelling the input data in order to make them time-corresponding. The second methodology is used for the assessment of the EI in the residual value and includes allocation between the life cycle before and after the refurbishment. This chapter of the dissertation focuses only on the embodied EI, while the operational EI are included in the next chapter.

5 A METHODOLOGY FOR THE COMPARISON OF REFURBISHMENT MEASURES (INCLUDING OPERATIONAL EI)

5.1 Introduction

In this chapter the development of the comparative methodology for the assessment of the EI of refurbishment measures is presented. This methodology includes the assessment of embodied and operational EI. In the present case it is applied on the case study of building envelope refurbishment. During the SLR it was found out that there is insufficient data about the efficiency of building envelope refurbishment measures for the Central European region, especially if the dynamic thermal calculation tools are used to calculate the operational energy use.

Improvement of the building envelope has been identified as one of the most effective measures in terms of environmental emission reduction (Amini Toosi et al., 2020; Pomponi et al., 2015; Thibodeau et al., 2019; Vilches et al., 2017). Almost every study dealing with the environmental assessment of refurbishment includes improvement of the envelope's thermal properties (Assiego de Larriva et al., 2014; Bari et al., 2020; Ghose et al., 2019, 2017b; Medgyasszay and Szalay, 2014; Oregi et al., 2017b, 2015b; Palacios-Munoz et al., 2019; Valančius et al., 2018; Van Gulck et al., 2020; Wang et al., 2015). The building envelope has the role of a physical barrier between the indoor and outdoor environment (Pomponi et al., 2015; Vilches et al., 2017). One of the most often applied solutions for the improvement of envelopes is the addition of thermal insulation, often as External Thermal Insulation Composite Systems (ETICS). These have been widely used in building since 1990s. They consist of different layers: adhesive, insulation, render with mesh reinforcement, primer and finish coat (Potrč et al., 2016). Different combinations of materials can be used in the system but it is necessary to ensure their compatibility. Several research studies have compared different insulation materials and assessed their environmental performance (Dylewski and Adamczyk, 2014; Potrč et al., 2016). Innovative insulation solutions were also studied (Rosa et al., 2014; Silvestre et al., 2019). The type of the insulation also influences the mass and material of other ETICS components. For example, rigid insulation types require less render that soft insulations, etc. Consequently, the environmental impacts of the whole system also change.

Rodrigues et al. investigated the impact of different insulation thickness on the environment (Rodrigues and Freire, 2017) and concluded that with certain thicknesses the embodied impacts of the materials are greater than the reduction of environmental impacts during the use phase. Thus, the environmental as well as economic effectiveness of the refurbishment measures should be assessed throughout the whole life cycle (for example with LCA) of the building since the additional impacts of the refurbishment measures are compensated during the operational phase. The focus of this study is the environmental payback time. It is defined as the total environmental impact of refurbishment measurement divided by the net annual reduction in environmental impact per year in the operation phase and it is expressed in years (Ardente et al., 2011; Ghose et al., 2017a; Mateus et al., 2019; Oregi et al., 2020; Rodrigues and Freire, 2017). The environmental payback time for different environmental categories is often assessed. According to Oregi et al., the payback times are most often assessed for the primary energy and GWP indicators.

The payback time is dependent on many factors. One of the most influential is the reduction of the operational energy demand. The operational energy use of buildings depends on the physical environmental parameters, such as exterior temperatures, solar radiation benefits, wind direction and speed, which are specific for each location and should, therefore, be calculated with tools that enable thermal dynamic energy simulations with precise outdoor data and which also consider the accumulation of heat in materials. User-dependent factors, such as internal gains or usage shedules are also important for a correctly determinating the internal gains, but were not the focus of this study. A precise determination of the operational energy use is a precondition for the correct assessment of the environmental emissions of the operational phase of the building. This information has to be coupled with additional information about the energy carrier used for heating and cooling in order to assess the reduction of environmental emissions.

The objective of this chapter is the development and clear explanation of a methodology for the comparison of the refurbishment measures that have an effect of the operational energy use. This methodology will be illustrated on the case of building envelope refurbishment measures for the climate of Central Europe. The payback times of environmental impacts will be assessed for different thickness and positions of the thermal insulation materials (namely expanded polystyrene, mineral wool, cellulose, aerogel and phenolic foam). Additionally, it will be tested what difference is made by applying the insulation on the inside of the wall for the relevant insulation materials. Since electricity is often the energy carrier used for heating and cooling today, it is also likely that the improvement of the electricity mix will reduce the payback times, which is often an important indicator of the effectiveness of refurbishment measures. Therefore, additional sensitivity analyses were performed in order to assess the influence of the electricity mix improvement on the payback time. Based on these findings, recommendations for future refurbishment measures of the building envelope can be made. Additional parameters, that are likely to change over time (climate change, the change of technology, etc.), were not in the scope of the study.

5.2 Methodology description

For comparison of the EI of refurbishment measures that affect the operational energy use, several steps are needed (Figure 33). In the first step (step 1) the environmental emissions associated with the refurbishment measures are assessed. In the second step (step 2) the reduction of operational energy use due to the refurbishment measures is calculated with a dynamic simulation tool. Based on the energy reduction, the potential reduction of the environmental impacts is assessed. The information was used to calculate the payback period for the refurbishment measures (step 3). A detailed description of individual steps is presented on the case study of a typical multi-residential house .

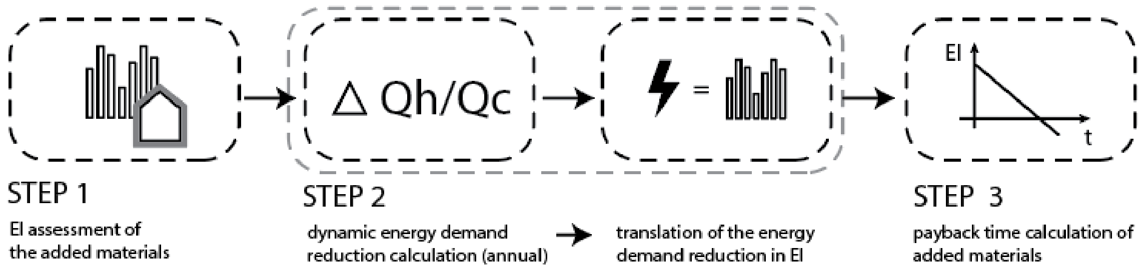

Figure 33: Steps for the environmental payback calculation of the added materials during the refurbishment
Slika 33: Koraki za izračun povračilnega časa okoljskih vplivov materialov, dodanih med prenovo

Again, the case study for the methodology validation is a multi-residential building in Slovenia that represents a typical reference building from the period 1971–1980, according to the TABULA project (Ballarini et al., 2014; Mastrucci et al., 2017). Buildings from this period (between 1950 and 1980) have high operational energy use and represent a major part of the building stock, thus their refurbishment could substantially contribute to climate change mitigation goals (Passer et al., 2016; Xing et al., 2011). The focus of the study will be the payback time of the envelope refurbishment measures, although it is necessary to mention that often, more than one refurbishment measure is required to meet the climate mitigation objectives (Steininger et al., 2021). A detailed presentation of the building is in the APPENDIX B.

In **step 1** the environmental impacts of the added materials for the building envelope refurbishment measures are assessed with the LCA method. The scope includes the production phases (including raw material extraction (A1), transport (A2) and manufacturing (A3)) according to EN 15978 (EN 15978, 2021). The methodology for the assessment is CML 2001 – Jan 2016 and the impact categories assessed are the global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), abiotic depletion of non-renewable material (ADPf) and of fossil fuels (ADPf), ozone depletion potential (ODP) and photochemical ozone creation potential (POCP). The functional unit is the production of 1 m^2 of the added insulation system. The impacts of the added materials were modelled in Gabi using the database Ecoinvent 3.6 and EPDs.

The life cycle inventories (LCI) of five different insulation materials, namely expanded polystyrene (EPS), mineral (stone) wool (MW), cellulose (CL), aerogel (AG) and phenolic foam (PF) (interior and exterior application) added for achieving for two different thermal transmittances of the wall (U-values) (0.17 and 0.10 W/m^{2}K) are presented in Table 12. The first U-value is 0.17 W/m^{2}K, which is below the Slovenian targeted value of 0.28 W/m^{2}K and the second U-value is 0.10 W/m^{2}K, which already applies to the requirements of nearly-zero energy building .

Table 12: LCI of the added thermal insulation system for the wall with U-value 0.17 and 0.10 W/m^{2}K
Preglednica 12: LCI dodanega toplotnoizolacijskega sistema za steno z U-vrednostjo 0,17 in 0,10 W/m^{2}K

MATERIALS ADDED FOR U-VALUE 0.17 W/m^{2}K

	Insulation (kg)	Wood fibre board (kg)	Wood (kg)	Adhesive (kg)	Anchors (nr)	Acrylic dispersion (kg)	Glass fibre (kg)	Cover plaster (kg)	Base plaster (kg)	Paint (kg)
EPS	4.20			9.00		0.25	0.15	2.90		
MW	17.00			13.00	6.00	0.25	0.15	2.90		
CL	17.43	7.60	16.80	4.50		0.25	0.15	2.90		
PF	3.75			9.00		0.25	0.15	2.90		
PF int	3.75			5.50					24.00	0.17
AG	11.55			12.50	6.00	0.25	0.15	2.90		
AG int	11.55			4.50	6.00				24.00	0.17

MATERIALS ADDED FOR U-VALUE 0.10 W/m^{2}K

	Insulation (kg)	Wood fibre board (kg)	Wood (kg)	Adhesive (kg)	Anchors (nr)	Acrylic dispersion (kg)	Alass fibre (kg)	Cover plaster (kg)	Base plaster (kg)	Paint (kg)
EPS	7.50			9.00		0.25	0.15	2.90		
MW	30.00			13.00	6.00	0.25	0.15	2.90		
CL	31.00	7.60	16.80	4.50		0.25	0.15	2.90		
PF	6.72			9.00		0.25	0.15	2.90		
PF int	6.72			5.50					24.00	0.17
AG	20.55			12.50	6.00	0.25	0.15	2.90		
AG int	20.55			4.50	6.00				24.00	0.17

The insulation materials were applied on the outer side of the exterior wall. For AG and PF, the difference made if the materials are applied on the inner side of the wall was tested. In these two cases, application on the inner side of the wall seems realistic since the thickness of the additional building envelope is relatively small and it does not claim much of the interior space. The downside of this application is that the heat capacity of the concrete block construction is not utilized. Although this application of the insulation on the inside is not encouraged, it is sometimes necessary due to the preservation of historic building envelopes and similar reasons. All the additional materials for the application of the insulation materilas (sub-constrcutions, new coatings, different coating thicknesses for individual metrials, etc. were also considered in the study.

In **step 2** the change of the heating and cooling demand due to the added materials was calculated with the dynamic thermal simulation tool TRNSYS (TRNSYS, 2022). This program is based on the calculation of a system of first-order differential equations, which describes the heat fluxes of individual elements in the hierarchical structure of the entire building. Depending on its mathematical-physical basis, the software package also enables dynamic simulations of individual systems in a non-stationary environment. The reduction of the energy demand for cooling and heating is calculated as the difference between the cooling and heating demand before the refurbishment measures and after the refurbishment measures. The focus is not on the precise determination of the absolute cooling and heating demand of the building but on the differences in these values that emerge because of the refurbishment. Thus, the model for the calculation can be simplified since only the parameters that are affected by the refurbishment have to be considered.

One floor is modelled and it is assumed that the relation to neighbouring upper and lower floor is adiabatic (no heat transfer between them). In other words, the linear and point bridges and the heat accumulation capacities of the floors were not considered, which is a limitation of this study. Each of the zones has the same internal gains and shading conditions. Heating is required if the room temperature falls below 20 degrees Celsius and cooling if the indoor temperature increases over 26 degrees Celsius, same as suggested in PHPP (PHPP, 2022). The weather file location is taken for Ljubljana ("Energy plus," 2022). According to the Köppen-Geiger climate classification, Ljubljana has a Cfb climate with warm summers and cool winters (Peel et al., 2007) which is a typical climate for Central Europe. The baseline model was modelled without any insulation (as before the refurbishment). After the addition of insulation, the reduction of heating demand and the potential increase of cooling demand was calculated. The simulation period is the whole year with an hourly simulation step. The background data used for the calculation of the energy demand before and after the refurbishment measure is presented in the APPENDIX F.

The reduction of the energy demand due to the refurbishment measures is translated into the reduction of environmental impacts. The energy carriers can be different, depending on the heating and cooling system, thus the associated environmental impacts are different, too. In the presented case, the necessary electricity demand for the functioning of the heat pump was calculated and associated with the environmental impacts of the electricity mix. The electricity demand is calculated by the equation 3, where W is power consumed by the heat pump expressed the kilowatts, Q is the amount of heating or cooling provided in kilowatts and *(s)CoP* is the seasonal coefficient of performance.

$$W = \frac{Q}{(s)CoP} \tag{3}$$

For the calculation the *s(CoP)* used is 2.8 as reported in the TABULA project. The electricity mix taken for the assessment of the environmental impacts of heating and cooling with the heat pump is the current electricity mix in Slovenia. Slovenia's electricity mix in 2020 is still heavily dependent on nuclear, thermal (coal-generated) and hydro energy.

In the **step 3** the environmental payback time for each of the added materials is calculated for the current electricity mix and a sensitivity analysis was performed for potential future mixes. The payback period ($PBenv$) according to the equation 4 is the ratio between the environmental impacts of the materials ($\Delta EI_{materials}$) and the change of the environmental impacts of the energy demand ($\Delta EI_{energy\ demand}$),

$$PBenv = \frac{\Delta EI_{materials}}{\Delta EI_{energy\ demand}} \tag{4}$$

Since the electricity mix is constantly improving to comply with the strict global energy and climate targets set out in the European Green Deal and in the Paris Agreement (EC, 2020; UN, 2016), the associated environmental emissions are also changing. Each EU member country was obliged to establish a decarbonizing scenario for the national electricity mix and report it in National Energy and Climate Plans (NECP) (European Commission, 2020). The conducted sensitivity analyses serve to evaluate how the change of the electricity mix influences the length of the payback period. The future electricity mix is a combination of hydro, nuclear, wind, solar and biomass generated electricity. Since the use of nuclear remains controversial, two hypothetical electricity mixes that replace nuclear generated electricity with renewable energy sources were also generated. In the first option, nuclear energy is replacement by solar-generated electricity and in the second by wind energy (Table 13). The total environmental emissions of the added materials for the selected environmental category are divided by the reduction of environmental emissions of the operational energy use.

In addition, we have to point out that also the climate conditions are changing and this will affect the the operational energy demand but this challenge is beyond the scope of this study.

Table 13: Environmental emissions of 1 kWh of electricity
Preglednica 13: Okoljske emisije 1 kWh električne energije

Environmental emission of 1 kWh of electricity				
	NOW	2050+	2050 solar	2050 wind
Nuclear [%]	36.00	28..99	0,00	0,00
Solids [%]	34.20	0,00	0,00	0,00
Natural gas [%]	0,00	0,00	0,00	0,00
Biomass [%]	0.00	2.85	2.85	02.85
Hydro [%]	28.60	25.59	25.60	25.59
Wind	0.00	2.59	2.60	31.59
Solar	1.20	34.95	63.94	34.95
ADP elements [kg Sb eq.]	1.56E-07	3.37E-06	6.13E-06	3.41E-06
ADP fossil [MJ]	4.83	0.44	0.708	0.456
AP [kg SO2 eq.]	0.00926	0.00018	0.000274	0.000179
EP [kg Phosphate eq.]	0.00296	0.000101	0.000169	0.000104
GWP 100 years [kg CO2 eq.]	0.422	0.0379	0.0583	0.0389
ODP, steady state [kg R11 eq.]	8.26E-09	1.12E-08	1.02E-08	5.93E-09
POCP [kg Ethene eq.]	0.000388	1.85E-05	2.92E-05	1.88E-05

5.3 Validation of the methodology on a case study

Step 1

In this step the environmental impacts of one square metre of the exterior wall with added thermal insulation with the declared U-value were assessed. In Table 14 the environmental emissions of 1 m^2 of different added insulation materials, including all the supplementary materials needed for the application, are presented. These values are used for the calculation of the payback times of the refurbishment measures. AG insulations cause the highest GHG emission compared to other insulation systems due to the GHG caused during the AG production. The GHG emissions of EPS and MW are comparable, while CL and PF have smaller environmental emissions than the other insulation systems. It is evident that for lower U-values more insulation is needed, thus the environmental emissions are higher. Also, the AG building envelope system has higher environmental emissions in other impact categories than other insulation materials, since the production of AG causes relatively high environmental emissions compared to other insulation systems. Only in the ADPe category has the CL building envelope system caused substantially more impact than the others. The high emissions in this category are caused by the use of borax as a fire retardant and boric acid as an insecticide during the production process of cellulose. The environmental emissions contributing to the POCP environmental category is higher in the cases of EPS and AG insulation.

A detailed analysis of the contribution of each composition of the added thermal insulation system, namely insulation, adhesive and the cover coat of the components to the overall impact, is presented in APPENDIX G.

Table 14: Environmental impacts of the added materials during the refurbishment of the exterior wall
Preglednica 14: Okoljski vplivi materialov, dodanih v študijskem primeru prenove zunanje stene

ENVIRONMENTAL IMPACTS OF ADDED INSULATION SYSTEMS PER M^2

	EPS		**MW**		**CL**		**PF**		**AG**		**PF int**		**AG int**	
U-value	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
GWP (kgCO_2eq)	33.54	47.44	36.72	51.82	26.63	34.89	24.10	30.65	111.95	186.83	30.61	37.16	118.46	193.34
ODP (kg R11eq)	2.73E-06	3.12E-06	3.69E-06	4.33E-06	3.29E-06	4.04E-06	2.56E-06	2.58E-06	2.85E-05	4.93E-05	2.56E-06	2.58E-06	2.88E-05	4.93E-05
AP (kg Sb eq.)	0.17	0.24	0.27	0.40	0.18	0.25	0.12	0.13	0.55	0.93	0.12	0.13	0.57	0.93
EP (kgPhosphate eq)	0.06	0.07	0.09	0.12	0.08	0.12	0.05	0.06	0.09	0.14	0.05	0.06	0.10	0.14
POCP (kg Ethene eq.)	0.04	0.07	0.02	0.03	0.02	0.02	0.01	0.02	0.04	0.07	0.01	0.02	0.04	0.07
ADPe (kg Sb eq.)	0.000224	0.000225	0.000281	0.000305	0.005013	0.010255	0.000545	0.000554	0.000598	0.001204	0.000545	0.000554	0.000911	0.001204
ADPf (MJ)	659.90	958.90	628.90	875.90	440.50	556.71	573.48	768.98	984.06	1582.02	573.48	768.98	1032.54	1582.02

Step 2

The reduction of the heating and increase of cooling demand due to the refurbishment measures on the exterior wall was simulated with the TRNSYS program. The values for the reduction of heating demand (ΔQh) and the increase of cooling demand (ΔQc) are similar for all the application since the U-values of the wall are the same (see Table 15). Thus, it can be concluded that the thermal capacity of the materials does not exert a significant influence. The total reduction of the energy demand is the sum of the heating energy reduction and the cooling energy increase (ΔQh+ ΔQc). In the case of PF application on the interior side of the exterior wall, only a minor increase of heating demand and cooling demand is observed. The results are similar for AG.

It is also important to point out that the lower U-value does not reduce the energy use substaintialy.

Table 15: The reduction of heating demand and the increase of cooling demand due to the refurbishment of the exterior wall of the case study

Preglednica 15: Zmanjšanje potreb po energiji za ogrevanje in povečanje potreb po energiji za hlajenje zaradi prenove zunanje stene v študijskem primeru stavbe

materials	**EPS**		**MW**		**CL**		**PF**		**AG**		**PF INT**		**AG INT**	
U-value (W/m2K)	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
ΔQh (kWh/m^2a)	-46.41	-48.48	-46.41	-48.43	-46.27	-48.48	-46.35	-48.48	-46.39	-48.29	-46.20	-48.31	-46.24	-48.19
ΔOc (kWh/m^2a)	2.66	3.01	2.66	3.06	2.63	2.98	2.65	3.01	2.66	3.26	2.78	3.14	2.79	3.32
ΔQh+ ΔQc (kWh/m^2a)	-43.75	-45.47	-43.75	-45.37	-43.64	-45.50	-43.70	-45.47	-43.73	-45.04	-43.42	-45.17	-43.45	-44.87

In step 3 the electricity demand reduction for heating and cooling is calculated. It is foreseen that the building is heated and cooled with a heat pump that has a COP of 2.8. The reduction of the energy demand is translated into the reduction of the environmental impacts.

Step 3

For the payback calculation the data from the previous steps are taken. Since the energy reduction of the heating demand and the increase of the cooling needs are similar in all cases, the length of the payback period depends on the environmental impacts of the added materials and the selected U-value of the refurbished wall. The calculated payback periods very greatly depend on the observed impact category (Table 16). In the GWP category the AG insulation has a substantially longer payback period compared to other materials. While the payback periods for the U-value 0.17 W/m^2K is between 1.33 (PF) and 2.02 years (MW), the payback times for refurbishment with AG is 6.17, thus more than 3 times higher, if it is placed on the exterior part of the wall, or even 6.58 years if it is placed on the inside. The payback periods for the ODP category are longer compared to the GWP payback time. The payback period for AG even exceeds the expected service life of the insulation, which is 50 years. The AP and EP categories have the shortest payback periods, for the majority of the materials below 1 year. Only the payback period for AG exceeds 1 year in the case of AP categories. In the case of POCP the shortest payback period is in the case of PF, followed by CL, MW, AG and EPS. All remain below 2.49 for the U-value 0.17 W/m^2K and below 3.92 for the U-value 0.10 W/m^2K. The ADPe category has the longest payback periods, which also exceed the RSL of the insulation materials. The payback times for CL, which are several hundred years, are also outstanding. The payback times for the ADPf category are between 2.1 and 7.43 years and are also the highest for refurbishment with the AG insulation.

For the current electric mix the payback times are the shortest for AP and EP. The payback times for the GWP impact category are also relatively short. Longer payback periods are expected for the ADPe and the ODP impact categories.

Table 16: The payback times of different environmental impacts for building envelope refurbishment for different U-values of the wall and thermal insulation materials for the current electricity mix
Preglednica 16: Povračilna doba okoljskih vplivov zaradi prenove ovoja stavbe z različnima U-vrednostima ovoja in različnimi toplotnoizolacijskimi materiali pri sedanji sestavi električne energije

PAYBACK TIME (years)														
material	**EPS**		**MW**		**CL**		**PF**		**AG**		**PF int**		**AG int**	
U-value (W/m^2K)	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
GWP	1.85	2.52	2.03	2.76	1.47	1.85	1.33	1.63	6.18	10.01	1.70	1.99	6.58	10.40
ODP	7.71	8.47	10.40	11.76	9.28	10.94	7.23	6.99	80.47	135.08	7.27	7.04	81.85	135.57
AP	0.43	0.58	0.67	0.98	0.45	0.61	0.31	0.32	1.39	2.28	0.31	0.32	1.45	2.29
EP	0.45	0.53	0.68	0.90	0.66	0.90	0.43	0.42	0.71	1.05	0.43	0.43	0.80	1.06
POCP	2.49	3.92	1.21	1.69	1.06	1.44	0.87	1.06	2.40	3.88	0.88	1.07	2.52	3.90
ADPe	33.37	32.38	41.90	43.86	750.14	1472.00	81.47	79.54	89.24	174.63	82.00	80.06	136.90	175.27
ADPf	3.18	4.45	3.03	4.07	2.13	2.58	2.77	3.57	4.75	7.41	2.79	3.59	5.01	7.44

The sensitivity analysis was performed for three different decarbonized electricity mix options. The first option (2050+) for Slovenia is that the nuclear power plant remains active (Table 17). The second, hypothetical option is that the electricity generated from the nuclear power plant would be replaced by solar-generated electricity (Table 18) and the third hypothetical option is that the nuclear power plant would be replaced by wind-generated electricity (Table 19). In all cases the GWP payback times are substantially prolonged. The payback times in 2050 would be between 14.82 and 22.56 years, in the case of AG even 68.08 years, for the U-value 0.17 W/m^2K. This is 5 to 10 times longer than in the case of the current electricity mix. The payback times are substantially prolonged if we are aiming for the U-value 0.10 W/m^2K and in this case, we have to be careful that the payback is achieved within the service life of the insulation system. Payback times for GWP are similar if the nuclear power plant were replaced by wind-generated electricity. On the other hand, if the nuclear energy were replaced by solar-generated electricity (PV cells) the payback times would decrease. Since the 2050+ and 2050 wind electricity mixes have similar environmental emissions, the payback times are also similar for all the categories except for the ODP. In this case the of 2050+ wind electricity mix, the payback times for this category are almost doubled. On the other hand, the replacement of nuclear-generated electricity with solar-generated electricity results in shorter payback times, except for the ODP category, which has a longer payback period. This is the consequence of higher environmental emissions of the 2050+ solar electricity mix due to the embodied emissions of PV cell production.

Table 17: The payback times of different environmental impacts for building envelope refurbishment for different U-values of the wall and thermal insulation materials for the future electricity mix (2050)
Preglednica 17: Povračilna doba okoljskih vplivov zaradi prenovoe ovoja stavbe z različnima U-vrednostima ovoja in različnimi toplotnoizolacijskimi materiali pri sestavi električne energije leta 2050

PAYBACK TIME FOR THE 2050+ ELECTRICTY MIX (years)														
material	**EPS**		**MW**		**CL**		**PF**		**AG**		**PF int**		**AG int**	
U-value (W/m^2K)	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
GWP	20.61	28.05	22.56	30.70	16.40	20.61	14.82	18.12	68.81	111.51	18.95	22.11	73.28	115.81
ODP	5.69	6.25	7.67	8.67	6.85	8.07	5.33	5.16	59.35	99.62	5.36	5.19	60.36	99.98
AP	22.16	29.63	34.64	50.25	23.31	31.60	15.69	16.61	71.32	117.26	15.79	16.71	74.34	117.69
EP	13.28	15.46	19.87	26.29	19.39	26.33	12.58	12.42	20.73	30.83	12.66	12.50	23.31	30.95
POCP	52.29	82.29	25.42	35.43	22.31	30.24	18.33	22.32	50.43	81.44	18.45	22.47	52.80	81.74
ADPe	1.54	1.50	1.94	2.03	34.72	68.14	3.77	3.68	4.13	8.08	3.80	3.71	6.34	8.11
ADPf	34.92	48.83	33.28	44.70	23.37	28.33	30.38	39.16	52.10	81.33	30.58	39.41	55.02	81.63

Table 18: The payback times of different environmental impacts for building envelope refurbishment for different U-values of the wall and insulation materials for the future electricity mix (2050 solar)
Preglednica 18: Povračilna doba okoljskih vplivov zaradi prenove ovoja stavbe z različnima U-vrednostima ovoja in različnimi toplotnoizolacijskimi materiali pri sestavi električne energije leta 2050 (sončna energija)

PAYBACK TIME FOR THE 2050 SOLAR ELECTRICTY MIX (years)														
material	**EPS**		**MW**		**CL**		**PF**		**AG**		**PF int**		**AG int**	
U-value (W/m^2K)	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
GWP	13.40	18.23	14.67	19.96	10.66	13.40	9.64	11.78	44.73	72.49	12.32	14.37	47.64	75.29
ODP	6.24	6.86	8.43	9.52	7.52	8.86	5.85	5.66	65.17	109.39	5.89	5.70	66.28	109.79
AP	14.56	19.47	22.76	33.01	15.31	20.76	10.31	10.91	46.85	77.03	10.38	10.98	48.84	77.32
EP	7.94	9.24	11.87	15.71	11.59	15.73	7.52	7.42	12.39	18.43	7.57	7.47	13.93	18.49
POCP	33.13	52.13	16.10	22.45	14.14	19.16	11.61	14.14	31.95	51.60	11.69	14.23	33.45	51.79
ADPe	0.85	0.82	1.07	1.12	19.09	37.46	2.07	2.02	2.27	4.44	2.09	2.04	3.48	4.46
ADPf	21.70	30.35	20.68	27.78	14.52	17.61	18.88	24.34	32.38	50.54	19.01	24.49	34.19	50.73

Table 19: The payback times of different environmental impacts for building envelope refurbishment for different U-values of the wall and insulation materials for the future electricity mix (2050 wind)
Preglednica 19: Povračilna doba okoljskih vplivov zaradi prenove ovoja stavbe z različnima U-vrednostima ovoja in razluičnimi toplotnoizolacijskimi materiali pri sestavi električne energije leta 2050 (veterna energija)

PAYBACK TIME PAYBACK TIME FOR THE 2050 WIND ELECTRICTY MIX (years)														
material	**EPS**		**MW**		**CL**		**PF**		**AG**		**PF int**		**AG int**	
U-value (W/m^2K)	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**	**0.17**	**0.10**
GWP	20.08	27.33	21.98	29.91	15.98	20.08	14.44	17.66	67.04	108.64	18.46	21.54	71.39	112.84
ODP	10.74	11.80	14.49	16.38	12.93	15.24	10.07	9.74	112.09	188.15	10.13	9.80	114.00	188.84
AP	22.28	29.80	34.84	50.53	23.44	31.78	15.78	16.70	71.72	117.92	15.88	16.81	74.76	118.35
EP	12.89	15.01	19.29	25.53	18.83	25.57	12.22	12.06	20.13	29.94	12.30	12.14	22.64	30.05
POCP	51.46	80.98	25.01	34.86	21.95	29.75	18.04	21.97	49.63	80.14	18.16	22.11	51.96	80.44
ADPe	1.53	1.48	1.92	2.01	34.32	67.34	3.73	3.64	4.08	7.99	3.75	3.66	6.26	8.02
ADPf	33.70	47.12	32.11	43.13	22.55	27.34	29.32	37.79	50.27	78.48	29.51	38.03	53.09	78.76

5.4 Discussion

Building envelope refurbishment remains one of the most important measures to reduce the GHG emissions of buildings in the future. But besides GHG there are also other impact categories that should be observed in order to get a comprehensive overview of the environmental impacts. The majority of the studies focus on the payback of the cost and GHG emissions: only seldom are other impacts observed, according to Oregi (Oregi et al., 2017a). Although GHG emissions are one of the primary concerns of the current times, they should not be minimized on account of other environmental impacts. To avoid the burden shifting, more categories should be considered.

It is important to point out that the electricity is a mixture of different sources which are changing all the time (Barros et al., 2020). Consequently, the electricity emissions are also subject to frequent changes. In some cases, researchers even suggest the use of hourly GHG emission factors for the electricity mix (Kono et al., 2017; Roux et al., 2016). Still, in the majority of the cases changes of the electricity mix over time are neglected, since a very accurate determination of the electricity mix over time would be very time-consuming. Therefore, the average electricity mixes for a specific location and time period are taken. On the other hand, some authors suggest the use of average energy mixes for selected periods, for example every 5 or 10 years. For example, in the work of Obrecht et al. (2021) average electricity mixes for every decade were used in order to obtain a more accurate result without substantially prolonging the calculation. In the case of the payback period calculation, this would only be applicable if the payback periods were longer than 10 years. However, for most of the impact categories the payback times calculated with the current electricity mix are shorter than 10 years and the approach of Obrecht et al. is not applicable. Only a more precise, yearly, seasonal or even hourly approach would be applicable in this case, but that would substantially prolong the calculation.

The improvement of the energy (electricity) mix is also resulting in the decreased environmental emissions of energy and consequently in longer payback times. Therefore, in the future materials with a lot of embodied emission will not be able to compensate their emissions within their lifetime. This is especially evident for AG, which has very good insulation characteristics but at the same time its production causes a lot of environmental emission. With the current electricity mix it is possible that the embodied impact of the refurbishment measures with AG are compensated, but once the embodied emission of the energy carriers (in our case the electricity mix) are reduced this will no longer be possible. It is evident that if an energy source that has minor environmental impacts is used, the payback period of the refurbishment measures is prolonged and, in some cases, it can never be compensated. However, with a limited amount of energy available for our consumption, the reduction of energy use is therefore also important in order to avoid energy scarcity. On the other hand, it is important to say that the materials used for the insulation of the envelope will also probably have smaller environmental emissions in the future, since they will be made in a more efficient way and with less energy.

Therefore, it is advised that refurbishment measures with low embodied energy are prioritized. However, low embodied energy cannot always be the key criterion. For example, EPS is widely used and has great insulation characteristics. It is a lightweight material, since its volume consists mostly of air captured between EPS. Thus, the environmental impacts and the payback times for the refurbishment measure are also rather low compared to other materials with similar insulation characteristics. However, the use of EPS will become more and more controversial in the future because it is derived from fossil fuels. The general trend is to replace fossil-based materials with products made from sustainable materials.

They payback times were calculated for the use of a heat pump as the generator for heat and cooling. Further research is needed to find out how the use of other energy carriers would influence the payback period. Furthermore, the embodied impacts of the heating device are not included in the study, which is a limitation of this study. Only in rare cases are the heating devices also included in the scope of the study (Marinelli et al., 2019). This leaves further possibilities for future research.

It is difficult to compare how the payback times change in case of interior or exterior application of the insulation. Application on the exterior side of the wall should show better results due to the heat storage capacity of the wall construction but for interior application different materials are used than for the exterior application. Consequently, it is difficult to determine if either the different materials or the heat storage capacity of the wall is causing the difference in results. To ensure the comparability between inside and outside application, the same materials should be used, but this would compromise the credibility since this would be applied in this way in practice.

The coupling of the environmental impacts payback period with the economical payback periods will enable sound and informed decisions about the refurbishment measures of the building envelope. Several decision support tools have already been developed but they are seldom applied in practice. They can be used to calculate the optimal combination of refurbishment measures. This will also enable a more informed decision for refurbishment investors. The study offers an insight into the environmental impacts of different building envelope refurbishment measures including the payback times. If these are coupled and adequately weighted with the economic and social impacts, the investors will have all the data needed to make an informed decision.

For policymakers it is important that future research focuses on finding a threshold for the refurbishments that also consider the fact that the payback periods will be longer in the future due the improved energy mixes.

The methodology is developed for the comparison of different refurbishment measures. Similar approaches have been used in other studies but this is the first one that combines dynamic energy modelling and the environmental payback time. It can also be used for other refurbishment measures that affect energy use during the use phase of buildings.

5.5 Chapter summary

A three-step methodology for the comparison of different refurbishment measures (including operational EI) was established. In the first step, the EI of the new materials used for the refurbishment are calculated. In the second step, the reduction of energy due to the refurbishment is calculated with a dynamic energy simulation tool and the energy reduction is translated into the avoided environmental impacts. Based on the previous steps, the environmental payback times are calculated. The methodology can be applied on each refurbishment measure that also affects the use of operational energy. This is the first time that the dynamic energy simulation and environmental payback time have been combined into a single methodology and applied to a case study in Central Europe.

The methodology is illustrated on the case of building envelope refurbishment. It is commonly discussed that the building envelopes of the existing buildings should be improved in order to achieve the desired operating energy reduction and minimize the environmental emissions of buildings. In this chapter the most common solutions for the envelope refurbishment of buildings are presented and environmental payback times for different U-values of the envelope are compared.

Additionally, a sensitivity analysis was performed to test how the results would change if the electricity mixes were improved. The main findings are that the thermal storage capacity of the walls modified with the installed thermal insulation material does not play a significant role in energy reduction and thus does not affect the payback time. Only small differences in energy reduction between different insulation materials and between the positioning of the materials (interior or exterior side of the wall) were observed. The impact on the environmental payback calculation is almost entirely dependent on the environmental impacts of the added materials and the energy carriers for each of the observed categories, namely GWP, ODP, AP, EP, POC, POCP, ADPe, and ADPf. It is likely that the environmental impacts of the energy carrier will be improved in the future and this will consequently prolong the environmental payback times. The payback times could even exceed the expected RSLs of the insulation materials and this raises the question of whether energy use reduction might become less desirable if we have access to enough renewable energy in the future. However, for the current situation, refurbishment is an important task and investors should also have an insight into the environmental impacts of the refurbishment measure in order to make informed and sustainable decisions.

6 CONCLUSION

6.1 Main findings

The interpretation of the current legislation for the calculation of environmental impacts with the LCA leaves many opportunities to calculate the associated environmental impacts. In the current practice, refurbishment is considered as the beginning of the new life cycle and all the impacts associated with the previous life cycle are generally neglected. The recognition of the allocation need between the life cycle before and after the refurbishment was observed only in one study.

To overcome this shortcoming, a new advanced methodology was developed that allocates the impacts between the life cycle before and after the refurbishment. It consists of two sub-methodologies that can also be implemented separately. The first methodology is used for remodelling data in order to make the input data time-corresponding. The second methodology proposes the assessment of the environmental impacts and the residual value of components and materials before and after a refurbishment. The focus of this part is on the embodied environmental impacts.

A research gap in the comparative assessment of the refurbishment measures was also identified, and another methodology was developed for a reliable comparison of the EI of refurbishment measures which also includes operational EI. The methodology is applied to the case of building envelope refurbishments. Different, commonly used insulation materials were mutually compared and recommendations for refurbishment measures are made based on this comparison.

The **main findings about modelling time-corresponding input data** are the following: due to the long lifespan of building materials and building components, the embodied environmental emissions are changing substantially depending on their time of production. Since the first databases appeared in the late 1990s, no data is available from before this time (Martínez-Rocamora et al., 2016). Also, information about the change of the production of several materials and components over time would require a profound background knowledge of several production processes and a very skilled assessor and data which is very difficult to obtain. The conducted study showed that the differences in the GHG emission may strongly depend on the time of production.

The relative share of the electricity mix GHG emission towards the total GHG emissions of a material or component was as high as 20 % for separate building components. If this electricity mix is replaced with an electricity mix that has higher environmental emissions, the relative contribution of the electricity mix to the total emissions can be even higher. When, by contrast, the modified electricity mix is almost decarbonized, the relative contribution to the total emissions may well be reduced to a point where it becomes negligible. It is assumed that the efficiency of the electricity mix use will increase over time and that the differences in results are even higher. Consequently, the materials produced in the past have higher environmental emissions and their residual value is also higher. Since the residual value is often a source of information for the refurbishment measures, it should be modelled accurately. The absolute differences in residual value are especially high if they are observed at the beginning of the RSL and decrease when approaching the end of the component's RSL. This also means that the use of time-accurate data is more important if the residual value is observed at the beginning of the lifetime.

The **main findings about the allocation of the EI between the life cycle before and after the refurbishment** are that the refurbishment measures should be calculated as a stage within the whole life cycle of the building and depictured in separate modules, but in practice the refurbishment is treated as the beginning of a new building life cycle. The conducted SLR revealed that none of the published papers has discussed the phases before refurbishment. Also, the residual value of the existing materials, which is the sum of non-amortized environmental impacts observed at that point of time, is currently seldom observed. The residual value can, among others, be a criterion for how to further process the materials and components after the refurbishment. It is also likely that in the future premature discarding could be connected to certain political measures.

Treating the refurbishment as the beginning of the new life cycle is in line with EN 15978 if the refurbishment was not taken into account at the outset, i.e. in any previous assessment. This applies for the majority of cases. The division of a building's life cycle into two separate life cycles indicates that the environmental impacts have to be **allocated** between the life cycle before and the life cycle after the refurbishment. To allow consistent calculations, a robust method is needed that includes the allocation between the life cycles (i.e. the cut-off, cut-off with module D, avoided burden, 50:50, and the PEF approach).

A visual representation of the allocation approaches is provided in the dissertation and a comprehensive overview is given. The choice of allocation approach depends on the scope of the study and therefore all the allocation approaches were treated equally in the thesis, although it is likely that the allocation approaches which emphasize a circular economy approach will prevail in the future. It is assumed that the PEF method and the cut-off method with module D that include the aspects of circularity will become the prevailing methods.

In the dissertation a newly developed four-step methodology for the calculation of the environmental impacts and the residual value of refurbishment measures including the allocation between the life cycles is presented

The differences between the different allocation approaches emerge if materials with recycled content are used or if the materials are being recycled or reused at the end of their life cycle. This conclusion is made on the assumption that the material pool for recycling within the scope remains the same and no depletion of virgin materials is caused.

The newly developed methodology also allows an exact determination of the residual value of the discarded materials and the residual value of the materials that were preserved during the refurbishment. The comparison of the residual value with the environmental values of new materials can give relevant information about the potential reduction of environmental impacts due to preservation of certain components. Based on this information, it is possible to compare refurbishment with potential replacement with new buildings.

Due to its comparative nature, the methodology for the comparison of refurbishment measures (including operational impacts) allows certain simplifications. It is applied on the case study of building envelope refurbishment and summarizes the **main findings about building envelopes refurbishment with different insulation materials.**

During the SLR it was identified that there is a lack of studies that report the payback times of building envelope improvement for the Central European region, especially if the payback time calculation is coupled with a dynamic energy demand calculation and with this work we are closing this gap.

Five different, often-applied building envelope insulation solutions were applied and their environmental payback times were calculated. The thicknesses of the insulation materials were adjusted to reach the same U-value for all insulation assemblies. The interior application was also studied for some materials. Aerogel insulation has relatively high environmental emission compared to other insulation types, namely EPS, mineral wool, cellulose and phenolic foam. Thus, the use of aerogel is recommended only in cases where a material with very good insulation properties is required. The payback times for different categories are summarized up in a table that can be used by investors to choose the right material with regard to the required environmental performance.

The application of the insulation on the interior side of the wall was tested in the cases of aerogel and phenolic foam insulation since they have relatively low thickness and do not take up too much of the interior space. In contrast with expectations, the payback period for the interior installation of the insulation was very similar to the exterior insulation. Thus, the position of the insulation was not as important as initially expected.

These findings answer the initial hypothesis.

HYPOTHESIS 1

> ***To evaluate the environmental impact categories (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP) of building refurbishment, the entire life cycle of the building, including the pre-renovation phases, must be considered in the LCA analysis.*** *The current methodology for evaluating the environmental impacts of building refurbishment is comparative and does not evaluate the entire life of the building but only the phase after renovation. Consequently, this leads to difficulties in evaluating the environmental impacts of the end-of-life phase and beyond the end-of-life phase of the building, as the analysis of these phases should also take into account materials installed in the past. The current methodology makes it more difficult to compare the environmental impacts of refurbishment with replacement new construction. It is also not possible to estimate how much the environmental impacts are affected by premature renovation where installed materials have not fully utilized their intended reference life.*

Answer: The advantage of the developed methodology that enables the allocation of the EI between the life cycle before and after a refurbishment and the calculation of the residual impacts of each life cycle at a chosen point is the inclusion of the information about the materials before the refurbishment which solves the problem of how to assess the end-of-life phase and the phase beyond the end of life of the building. The assessment of the amortization of the materials and the estimation of the residual value of the materials observed at a certain point in time enables the evaluation of potential damage caused by premature refurbishment and enables a more comprehensive comparison of the refurbished building with a newly built building. Therefore, it is confirmed that phases prior to the refurbishment should also be considered for the correct assessment of the environmental impacts of refurbishment measures.

HYPOTHESIS 2

> ***When calculating the environmental impacts of the refurbishment of existing buildings and including the whole lifecycle, we can use data on the environmental impacts of related modern materials for already-installed materials.*** *Studies of embedded energy of materials suggest that the impacts of materials in buildings with high energy consumption are relatively small and thus it is sufficient to use data for current materials with a similar production method, since the difference will not be noticeable. We conclude that the situation is similar for environmental impact categories.*

Answer: In the work it was confirmed that the environmental impacts of the energy and electricity mixes used for the production are subjected to considerable changes over time and affect the EI of the materials. Therefore, the initial hypothesis that data of related modern materials can be used to evaluate the environmental impacts and the residual value of existing buildings (which contain materials that were produced in the past) is rejected.

HYPOTHESIS 3

> ***Due to the different heat accumulation in the building due to different materials and installation methods, the effects of refurbishment of the envelope of multi-apartment buildings are differently reflected in selected environmental impact categories (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP).*** *Due to the different heat accumulation in the building due to different materials and installation methods of thermal insulation, there are differences in energy consumption during the use phase. Also, the environmental impacts of the built-in materials are different and consequently, the payback time of the environmental impacts of the refurbishment measures is different.*

Answer: The variety of materials and installation possibilities compared in the study showed that, in contrast with the expectation, the payback period for the interior installation of the insulation was very similar to the exterior application. Also, the EI of the auxiliary materials need for the installation are not significant when compared to the EI of the insulation materials. Therefore, it can be concluded that the impact of heat accumulation due to the use of different insulation materials and due to the different position of the insulation materials during the refurbishment of the building envelope calculated with the suggested methodology is negligible and the EI and the payback period largely depend on the EI of the material itself. A more detailed model for the calculation of the energy demand would be required but it is assumed the payback periods would not be affected so much since the energy reduction would improve only to a certain percentage and the EI of the materials are the dominant factor. Thus, the hypothesys is rejected.

6.2 Scientific contribution of the conducted work to the state-of-the-art

The main contributions of the doctoral dissertation can be listed as:

- Development of the sub-methodology for modelling time-corresponding input data.
- Development of the sub-methodology for the assessment of EI and the residual value including allocation between the life cycle before and after refurbishment.
- Development of an advanced methodology for the assessment of the EI of building refurbishment.

- Development of the methodology for the comparison of refurbishment measures (including operational EI).
- Evaluation of potential building envelope refurbishment measures with their environmental impacts.

In order to identify the main open issues related to LCA and refurbishment of buildings, a comprehensive systematic literature review was performed. Similar wide analysis of this topic has not been found in the literature. The main findings were used to form the research questions, but the survey can also serve other researchers as the basis for their work.

Development of the sub-methodology for modelling time-corresponding input data. LCA analyses rarely take into account actual material production data (especially past, but could be also future data) and consequently also the fact that they can have various embodied environmental emissions. Therefore, a methodology for how to remodel the embodied emissions of the materials was developed. The methodology offers the possibility to model material datasets as single datasets, which allows the change of specific inputs. It is assumed that the production processes stay roughly unchanged over time and that the energy carriers used during production (i.e. electricity) in the future will be used more efficiently. The application of this methodology is very useful in all cases where LCA analysis is dealing with products with a long lifespan, and can be used for remodelling the datasets for the past and for the future. The approach has never been discussed so far and it is now published under the title "The role of electricity mix and production efficiency improvements on greenhouse gas (GHG) emissions of building components and future refurbishment measures" in The International Journal of Life Cycle Assessment (Potrč Obrecht et al., 2021).

Development of the sub-methodology for the assessment of EI and the residual value including the allocation between the life cycle before and after the refurbishment. This is the first time that a methodology bridges the discrepancy between the current practice and the demands of the standards that demand the observation of the whole life cycle. Additionally, the advantages and use of the individual allocation procedures is illustrated. The novelty and the scientific contribution of the work is confirmed by the acceptance of the paper "An LCA methodology for assessing the environmental impacts of building components before and after refurbishment" in the Journal of Cleaner Production (Potrč Obrecht et al. 2021 b)**Development of an advanced methodology for the assessment of the EI of building refurbishment.** The use of time-corresponding input data for the assessment of EI and the residual value for the life cycle before and after refurbishment improves the accuracy of LCA results and increases the overall credibility of the method. The combination of both of the sub-methodologies combines the advantages into a single, advanced methodology that thoroughly and consistently assesses the EI of the refurbishments.

Development of the methodology for the comparison of refurbishment measures (including operational EI). The comparative nature of the new methodology reduces the workload and the time needed for the reliable assessment of the environmental impacts of the refurbishment measures. The methodology provides combination of the dynamic energy simulation tools with the environmental payback times with clearly exposed transparency and reproducibility, which is often lacking in existing studies. The main scientific contribution of this part is a clear, step-by-step demonstration of the methodlogy, since during the SLR it was found out that the approach was often applied but never precisely explained in the methodological part of the papers. In this sense, the doctoral dissertation closes this gap by the clear explanation of the comparative methodology and its illustration on a case study.

Evaluation of potential building envelope refurbishment measures with their environmental impacts. The SLR of the current literature published on the topic LCA and refurbishment has shown that there is a lack of information about the environmental impacts of various types of building envelope refurbishment, especially for the area of Central Europe. The environmental impacts and environmental payback times were assessed for five different, commonly used insulation materials. The values were calculated for two different U-values of the envelope and different positions of the insulation (inside, outside), where reasonable. The obtained results are useful for the selection of the most effective interventions into the envelope improvement from the environmental point of view.

Certain published papers were referred to within the description of individual scientific contribution of the PhD study, whereby all papers (including the conference presentations) are thematically shown in Figure 1. It should be mentioned, however, that the preparation and submission of additional papers is planned in the near future.

Although, the potential impact of the doctoral dissertation on the overall mitigation of the greenhouse gas (GHG) emissions cannot be considered as a scientific contribution, this aspect cannot be completely overlooked. It is believed that the developed methodology will be included in the suggested LCA improvements for buildings provided by IEA EBC Annex 72.

6.3 Further research and outlook

Most of our future research work will be oriented into the improvement of the robustness of the developed methodologies and the facilitation of their application.

Although remodelling does require certain assumptions, the proposed **sub-methodology for modelling time-corresponding input data increases** the credibility of the results. Firstly, there are assumptions about the evolution of the energy mixes used for production. Therefore, it is necessary to establish a common database with the foreseen environmental emission for individual energy carriers in the future. In this sense, a guideline on how to predict the increased energy use efficiencies in the future as well as information about the potential improvements of the production processes of individual materials would be needed.

The **sub-methodology for the assessment of EI and the residual value including allocation between the life cycle before and after the refurbishment** will increase the transparency and reliability of the environmental impacts assessment during refurbishment of buildings. During the calculation, a number of determinations are crucial, especially with regard to input data. Firstly, the allocation approaches must be chosen and they should be dependent on the scope of the task. The practitioners should have general instruction as to which of the allocation approaches is encouraged and should be used since the allocation approaches can also promote certain measures (e.g. promote recyclability).

Secondly, specific information needed for the calculation of the environmental impacts with the chosen allocation approach should be provided. Some of the allocation methods require data about the difference in quality between the virgin and recycled materials. The recycling, reuse and landfilling rates for the materials should also be provided on a national or regional level. Also, the use of different RSL data can influence the result and these can be obtained from different databases. It should be part of future research to obtain more reliable data for all the mentioned variables. This will increase the quality and the comparability of the obtained results.

The complexity of **the advanced methodology for assessment the embodied EI** in the case of building refurbishments has shown that it would be advisable to develop a tool that would reduce the workload and time required. Further research on the sensitivity of the methodology towards various scenarios and predictions is needed. In the next step, the methodology might be optimized.

The **methodology for the comparison of the refurbishment measures** was illustrated on the case of building envelope refurbishment. It is recommended that the scope of the insulation materials should be extended in the future, and results should be provided for different climatic regions and for different heating/cooling energy sources. A part of future research might be the coupling of the information about the environmental impacts of building envelope improvement with additional indicators for the economic and social aspects during refurbishments. While the economic indicators are not difficult to obtain, the development of social indicators is still in the early phases, thus it is generally not available.

Besides the future work needed to improve the developed methodologies, the LCA methodology has a few issues that have to be resolved. In the IEA EBC Annex 72 group of experts specific challenges were identified that should receive further attention in the future. Among them are the harmonization of the operational energy demand calculation, the dynamic parameters, the establishment of national databases, the harmonization of the RSL databases and the development of tools for synchronizing building information modelling (BIM) and LCA. The improvement of the methodology for the assessment of refurbishment measures is only one of the challenges, and it was partly resolved within this doctoral dissertation. It will contribute to a trustworthy and internationally comparable method for the assessment of the environmental impacts that will allow correct monitoring of the reductions of emissions caused by buildings. As such it will support the EU Green Deal, facilitate the achievement of the SDG's climate change mitigation goal and hopefully indirectly contribute to future IPCC reports being less alarming.

7 RAZŠIRJENI POVZETEK DELA V SLOVENSKEM JEZIKU

7.1 Uvod

Podnebne spremembe so ena glavnih groženj, s katerimi se sooča človeštvo. Poročila Medvladnega odbora za podnebne spremembe (IPCC) navajajo, da so za dvig svetovni temperatur odgovorne toplogredne emisije, ki jih povzroča človek (IPCC, 2021). Blaženje podnebnih sprememb je ena najpomembnejših nalog v prihodnosti, kar potrjuje tudi dejstvo, da je to eden izmed ciljev, ki so si ga Združeni narodi zastavili za trajnostni razvoj družbe (United Nations, 2019). Ukrepi morajo biti sprejeti na različnih področjih, zlasti v gradbeništvu, ki glede na letna poročila Združenih narodov in Mednarodne agencij za energije (IEA) največ prispeva k podnebni spremembam (IEA and UNEP, 2019).

Gradbeni sektor rabi 40 % celotne energije in 30 % vseh surovin. Stavbe so odgovorne za 33 % emisij toplogrednih plinov (Chau et al., 2015b). Predvideva se, da je 80 % celotnega stavbnega fonda, ki bo v uporabi leta 2050, že zgrajenega (Vilches et al., 2017). To pomeni, da bodo za velik delež izpustov toplogrednih plinov odgovorne že obstoječe stavbe. Zato je obnova javnih in zasebnih stavb pomemben ukrep in je bila opredeljena kot ključen ukrep "Evropskega zelenega dogovora", ki je niz političnih pobud EU s splošnim ciljem doseganja ogljične nevtralnosti EU do leta 2050. Cilj strategije, imenovane »Renovation wave« je podvojiti stopnjo obnove stavbnega fonda v naslednjih letih (EC, 2020). Poleg povečanja stopnje obnove je pomembno, da se izboljša tudi kakovost obnove. Študija Steiningerja et al. (2021) poudarja, da je podnebno nevtralnost mogoče doseči le s temeljitimi prenovami stavbnega ovoja, z zamenjavo njihovih ogrevalnih sistemov ali kombinacijo obeh ukrepov. Manj ambiciozni ukrepi obnove ne bodo prinesli želenih rezultatov.

Za celovito vrednotenje vplivov na okolje, ki jih povzročimo s prenovo stavb, moramo analizirati celoten življenjski cikel stavb, kar vključuje fazo proizvodnje, fazo rabe in fazo po koncu življenjske dobe stavb. Metoda LCA se uporablja za vrednotenje okoljskih vplivov celotne življenjske dobe stavb, vendar ni prilagojena za vrednotenje okoljskih vplivov prenove stavb. Prevladujoč pristop ocenjevanja okoljskih vplivov prenove stavb upošteva le okoljske vplive proizvodnje in vgradnje novih materialov ter zamenjave obstoječih materialov (Oregi et al., 2015a), kar je v primerjalnih študijah povsem upravičeno. Ker standard EN 15978 opredeljuje prenovo le kot podfazo v življenjskem ciklu stavbe, je očitno, da je potrebno za celostno analizo upoštevati tudi predhodne faze. Torej tudi fazo proizvodnje materialov, ki je prisotna pred prenovo stavbe in fazo rabe stavbe, ki vključuje tudi podatke o vzdrževanju stavbe. Neupoštevanje predhodnih faz povzroča težave pri vrednotenju okoljskih vplivov konca življenjske dobe zaradi nepopolnih podatkov. Onemogoča tudi izračun amortizacije posameznih materialov in s tem oceno okoljske škode zaradi prezgodnje zamenjave komponent ali materialov. V okviru doktorske naloge je bila razvita napredna LCA metodologija za ocenjevanje okoljskih vplivov prenov, ki vključuje tudi faze pred prenovo in rabo časovno ustreznih podatkov za analizo življenjskega cikla stavbe (LCA).

Napredna metodologija je sestavljena iz dveh delov. Prvi del omogoča prilagajanje trenutno dostopnih podatkov za proizvodnjo materialov in komponent tako, da ustrezajo dejanskemu času proizvodnje. Drugi del metodologije zagotavlja možnost za ustrezno razporejanje (alokacijo) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej. Vzporedno je bila razvita LCA metodologija za primerjanje ukrepov prenove, ki poleg vplivov zaradi proizvodnje materialov (t.i. utelešenih vplivov) vključuje tudi okoljske vplive v času rabe stavbe.

V nalogi je poseben poudarek namenjen okoljskim vplivom prenove fasadnega ovoja, saj ta praviloma predstavlja največji potencial za zmanjšanje okoljskih vplivov stavbe.
Naloga je sestavljena iz uvoda, teoretičnega ozadja, predstavitve raziskovalnih hipotez in metod, opisa razvoja napredne metodologije za vrednotenje okoljskih vplivov prenove stavbe, opisa razvoja metodologije za primerjavo okoljskih vplivov prenov ter zaključkov naloge.

7.2 Teoretično ozadje

7.2.1 LCA metoda

Metoda ocenjevanja življenjskega cikla (LCA) se uporablja za ugotavljanje okoljskih vplivov proizvodov in procesov na okolje. Metoda sistematično analizira vplive na okolje za proizvode in procese v njihovem celotnem življenjskem ciklu. Prva faza metodologije (1) je opredeliti cilj in obseg raziskave, (2) v drugi fazi se zbirajo informacije o materialnih in energetskih tokovih (ta faza se imenuje ocena inventarja življenjskega cikla (LCI) ali popis življenjskega cikla), (3) tretja faza: materiali in energijski tokovi se dodelijo okoljskim kategorijam in se jim pripišejo karakterizacijski faktorji, s katerimi izračunamo prispevek posameznih tokov k opredeljeni okoljski kategoriji; (4) četrta faza je interpretacija rezultatov.

Metoda je bila s standardi EN 15804 in EN 15978 prilagojena za gradbene materiale in stavbe. Posebnosti posamezne faze pri LCA metodi so naslednje:

- Opredelitev cilja in obsega:
    - Opredelitev funkcionalne enote: na ravni stavbe je funkcionalni ekvivalent opredeljen v skladu z EN 15978. Vključuje tip stavbe, ustrezne tehnične in funkcionalne zahteve, način uporabe in zahtevano življenjsko dobo.
    - Opredelitev obsega sistema: standardi življenjsko dobo stavbe delijo na proizvodno fazo (ki jo sestavljajo faze pridobivanja surovin- A1, transport surovin- A2,

proizvodnja gradbenih materialov - A3, njihov transport - A4 in njihova vgradnja - A5), fazo rabe (vključno z rabo - B1, vzdrževanjem - B2, popravilom - B3, zamenjavo - B4, prenovo - B5, rabo energije v fazi rabe - B6 in rabo vode v fazi rabe - B7), faza izteka življenjske dobe stavbe (obsega fazo dekonstrukcije - C1, transport materialov - C2, faza obdelave odpadkov - C3 in končno fazo odstranjevanja - C4) in fazo po izteku življenjske dobe stavbe- fazo D (vsebuje scenarije ponovne uporabe, recikliranja in pridobivanja energije zaradi izgorevanja odpadnih materialov). Posebna pozornost je namenjena razlikovanju med utelešenimi vplivi materialov (ti nastanejo zaradi proizvodnje in rabe materialov) in okoljskimi vplivi, povzročenimi zaradi rabe stavbe. Ocena se lahko osredotoči tudi na določen del življenjskega cikla: od zibelke do vrat (stopnje A1-A3); od zibelke do groba (stopnje A1-C4); od zibelke do zibelke (stopnje A-D).

- Opredelitev alokacij: kadar je treba okoljske vplive razdeliti med dva življenjska cikla, je treba opredeliti pristop alokacije. Pristopi alokacije bodo podrobneje opredeljeni v poglavju o razvoju napredene metodologije za ocenjevanje okoljski vplivov prenove.
- Opredelitev mejnih pravil: v praksi je celoten inventar stavbe vedno neznan, saj so stavbe zelo kompleksni izdelki, ki vsebujejo več materialov, zato je treba z mejnimi pravili določiti, kaj bo upoštevano v študiji.
- Opredelitev scenarijev: zaradi dolgega življenjskega cikla stavbe je treba nekatere stvari predpostaviti oziroma določiti scenarije.

- Ocena inventarja:
    - Za oceno inventarja se strokovnjaki opirajo na že vzpostavljene baze podatkov o inventarju življenjskega cikla. V nalogi je uporabljena baza Ecoinvent (Wernet et al., 2016). Pomembno je, da podatki izhajajo iz enega samega vira in da so vsi modelirani na enak način.

- Ocena okoljskih vplivov inventarja:
    - Vplivi se običajno karakterizirajo na problemski ravni. Ta pristop nudi celovitejši vpogled v okoljske vplive. Drugi karakterizacijski pristop je na škodni ravni. Tu so okoljski vplivi dodatno razvrščeni v splošne problematike (npr. zdravje ljudi, naravno okolje itd.) ali celo uravnotežene na eno samo vrednost. Za stavbe se večinoma uporablja metoda karakterizacije CML ali ILCD na problemski ravni. V nalogi je bila uporabljena metoda CML (CML-IA Characterisation Factors, 2016).

- Interpretacija rezultatov:
    - Čeprav je normalizacija neobvezen korak študij LCA, lahko omogoči lažjo interpretacijo rezultatov. Pogosto se rezultati normalizirajo na kvadratni meter stavbe ali na osebo. Tako si lahko olajšamo tudi razlago rezultatov. Analize negotovosti, občutljivosti in scenarijev lahko pokažejo vpliv nekaterih odločitev ali kakovosti podatkov na končne rezultate (Gantner et al., 2015).

7.2.2 Sistematski pregled literature

V sistematskem pregledu literature smo raziskali znanstvene članke, ki so bili objavljeni na temo LCA in prenova. Ključne besede za iskanje so bile "life cycle assessment" OR "LCA" AND "refurbishment" OR "renovation" OR "retrofitting" AND "building". Raziskane baze podatkov so bile Science Direct, Scopus, Web of Science in Springer. Rezultati so bili omejeni na angleški jezik in recenzirane izvirne in pregledne članke.

Po začetnem iskanju smo prišli do vzorca 396 člankov. Po prvem filtriranju, na podlagi naslova, smo zožili obseg na 211 člankov. Po branju povzetkov je bil vzorec zožan na 126 prispevkov, na koncu pa smo po branju celotnih prispevkov prišli do nabora 94 ustreznih člankov, ki so bili nadalje analizirani. Analiza je pokazala, da se pri vrednotenju okoljskih vplivov prenova večinoma obravnava kot začetek novega življenjskega cikla stavbe. Pokazala se je tudi vedno večja pomembnost rabe časovno ustreznih podatkov. Večinoma je to poudarjeno pri izračunu okoljskih vplivov v času rabe (Kono et al., 2017; Roux et al., 2016), opaženo pa je bilo tudi spreminjanje utelešenih okoljskih vplivov materialov zaradi tehnološkega izboljšanja proizvodnje, povečane energije učinkovitost proizvodnje, rabe okolju prijaznejše električne energije ali virov energije, itd. Pri pregledu literature smo opazili le dve študiji, in sicer Passer et al. (2016) in Ghose et al. (2020), ki upoštevata, da se vplivi na okolje s časom spreminjajo.

Ugotovili smo tudi, da za področje Slovenije ne obstaja nobenih informacij o vplivu ukrepov prenove fasadnega ovoja na okolje. Poročilo o okoljskih vplivih posameznih ukrepov prenove fasadnega ovoja je koristno tudi za investitorje in za proizvajalce izolacijskih materialov. Na podlagi slednjih ugotovitev smo opredelili raziskovalne cilje in postavili posamezne hipoteze.

7.3 Raziskovalni cilji, hipoteze in metode dela

Glavni cilj naloge je bil razvoj nove napredne metodologije za vrednotenje okoljskih vplivov prenove stavb, ki vključuje tudi faze pred prenovo in rabo časovno ustreznih podatkov za analizo življenjskega cikla stavbe (LCA). Na ta cilj sta vezani prvi dve hipotezi naloge.

HIPOTEZA 1

Za vrednotenje okoljskih vplivnih kategorij (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP) prenove stavbe moramo pri analizi LCA obravnavati celotni življenjski cikel stavbe vključno s fazami pred prenovo. Trenutna metodologija za vrednotenje okoljskih vplivov prenove stavbe po metodi LCA je primerjalna in ne vrednoti celotne življenjske dobe stavbe, temveč le faze po prenovi. To posledično privede do težav vrednotenja okoljskih vplivov faze izteka življenjske dobe in faze po izteku življenjske dobe stavbe, saj bi bilo v analizi teh faz treba upoštevati tudi v preteklosti vgrajene materiale. Hkrati je zaradi trenutne metodologije težja primerjava okoljskih vplivov prenove z nadomestno novogradnjo in ni možno oceniti, koliko se poveča okoljski vpliv v primeru predčasne prenove, kjer vgrajeni materiali niso v celoti izkoristili svoje predvidene referenčne življenjske dobe.

HIPOTEZA 2

Pri izračunu okoljskih vplivov prenove obstoječe stavbe z upoštevanjem njene celotne življenjske dobe lahko za že vgrajene materiale uporabimo podatke okoljskih vplivov sorodnih sodobnih materialov. Študije vgrajene energije nakazujejo, da je vpliv vgrajene energije pri stavbah z veliko rabo energije v času rabe, relativno majhen in da zadostuje, če uporabimo podatke za aktualne materiale s podobnim načinom proizvodnje. Sklepamo, da je situacija podobna tudi za okoljske vplivne kategorije.

Ugotovili smo tudi, da manjkajo podatki o okoljskih vplivih prenove fasadnega ovoja za področje srednje Evrope, zlasti kadar se upošteva tudi zmanjšanje rabe energije. Zato smo dodali še tretjo hipotezo.

HIPOTEZA 3

Učinki prenove fasadnega ovoja večstanovanjskih stavb se zaradi različnih vrst in načinov vgradnje toplotne izolacije različno odražajo na izbranih okoljskih vplivnih kategorijah (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP). Različne toplotne akumulacijske kapacitete v stavbi zaradi različnih vrst in načinov vgradnje toplotne izolacije povzročajo razlike pri rabi energije v obratovalni fazi stavbe. Dodatno moramo upoštevati tudi okoljske vplive vgrajenih materialov. Čas povrnitve okoljskih vplivov po metodi LCA se zato lahko razlikuje od časa energijske povrnitve.

Metode, uporabljene pri delu, so LCA, študija primera, analiza občutljivosti in sistematski pregled literature.

Zaradi kompleksnosti hipotez so končni rezultat naloge tri različne metodologije. Prva metodologija je razvita tako, da omogoča preoblikovanje obstoječih podatkov LCI v časovno ustrezne glede na čas proizvodnje gradbenih materialov in komponent. Druga metodologija je nov pristop, kako oceniti utelešene okoljske vplive in preostalo vrednost materialov in komponent stavbe s porazdelitvijo vplivov med življenjskim ciklom pred prenovo in po njej. Združena prva in druga metodologija sestavljata napredno metodologijo za vrednotenje okoljskih vplivov prenove stavb. Tretja metodologija je primerjalna metodologija za oceno učinkovitosti ukrepov prenove stavb, prikazana na primeru prenove fasadnega ovoja stavbe. Vključuje tudi okoljske vplive rabe stavbe v času njene uporabe.

7.4 Napredna metodologija za vrednotenje okoljskih vplivov prenove

Napredna metodologija je sestavljena iz dveh delov. Prvi del omogoča, da se materialom in proizvodom določene vhodne podatke prilagodi tako, da bolje ustrezajo dejanskemu času proizvodnje. Ta del je opisan v poglavju »Razvoj in verifikacija metodologije za modeliranje časovno ustreznih podatkov«. Drugi del zagotavlja možnost uporabe razporejanja (alokacije) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej. Ta del je opisan v poglavju »Razvoj in verifikacija metodologije za porazdelitev okoljskih vplivov med življenjskim ciklom pred in po prenovi«. Povezava posameznih delov metodologije je predstavljena v poglavju »Napredna metodologija za vrednotenje okoljskih vplivov prenove«.

7.4.1 Razvoj in verifikacija metodologije za modeliranje časovno ustreznih podatkov

Različne študije so potrdile, da okoljski vplivi proizvodnje električne energije pomembno doprinesejo k celotnim okoljskim vplivom posameznih proizvodov, zato je pomembno, da se pri vrednotenju okoljskih vplivov materialov uporabljajo ustrezni podatki za proizvodnjo električne energije po energentih. Ti so podvrženi velikim spremembam skozi čas. Cilj tega dela raziskave je bil ugotoviti, kolikšen vpliv ima sprememba proizvodnje električne energije po energentih na celotne (utelešene) okoljske vplive gradbenih materialov ter na preostalo vrednost okoljskih vplivov stavbe in njenih sestavnih delov. Preostala vrednost okoljskih vplivov je vsota neamortiziranih utelešenih okoljskih emisij, ocenjenih v določenem trenutku. Pri izračunu preostale vrednosti se upoštevajo okoljski vplivi proizvodne faze (modul A1-A5), vzdrževanje (B4) in faze konca življenjske dobe (modul C1-C4) po EN 15804 (CEN 2012). Gradbeni materiali in komponente se amortizirajo v okviru njihove referenčne življenjske dobe (RSL), stavba pa se mora amortizirati v obravnavanem referenčnem obdobju (RSP). Z izračunom preostale vrednosti obstoječih materialov in proizvodov v stavbi je mogoče oceniti njihovo amortiziranost in s tem lažje določiti nadaljnje potrebne ukrepe med prenovo.

V nalogi razvita metodologija omogoča preoblikovanje trenutnih podatkov o okoljskih vplivih posameznih materialov v časovno ustrezne podatke s spremembo sestave energentov za proizvodnjo električne energije in spremembo učinkovitosti rabe energije pri proizvodnji. Metodologija vključuje tri faze. V prvi fazi se določijo okoljski vplivi proizvodnje električne energije po energentih v izbranih obdobjih. V drugi fazi se podatki o inventarju življenjskega cikla preoblikujejo tako, da se trenutni podatki o okoljskih vplivih proizvodnje električne energije zamenjajo z modificiranimi podatki o okoljskih vplivih proizvodnje električne energije, pridobljenih v prejšnji fazi. V tretji fazi se preostala vrednost okoljskih vplivov stavbe izračuna z uporabo predhodno spremenjenih podatkov.

Metodologijo smo predstavili na primeru referenčne stavbe, ki predstavlja tipično stanovanjsko stavbo iz obdobja med letoma 1971 in 1980. Izbrana je bila v okviru mednarodnega projekta TABULA (Ballarini et al., 2014; Mastrucci et al., 2017). Funkcionalna enota (FU) je opredeljena kot celotna stavba z RSL 60 let. Rezultati so predstavljeni za kategorijo GWP.

V prvi fazi smo določili okoljske vplive proizvodnje električne energije po energentih za vsako desetletje od 1970 do sedaj. Podatke o sestavi električne energije po energentih v preteklosti smo pridobili od Slovenskega statističnega urada. Ocenili smo tudi okoljske vplive proizvodnje električne energije v prihodnosti. Ti so bili izračunani na podlagi podatkov Energetskega koncepta Slovenije (ECS) (Slovenian Ministry of Infrastructure, 2017) in Nacionalnih energetskih in podnebnih načrtov (NECP) (European Commission, 2020). Variirali smo torej več podatkov iz različnih časovnih obdobij, kar predstavlja neke vrste študijo občutljivosti, z namenom oceniti pomembnost uporabe časovno ustreznih podatkov v prihodnosti.

V drugi fazi smo preoblikovali podatke o inventarju življenjskega cikla. V prvem koraku druge faze so bili zamenjani podatki o proizvodnji električne energije po energentih samo v osnovnih procesih podatkovne zbirke. V drugem koraku se osnovni procesi nadalje razdelijo na pod-procese, v vsakem od procesov in pod-procesov so bili zamenjani podatki o proizvodnji električne energije po energentih tako, da ustrezajo obdobju, v katerem je bila komponenta ali material proizveden. Tretji korak sledi načelu prejšnjega, poleg tega pa upošteva tudi spremembo učinkovitosti proizvodnje. Predvideva se 0,5 % povečanje učinkovitosti rabe električne energije na leto (tako kot v Van De Moortelu (2019)), saj bolj natančnih podatkov ni bilo mogoče pridobiti.

V tretji fazi smo izračunali preostalo vrednost okoljskih vplivov na poenostavljen način, ker je bil cilj študije oceniti, kako lahko sestava energentov pri proizvodnji električne energije vpliva na preostalo vrednost stavbe, in ugotoviti, ali lahko razlike vplivajo na odločitve o prihodnjih ukrepih prenove. Za izračun preostale vrednosti smo uporabili samo faze proizvodnje materialov (A1 do A3 po EN 15978).

V obravnavanem primeru je bil relativni delež emisij toplogrednih plinov zaradi proizvodnje električne energije kar do 20 % vseh emisij za posamezne gradbene komponente. Če se ta električna energija nadomesti z električno energijo z večjimi okoljskimi emisijami, je lahko relativni prispevek električne energije k skupnim emisijam še večji. Kadar pa je proizvodnja električne energije skoraj razogljičena, se lahko relativni prispevek k skupnim emisijam zmanjša na točko, ko postane zanemarljiv. Sprememba proizvodnje električne energije vpliva tudi na preostalo vrednost stavbe. V opazovanih primerih so bile razlike zaradi upoštevanja različnih mešanic energentov za proizvodnje električne energije okrog 10 %. Razlike se dodatno povečajo, če je upoštevana tudi sprememba učinkovitosti proizvodnje. Na podlagi teh ugotovitev lahko trdimo, da je treba časovno spremenljive parametre obravnavati dinamično, saj tako dobimo pravilnejše in zanesljivejše rezultate.

7.4.2 Razvoj in verifikacija metodologije za porazdelitev okoljskih vplivom med življenjskim ciklom pred in po prenovi

V skladu s standardom EN 15978 je treba prenovo obravnavati kot eno fazo celotnega življenjskega cikla. Vendar je bilo pri pregledu literature ugotovljeno, da se prenova večinoma obravnava kot začetek novega življenjskega cikla stavbe. To pomeni, da prenova razdeli življenjski cikel stavbe na dva življenjska cikla (pred prenovo in po prenovi) in posledično se morajo tudi okoljski vplivi posameznih komponent in materialov razdeliti med tema življenjskima cikloma (Allacker et al. 2017; Ekvall 2000; Ekvall and Tillman 1997; Frischknecht 2010; Kim, Hwang, and Lee 1997; Mirzaie, Thuring, and Allacker 2020). Obstaja več možnosti razdelitve vplivov oziroma metod alokacije. V nalogi so bili uporabljeni (1) pristop »cut-off«, (2) pristop »cut-off« z modulom D, (3) pristop »avoided burden«, (4) pristop 50:50 in (5) pristop PEF. S porazdelitvijo vplivov dobimo tudi vpogled v to, kateri materiali so bili pri prenovi ohranjeni oziroma ponovno uporabljeni med prenovo, in s tem tudi vse potrebne podatke za vrednotenje faze konca življenjskega cikla. Vključevanje porazdelitve vplivov tudi zmanjša verjetnost, da se posamezni okoljski vplivi upoštevajo večkrat (na primer enkrat v življenjskem ciklu pred prenovo in enkrat v življenjskem ciklu po prenovi). Zato je bil cilj tega dela naloge razvoj metodologije, ki ocenjuje okoljske vplive prenove tako, da jih razdeli med življenjskim ciklom pred prenovo in po prenovi.

Nova metodologija je kombinacija že obstoječih metodologij, ki so združene na inovativen način. Sestavljena je iz štirih korakov.

V prvem koraku se določijo vhodni in izhodni materialni in energijski tokovi za življenjski cikel pred prenovo in za življenjski cikel po prenovi. Za vsak življenjski cikel je treba navesti, kateri vhodni materiali so iz primarnih surovin in kateri so deloma ali v celoti reciklirani. Določiti je potrebno tudi, kateri materiali se reciklirajo, kateri se ponovno uporabijo in kateri se završejo po koncu svojega življenjskega cikla. Ta korak je izhodišče za nadaljnje izračune.

V drugem koraku se ovrednotijo okoljski vplivi materialov in proizvodov ter z izbrano metode alokacije porazdelijo med življenjskim ciklom pred prenovo in življenjskim ciklom po prenovi. Alokacijski pristop »cut-off« (imenovan tudi 100:0) upošteva, da se okoljski vplivi faze proizvodnje za izdelek pripisujejo prvi uporabi tega izdelka in sledijo načelu »onesnaževalec plača« (Gervasio and Dimova, 2018). Materiali, ki se ponovno uporabijo, ne nosijo nobene okoljske obremenitve (Allacker et al. 2017; Frischknecht 2010; Gervasio and Dimova 2018). Drugi alokacijski pristop, »cut-off z modulom D«, izboljšuje prejšnji pristop z uvedbo modula D. Modul D je faza, ki presega sistemske meje življenjskega cikla stavbe in vključuje možne koristi ali obremenitve zaradi recikliranja, ponovne uporabe in pridobivanja energije s sežigom po koncu življenjske dobe ter s tem pripomore h krožnemu gospodarjenju. Alokacijski pristop »avoided burden« (imenovan tudi 0:100) upošteva okoljske koristi potencialnega recikliranja ali ponovne uporabe že v prvem življenjskem ciklu. Naslednji pristop »50:50« deli bremena in koristi med prvim in drugim življenjskim ciklom. Lahko ga razumemo kot kompromis med pristopom cut-off in pristopom »avoided burden«. Alokacijski pristop okoljskega odtisa izdelka »PEF« temelji na pristopu 50:50 in uvaja dva parametra: enega za upoštevanje zmanjšanja kakovosti materialov in drugega za upoštevanje povpraševanja trga po recikliranih izdelkih (Gervasio and Dimova, 2018). Te parametre je zaradi pomanjkanja podatkov (Spirinckx et al., 2018) včasih težko določiti.

V tretjem koraku se izdela scenarij vzdrževanja materialov in komponent v skladu z izbrano bazo podatkov o njihovih referenčnih življenjskih dobah. V razviti metodologiji ta korak podaja informacije o periodi, v kateri je materiale ali komponente potrebno zamenjati oziroma jih vzdrževati. Posledično se v postopku izračuna tudi stopnja amortiziranosti gradbenih materialov in komponent.

V četrtem koraku se oceni preostala vrednost okoljskih vplivov za posamezen proizvod ali stavbo. Okoljske vrednosti, izračunane v koraku 2, se linearno porazdelijo glede na življenjsko dobo (določeno v koraku 3) in določi se, kolikšen delež je ostal neamortiziran.

Metodologijo smo preizkusili na izbranih gradbenih komponentah referenčne stavbe, ki je ista kot v prejšnjem poglavju. Spremenljiva parametra sta bila: metoda alokacije in baza podatkov o življenjskih dobah. Primerjava različnih pristopov alokacije je pokazala, da se razlike med ovrednotenimi okoljskimi vplivi pojavijo v primerih, kadar se uporabijo reciklirani materiali, kadar se materiali reciklirajo ob koncu življenjske dobe ali v primeru ponovne uporabe materialov ali komponent. Večje razlike pri ovrednotenju okoljskih vplivov so vidne v življenjskem ciklu po prenovi, saj so v tem ciklu večji deleži ponovno uporabljenih in recikliranih komponent zaradi materialov in komponent, ki smo jih ohranili v stavbi med postopkom prenove. Študija je potrdila tudi, da ima izbira baze podatkov o življenjskih dobah materialov in komponent velik vpliv na scenarije vzdrževanja in posledično vodi do različnih preostalih vrednosti okoljskih vplivov materialov in komponent ter tudi stavb. Zato je ključnega pomena navesti, katera baza se uporablja za določitev njihove življenjske dobe.

Na podlagi rezultatov smo ugotovili, da razvita metodologija omogoča celovitejše in zanesljivejše ovrednotenje okoljskih vplivov prenove in odpravlja prej ugotovljene pomanjkljivosti trenutnih pristopov.

7.4.3 Napredna metodologija za ocenjevanje okoljskih vplivov prenove

V prejšnjih dveh poglavjih je bila predstavljena problematika uporabe časovno neustreznih podatkov za oceno okoljskih vplivov prenove stavb in poudarjena pomembnost porazdelitve okoljskih vplivov med življenjskim ciklom pred in po prenovi.

Napredna metodologija temelji na metodologiji za porazdelitev okoljskih vplivov med življenjskima cikloma pred in po prenovi, za katero se preoblikujejo vhodni podatki v dveh pod-korakih. V prvem pod-koraku se za proizvodnje električne energije po energentih zmodelirajo ustrezne mešanice energentov za proizvodno električne energije za izbrana časovna obdobja in okoljsko ovrednotijo njihove emisije. V drugem pod-koraku se premodelirajo podatki o inventarju z uporabo prej modeliranih podatkov za proizvodnjo električne energije po energentih.

Nato se v prvem koraku metodologije za porazdelitev okoljskih vplivov opredelijo vhodni in izhodni tokovi med življenjskima cikloma pred in po prenovi stavbe. V drugem koraku se za materiale in komponente okoljski vplivi ocenijo z izbrano metodo alokacije. V tretjem koraku se izdela scenarij vzdrževanja materialov, komponent ali stavbe v skladu z izbrano bazo podatkov o njihovi referenčni življenjski dobi. Pri tem je potrebno poudariti, da se okoljski vplivi vzdrževanja stavbe prav tako izračunajo s časovno ustreznimi podatki (izračunanimi po postopku, opisanem v pod-korakih). V četrtem koraku se izračuna preostala vrednost okoljskih vplivov za materiale, komponente ali stavbo.

Metodologijo smo predstavili in verificirali na enoti (1 m^2) zunanje stene iste referenčne stavbe, ki je bila uporabljena že pri prejšnjih dveh poglavjih. V nalogi smo podali primerjavo med materiali, modeliranimi s trenutnimi podatki za proizvodnjo električne energije po energentih, in materiali, ki so bili predhodno modificirani tako, da podatki o proizvodnji električne energije po energentih ustrezajo času njihove proizvodnje.

Rezultati študije so pokazali, da so v obravnavanem primeru razlike med neamortizirnimi okoljskimi vplivi, izračunane s časovno ustreznimi ali trenutnimi podatki, v razponu od 4 do 11 %. Ugotovili smo, da so za življenjski cikel pred prenovo stavbe okoljski vplivi in vrednost neamortiziranih okoljih vplivov na splošno višji, če se uporabijo časovno ustrezni podatki iz preteklosti, saj so okoljski vplivi proizvodnje električne energije po energentih višji. Razlike v rezultatih so tako velike, da je ne smemo zanemariti.

7.5 Metodologija za primerjavo okoljskih vplivov ukrepov prenove (vključuje okoljske vplive v času uporabe stavbe)

Metodologija je namenjena le za primerjave okoljskih vplivov določenih ukrepov na stavbi, zato glede na običajno LCA metodologijo dopušča poenostavitve. Primerja se le tiste dele, ki se pri prenovi stavbe dodajo ali odvzamejo in na katere ima prenova vpliv (na primer na zmanjšanje rabe energije v času uporabe stavbe). Cilj tega poglavja je prikaz razvoja metodologije in njena razlaga. Uporablja se lahko za primerjavo tistih ukrepov prenove, ki vplivajo na rabo energije stavbe.

Razvita metodologija vključuje več korakov. V prvem koraku se okoljski vplivi dodanih materialov in komponent za ukrepe prenove fasadnega ovoja stavbe ocenijo z metodo LCA. V analizo mora biti vključena faza proizvodnje, vključno s pridobivanjem surovin (A1), prevoza (A2) in proizvodnjo (A3).

V drugem koraku se izračuna zmanjšanje rabe energije stavbe med njenim delovanjem zaradi ukrepov prenove. V kolikor je namen primerjave tudi ocena vpliva ukrepov v smislu dinamičnega energijskega odziva stavbe zaradi akumulacijskih učinkov materialov, je izračune potrebno izvesti z orodjem za dinamično simulacijo rabe energije stavbe. Na podlagi zmanjšanja rabe energije se oceni potencialno zmanjšanje vplivov na okolje v fazi rabe stavbe. V tretjem koraku se podatki iz prvega in drugega koraka uporabijo za izračun povračilne dobe okoljskih vplivov za ukrepe prenove.

Metodologijo smo prikazali na primeru prenove fasadnega ovoja stavbe. Za predstavitev so bile uporabljene najpogostejše rešitve za energijsko prenovo fasadnega ovoja z različnimi toplotnoizolacijskimi sistemi in ciljno enakim toplotnim uporom, R, (enaka U-vrednost) ter primerjane njihove okoljske povračilne dobe. Primerjali smo tudi okoljske vplive toplotnoizolacijskih sistemov, vgrajenih na zunanji oziroma notranji strani nosilne konstrukcije.

V okviru raziskovalnega dela smo izvedli tudi študijo občutljivosti, s katero smo ocenili, kako izboljšanje vplivov proizvodnje električne energije po energentih vpliva na povračilno dobo okoljskih vplivov - kar pa je lahko pomemben pokazatelj učinkovitosti ukrepov energijske prenove stavbe.
Glavne ugotovitve, ki sledijo iz naloge, so, da toplotna kapaciteta nosilnega sloja fasadnega ovoja, na katerega se aplicira toplotnoizolacijske sisteme, ne igra pomembne vloge pri zmanjševanju energije za ogrevanje/hlajenje. Lega toplotnoizolacijskega sistema fasadnega ovoja (zunaj ali znotraj) torej nima bistvenega vpliva na rabo energije v fazi rabe stavbe in s tem na povračilno dobo okoljskih vplivov. Razlika v času povračilnih dob je skoraj v celoti odvisna od okoljskih vplivov dodanih materialov.

7.6 Zaključki

7.6.1 Glavne ugotovitve

Pri vrednotenju okoljskih vplivov stavb se prenova običajno obravnava kot začetek novega življenjskega cikla stavbe. Omenjeni pristop ne zagotavlja zanesljivosti dobljenih rezultatov in posledično so lahko napačni tudi zaključki o okoljskih vplivih različnih tehnologij ter materialov. Glavni cilj doktorske disertacije je bil razvoj napredne metodologije za vrednotenje okoljskih vplivov prenove stavb, ki bo odpravila omenjene pomanjkljivosti.

Napredna metodologija, ki smo jo razvili v okviru doktorskega dela, je sestavljena iz dveh delov. Prvi del omogoča prilagajanje trenutno dostopnih podatkov tako, da ustrezajo dejanskemu času proizvodnje. Drugi del metodologije zagotavlja ustrezno razporejanje (alokacijo) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej. Oba dela metodologije lahko uporabimo tudi ločeno.

Vzporedno smo razvili metodologijo LCA za primerjanje ukrepov prenove, ki poleg utelešenih vplivov vključuje tudi okoljske vplive v času rabe stavbe. Naše ugotovitve iz razvoja in uporabe metodologije lahko vežemo na tri različne vsebinske skupine: preoblikovanje trenutno dostopnih podatkov v časovno ustrezne; uporabo razporejanja (alokacije) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej; primerjavo ukrepov prenove, ki poleg utelešenih vplivov vključuje tudi okoljske vplive v času rabe stavbe.

Glavne ugotovitve metodologije za preoblikovanje trenutno dostopnih podatkov v časovno ustrezne: Izvedena raziskava je pokazala, da se izračuni okoljskih emisij istih gradbenih materialov in komponent lahko bistveno razlikujejo v odvisnosti od časa njihove proizvodnje. Podatkov o okoljskih emisijah za materiale iz preteklosti ni, prav tako manjkajo informacije o proizvodnih procesih v preteklosti. Izkazalo se je, da je razlika med okoljskimi vplivi sedanjih materialov in materialov, poizvedenih v preteklosti, velika, in da uporaba podatkov o okoljskih vplivih, kakršne imamo za današnje materiale, zato ni smiselna.

Nova metodologija omogoča preoblikovanje trenutno dostopnih podatkov v časovno ustrezne z zamenjavo podatkov o proizvodnji električne energije po energentih obstoječim podatkom. V študiji smo ugotovili, da emisije proizvodnje električne energije predstavljajo tudi 20 % celotnih toplogrednih emisij posameznih materialov oziroma komponent, zato je zelo pomembno, da je sestava energentov za proizvodnje električne energije ustrezna glede na čas proizvodnje. V primeru, da so energijski viri skoraj razogljičeni (kot se pričakuje v prihodnosti), se lahko relativni prispevek k skupnim emisijam zmanjša do nivoja, ko postane zanemarljiv.

V preteklosti so bili materiali proizvedeni z energijskim viri, ki so imeli večje vplive na okolje kot sedanji. Posledično to tudi pomeni, da je neamortiziran delež okoljskih vplivov ob prenovi stavb večji. Podatek o okoljski amortiziranosti materialov in komponent je pogosto vir informacij za odločanje o ukrepih prenove, zato ga je treba natančno modelirati. Absolutne razlike neamortiziranih okoljskih vplivov so še posebno velike, kadar jih opazujemo na začetku referenčne dobe in se zmanjšujejo, ko se približujemo koncu življenjske dobe. Posledično to pomeni, da je uporaba časovno ustreznih podatkov pomembnejša, če jih opazujemo na začetku življenjske dobe gradbenih materialov in elementov.

Glavne ugotovite metodologije za ustrezno razporejanje (alokacijo) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej: EN 15978 dovoljuje obravnavo prenove stavbe kot začetek novega življenjskega cikla, če prenova ni bila upoštevana na začetku. Razdelitev življenjskega cikla stavb na dva ločena življenjska cikla pomeni, da je treba tudi vplive na okolje ustrezno razporediti med življenjska cikla pred in po prenovi. Novo metodologijo z uporabo alokacije okoljskih vplivov smo razvili z namenom optimizacije omenjenega postopka. Metodologija, zasnovana na ta način, omogoča natančno določitev preostale vrednosti materialov, ki so bili ali ohranjeni ali zavrženi med prenovo. Primerjava neamortiziranih okoljskih vplivov materialov z okoljskimi vplivi novih materialov poda informacije o tem, koliko smo zmanjšali okoljski vpliv celotne prenove zaradi ohranitve določenih komponent ali materialov. Na ta način tudi omogočimo zanesljivo primerjavo vplivov med prenovo stavbe in potencialno zamenjavo le-te z novogradnjo. V metodologiji smo uporabili tudi različne pristope alokacije. Razultati so pokazali, da se največje razlike med njimi pojavijo predvsem v primerih, ko se uporabljajo reciklirani materiali ali če se materiali reciklirajo, oziroma ponovno uporabijo na koncu svojega življenjskega cikla.

Glavne ugotovitve metodologije za primerjave ukrepov prenove, ki poleg utelešenih vplivov vključuje tudi okoljske vplive v času rabe stavbe: Metodologija je namenjena za primerjave okoljskih vplivov pri prenovah, zato glede na običajno LCA metodologijo dopušča poenostavitve. Omenjeno metodologijo smo preizkusili na primeru prenove fasadnega ovoja stavbe. Primerjali smo okoljske vplive petih različnih, pogosto uporabljenih fasadnih ovojev. Debeline toplotnoizolacijskih materialov so bile prilagojene tako, da so vse obravnavane sestave fasadnih ovojev dosegle enak toplotni upor oziroma U-vrednost. Ugotovili smo, da ima aerogel kljub manjši potrebni debelini relativno velike okoljske vplive v primerjavi z ekspandiranim polistirenom, mineralno volno, celulozo in fenolno peno. Izračuni povračilnih dob okoljskih vplivov za različne kategorije so pokazali, da se povračilne dobe zelo razlikujejo glede na opazovano okoljsko kategorijo.

Iz posameznih primerov, v katerih smo primerjali tudi, kako se okoljski vplivi razlikujejo, če toplotnoizolacijski material vgradimo na zunanji ali notranji strani nosilne konstrukcije, smo v nasprotju s pričakovanji ugotovili, da sta povračilni dobi za zunanjo ali notranjo namestitev toplotne izolacije zelo podobni. S tem smo dokazali, da toplotnoakumulacijska masa na rezultat nima bistvenega vpliva.

Na osnovi rezultatov smo podali tudi natančne odgovore posameznih hipotezam, ki smo jih definirali v okviru teme doktorske disertacije:

HIPOTEZA 1: **Za vrednotenje okoljskih vplivnih kategorij (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP) prenove stavbe moramo pri analizi LCA obravnavati celotni življenjski cikel stavbe vključno s fazami pred prenovo**.

Odgovor: Razvita metodologija za razporejanje (alokacijo) vplivov na okolje in preostale vrednosti materialov ter gradbenih elementov v življenjski cikel pred prenovo in po njej, vključuje informacije o materialih pred prenovo. Na ta način lahko ocenimo okoljske vplive faze ob koncu življenjske dobe in vplivov, ki presegajo življenjski cikel stavbe (modul D). Ocena stopnje amortizacije materiala in preostale vrednosti ob določenem trenutku omogoča oceno škode zaradi prezgodnje obnove in s tem olajša primerjavo prenovljenega objekta z novozgrajeno stavbo. S tem smo potrdili, da je treba za pravilno oceno okoljskih vplivov prenove stavb upoštevati tudi faze pred njihovo prenovo.

HIPOTEZA 2: **Pri izračunu okoljskih vplivov prenove obstoječe stavbe z upoštevanjem njene celotne življenjske dobe lahko za že vgrajene materiale uporabimo podatke okoljskih vplivov sorodnih sodobnih materialov.**

Odgovor: V doktorski disertaciji smo dokazali, da se okoljski vplivi strukture energijskih virov zaradi postopnih sprememb same strukture skozi čas zelo spreminjajo in da imajo na ta način velik vpliv tudi na okoljske vplive proizvedenih materialov. S tem smo v nalogi zastavljeno hipotezo, da se trenutni podatki o okoljskih vplivih lahko uporabljajo tudi za materiale, ki so proizvedeni v preteklosti, zavrnili.

HIPOTEZA 3: **Učinki prenove fasadnega ovoja večstanovanjskih stavb se zaradi različnih vrst in načinov vgradnje toplotne izolacije različno odražajo na izbranih okoljskih vplivnih kategorijah (GWP, ODP, AP, EP, ADP-elements, ADP-fossil, POCP).**

Odgovor: Primerjava okoljskih vplivov različnih vrst materialov in njihovih načinov vgradnje je na več primerih pokazala, da je okoljska povračilna doba vgrajene toplotne izolacije z upoštevanjem delovanja stavbe (rabe energije z dinamičnimi učinki akumulacije toplote) zelo malo odvisna od njene lege (zunanja, notranja). Istočasno smo tudi ugotovili, da so okoljski vplivi pomožnih materialov, potrebnih za vgradnjo toplotnoizolacijskega sloja v primerjavi z okoljskimi vplivi toplotne izolacije same, relativno majhni. Zato lahko sklepamo, da toplotnoakumulacijske sposobnosti nosilnega materiala ne vplivajo bistveno na okoljske emisije ukrepov prenove.

7.6.2 Doprinos k znanosti

Temeljit pregled in analiza virov so bili, poleg prepoznanih aktualnih trendov glede odprtih vprašanj na področju LCA v znanstveno-strokovnih krogih, ključni za določitev znanstvenih vprašanj. Istočasno, zaradi izjemne obsežnosti, lahko služita tudi kot koristno orodje drugim raziskovalcem.

Modeliranje časovno ustreznih vhodnih podatkov: Nova metodologija omogoča ustrezno preoblikovanje utelešenih okoljskih emisij materialov, kar je pomembno predvsem za izdelke z zelo dolgo življenjsko dobo, saj vemo, da so podatki časovno vezani na proizvodno tehnologijo in stanje tehnike. Okoljske emisije na ta način lahko ocenjujemo za preteklost in prihodnost. Razvoj in implementacijo metodologije smo opisali v članku »The role of electricity mix and production efficiency improvements on greenhouse gas (GHG) emissions of building components and future refurbishment measures«, ki smo ga objavili v The International Journal of Life Cycle Assessment ((Potrč Obrecht, Jordan, Legat, and Passer 2021).

Metodologija za oceno okoljskih emisij in preostale vrednosti, ki vključuje alokacijo med življenjski ciklom pred in po prenovi: Razvili smo metodologijo, ki omogoča, da se ustrezneje alocira okoljske vplive med življenjskim ciklom pred prenovo ter življenjskim ciklom po prenovi. Ocenili smo tudi so prednosti in slabosti posameznih postopkov alokacije. Izvirnost omenjenega pristopa in prednosti razvite metodologije smo prikazali tudi v članku »An LCA methodology for assessing the environmental impacts of building components before and after refurbishment«, ki smo ga objavili v Journal of Cleaner Production (Potrč Obrecht et al. 2021).

Napredna metodologija za oceno okoljskih vplivov prenove vključuje obe prej omenjeni metodologiji in s tem izboljša natančnost in pravilnost rezultatov.

Razvoj metodologije za primerjavo okoljskih vplivov ukrepov prenove (vključno z okoljskimi vplivi faze uporabe stavbe): Kombinacija dinamičnih orodij za simulacijo energije ter izračuna okoljskih povrnitvenih časov je bila sicer že uporabljena v praksi, vendar brez natančne definicije metodologije in postopkov. V doktorski disertaciji smo z razvojem nove metodologije in natančnim prikazom le-te to pomanjkljivost odpravili. Omenjena metodologija omogoča zanesljivo primerjavo vplivov posameznih prenovitvenih ukrepov, ter s tem tudi okoljsko optimizacijo prenove stavb.

Potencialnega prispevka doktorske disertacije pri zmanjševanju emisij toplogrednih plinov sicer ni mogoče obravnavati kot neposredni znanstveni dosežek, vendar tega vidika ni mogoče v celoti spregledati. Pričakujemo, da bodo posamezni postopki, ki smo jih razvili in verificirali vključeni tudi v predloge izboljšave metodologije LCA za stavbe s strani IEA EBC Annex 72 (Assessing Life Cycle Related Environmental Impacts Caused by Buildings).

7.6.3 Nadaljnje raziskave

Predvideva se, da bo večina prihodnjega raziskovalnega dela usmerjena v izboljšanje razvitih metodologij in poenostavitev njihove uporabe.

Metodologija za modeliranje časovno ustreznih vhodnih podatkov povečuje verodostojnost rezultatov, kljub temu, da za energijske vire materialov in proizvodov iz preteklosti zahteva določene predpostavke. Smiselno bi bilo vzpostaviti baze podatkov o pričakovanih okoljskih vplivih posameznih energijskih virov v prihodnosti, istočasno pa tudi analizirati potencialne izboljšave proizvodnih procesov.

Metodologija za oceno okoljskih emisij in preostale vrednosti, ki vključuje alokacijo med življenjski ciklom pred in po prenovi povečuje preglednost in zanesljivost ocen okoljskih vplivov prenove. Potrebna bi bila učinkovita podpora pri izbiri ustreznega pristopa alokacije, ter tudi zadostne informacije za izračun okoljskih vplivov s posameznimi pristopi. Ugotovili smo, da pogosto manjkajo podatki o razliki v kakovosti med neobdelanimi in recikliranimi materiali, o stopnji recikliranja in ponovne uporabe ali odlaganja materialov. Omenjeno področje spada v okvir nacionalne okoljske politike. Na mednarodnem nivoju bo potrebno uskladiti tudi baze podatkov o življenjskih dobah posameznih materialov.

Zaradi kompleksnosti **metodologije za vrednotenje okoljskih vplivov prenove stavb** bi bilo smiselno optimizirati posamezne postopke. Istočasno so potrebne nadaljnje raziskave o občutljivosti metodologije na različne scenarije in napovedi.

Metodologija za primerjavo okoljskih vplivov ukrepov obnove (vključno z okoljskimi vplivi faze rabe) je bila prikazana na primeru različnih načinov prenove fasadnega ovoja. V prihodnje je potrebno razširiti nabor toplotnih izolacij in sistemov, ter analize razširiti na druga klimatska področja in vire ogrevanja/hlajenja.

Metodologija LCA sicer kaže določene pomanjkljivosti, istočasno pa ima široke možnosti za implementacijo. Smiselno bi bilo poenotiti metodologije za izračune rabe energije v času uporabe stavbe, opredeliti kako se v metodologiji obravnavajo dinamični parametri, vzpostaviti nacionalne baze podatkov, uskladiti podatkovne baze za življenjske dobe materialov, ter sinhronizirati informacijsko modeliranje stavb (BIM) in LCA. Odprtih vprašanj na področju LCA metodologij je še veliko; z razvojem metodologije za izračun okoljskih vplivov prenove stavb smo v okviru te disertacije uspešno odgovorili na enega, a zelo pomembnega. Naše delo bo prispevalo k bolj zanesljivi in celoviti metodologiji LCA za uporabo v gradbeništvu, ter posredno tudi k uspešnejšemu doseganju zavez Evropskega zelenega dogovora (EU Green Deal).

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APPENDIX A

The detailed results of the systematic literature review

		BUILDING TYPE							SCOPE OF THE REFURBISHMENT										TIME OF THE REFURBISHMENT		LCA ANALYSIS							
Year	Author	Residential - multi family	Residential - single family	Residential - not specified	Office buildings	Schools	Mixed use/other	NOT SPECIFIED	Foundation, floor	Structural parts, columns	Staircases	Windows and doors	Exterior walls (including finishes)	Ceilings, floors (including finishes)	Internal walls (and internal doors	Roofs	HVAC	OTHER	YEARS BEFORE REFURBISHMENT	YEAR OF ORIGINAL BUILDING	Database	RSL	Methodology	Impact categories	LCC	EMBODIED EI	OPERATIONAL EMISIONS	ELEMENTS BEFORE REFURBISHMENT INCLUDED IN THE CALCULATION
2015	Nicolae					x							x			x			43	1972				GWP, AP, EP, POCP, EE,				
2017	Vilches																											
2016	Pombo																											
2018	Schwartz																											
2014	Assiego de Larriva		x										x			x	x		41	1983		50		GWP, EE		x	x	
2015	Wang	x	x									x	x			x	x			1945, 1960, 1975	ecoinvent , Gabi			PE, GWP, EE				
2015	Mangan	x											x				x	x			ICE	30		PE, GWP, EP		x		
2014	Cetiner	x							x			x	x			x			15,20,25		ecoinvent	50	Impact 2002+			x	x	
2013	Cellura	x	x	x	x	x	x					x	x				x							GWP		x	x	
2017	Oregi	x							x			x	x			x	x		53	1963	ecoinvent, gabi, EPD	50	CML	NRPE		x		
2018	Valančius		x										x									60	IPPC	NRPE, GWP		x	x	
2018	Volf					x						x	x								EPD, ecoinvent	40		GWP, AP, EP, NRPE		x	x	
2015	Cappelletti																									x		
2017	Rodrigues		x									x	x			x	x			1900s		50	CED, RECIPE	NREP, GWP, ODP, TA, FE, ME	yes	x	x	
2018	Favi																									x		
2017	Moschetti		x									x	x	x	x	x	x								x	x		
2018	Berglund	x															x		58	1960	ecoinvent	50	RECIPE	18 impact categories		x	x	
2016	Monteiro		x																									

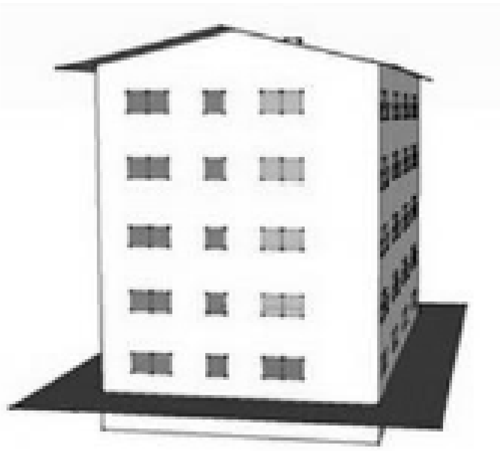
2005	**Dong**							x			x			x		1930, 1960,1980				PE, GWP, water pollution index, solid waste	x		
2018	**Fort**				x										56	1962				GWP, EE	x		
2017	**Ghose**								x	x			x				ecoinvent		UseTox,Recipe, ILCD	GWP			
2017	**Almeida**																				x		
2018	**Marique**			x					x	x				x	71	1934				GWP, CED			
2017	**Gustafsson**									x	x		x				ecoinvent	30	ILCD	NREO, GWP, EM, EP	x	x	x
2015	**Ferreira**	x														1700s	Gabi	50			x		
2014	**Brown**	X						x	x	x		x	x				ecoinvent	DIFFERENT FOR COMPONENTS	CML	GWP			
2011	**Ardente**					x			x	x		x	x							GWP			
2015	**Kmet'kovä**		x															30		GWP, GER	x	x	x
2015	**Tadeu**	x						x	x	x		x	x			2000s		30	IPCC/CML	GWP, NREP, CED		x	x
2008	**Gong**																						
2018	**Mateus**		x						x	x			x	x		1960-1990		30	CML	CED, GWP, EP, AP, ODP, POCP, ADPe, ADPf	x	x	x
2017	**Ghose**			x					x	x		x	x	x	nd			25		GWP, EP, AP, ODP, POCP, ADPe, ADPf, Usetox, PMF, IR		x	x
2017	**Rodrigues**		x							x		x				2000s		50		CED, NRPE, GWP, TA, FE, ME		x	x
2016	**Menna**						x			x	x	x		x			ecoinvent	nd	EPD2008	GWP, ODP, POCP, AP, EP, NREP			
2016	**Holopainen**	x						x	x	x		x	x			1960-1977		30			x	x	x
2016	**Schwartz**	x							x	x			x		45	1950	Bath ICE	60		GWP	x	x	x
2018	**Sierra-Pérez**				x			x	x	x		x					ecoinvent	50	CML	GWP, AP, POCP, EP, EE		x	x
2016	**Fregonara**	x							x	x		x									x	x	
2015	**Oregi**	x							x	x							ecoinvent	50	CML	NRPE		x	x
2015	**Napolano**						x			x					x structural		ecoinvent			GWP, ODP, POCP, AP, EP, NREP		x	

2018	**Berg**		x									x		78	1936	ecoinvent	60		GWP		x	x	
2018	**Wrålsen**	x						x	x	x		x				ecoinvent	30		GWP, IR, ECOTOXICITY, ETC		x	x	
2017	**Weiler**	x												ca 50	1975	ecoinvent	50		GWP		x	x	
2015	**Lasvaux**	x							x			x		45	1965	KBOB	60		GWP, CED		x	x	
2014	**Bull**				x	x		x	x		x	x					60		GWP	x	x	x	
2018	**Marini**																						
2010	**Dodoo**	x						x	x		x	x		25	1995		50		PE		x	x	
2014	**Afshari**			x				x	x		x	x					30		GWP		x	x	
2016	**Almeida**	x						x	x		x	x		ca 70	1950	ecoinvent	30		GWP, CED NREP, CED TOTAL				
2017	**Ascione**			x				x	x			x					20				x	x	
2013	**Ostermeyer**	x						x	x		x	x				ecoinvent	30	RECIPE; IPPC; CED	GWP, CED		x	x	
2014	**Antipova**		x					x	x		x	x		ca 70	1945				GWP		x	x	
2017	**Anand**																						
2018	**Almeida**	x		x				x	x		x	x	x		1950-1987				GWP, CED	x	x	x	
2013	**McGrath**	x														ecoinvent, ICE	50, 80	RECIPE			x	x	
2019	**Sharif**			x	x			x	x		x	x							GWP, TEC	x	x	x	
2017	**Sharif**																						
2015	**Kovacic**	x							x					ca 80	1931	okobaudat	50		GWP, CED	x	x	x	
2018	**Rodrigues**		x					x	x		x						50	RECIPE	GWP, ODP, AP, MEP, FEP	x	x	x	
2016	**Pombo**	x						x	x		x				1960	ecoinvent	50	CML	GWP, ADPF, ADPe, EP, ODP,	x	x	x	
2018	**Rocchi**		x						x									Impact 2002	NREP, ODP, GWP	x			
2018	**Le**																						
2016	**Passer**	x							x			x		53	1961	ecoinvent	60		GWP, CED		x	x	
2018	**Mora**	x				x		x	x		x	x			1960	ecoinvent	30		GWP CED				
2020	**Bari**	x					x		x	x			x				50		GWP	x	x		
2019	**Conci**	x						x	x		x	x	x			ecoinvent	100		GWP	x	x	x	x
2020	**Feng**		x			x		x	x		x	x			1940	ecoinvent	50	TRACI	GWP		x	x	
2020	**Galimshina**	x				x		x	x			x			1960	Bauteilkatalog	60		GWP	x	x	x	
2020	**Ghose**			x				x	x		x	x	x			ecoinvent	30	CML	GWP, ODP; PCOP; AP; AD, PMF, IR		x	x	

2019	**Ghose**				x							x	x			x	x	x		ecoinvent	30	CML	GWP, ODP; PCOP; AP; AD, PMF, IR		x	x		
2020	**Van Gulck**	x											x						1950	ecoinvent	60	RECIPE		x	x	x		
2019	**Hasik**				x							x			x	x				Tally	60	TRACI	GWP, ODP, POCP, AP,AD, EP, NRE		x	x		x
2020	**Mastrucci**	x	x					x				x	x			x	x				100		GWP		x	x		
2019	**Mateus**		x									x	x	x		x	x	x	1961		30	CML	GWP, ODP, POCP, AP, AD, EP, NRPE		x	x		
2020	**Mercader-Moyano**	x										x	x							ITEC, ECOIVENT	50		GWP, ADP	x	x	x		
2020	**Montana**	x										x	x			x			1969	Okobaudat	50		GWP, PE	x	x	x		
2019	**Nydahl**	x										x	x			x	x	x	1965				GWP		x	x		
2020	**Augusto de Oliveira Fernandes**	x	x						x			x	x	x		x	x	x		Dutch National Database, ecoinvent	30		GWP, AD, ODP, POCP, AP, EP, FTP, FAETP, MAETP, TETP		x	x		
2020	**Oregi**	x										x	x				x	x	1960		50	CML		x	x	x		
2019	**Palacios-Munoz**	x										x	x			x			1956	ecoivent	60	IPCC	GWP		x	x		
2019	**RamÃrez-Villegas**	x										x	x			x	x	x	1969	EPD, ecoinvent, gabi	50	CML	GWP, AD, AP, EP, NW	x	x	x		
2019	**RamÃrez-Villegas**	x										x	x			x	x	x	1969	EPD, ecoinvent, gabi	50	CML	GWP, AD, AP, EP	x	x	x		
2020	**Rodriguez**				x												x			Okobaudat, EPD			GWP		x			
2020	**Salgado**							x		x										Gabi		TRACI	GWP, ODP, HT, AC, ET		x			
2020	**Sedlakova**	x									x	x	x	x	x	x	x			eToolLCD, EPD	60	CML	GWP, ODP, AP, EP, POCP, ADP		x	x		
2020	**Shirazi**		x						x			x	x			x	x	x	1970s	Athena library		TRACI	GWP, AP, HH, ODP, POCP, EP		x	x		
2019	**Silvestre**	x											x							ecoinvent, ELCD	50	CML	GWP, NRPE	x	x	x		
2019	**Silvestre**	x											x							ecoinvent, ELCD	50	CML	GWP, NRPE	x	x	x		

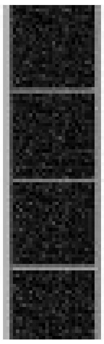
APPENDIX B

REFERENCE BUILDING



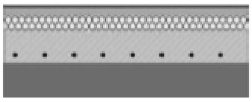
Foundation slab [m^2]	506.50
Exterior walls [m^2]	1241.90
Windows [m^2]	267.90
Slabs [m^2]	2532.50
Inner walls [m^2]	4216,00
Roof [m^2]	646.60
Conditioned volume [m^3]	8863.80
Shape factor [m^{-1}]	0.30
Window-wall ratio (S)	0.16
Window-wall ratio (W)	0.28
Window-wall ratio (E)	0.27
Window-wall ratio (N)	0.06

EXTERIOR WALL 1m^2



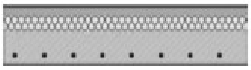
	Thickness [cm]	**Volume [m^3]**	**Mass [kg]**
Cover coat (OUT)	0.015	0.029	28.00
Concrete brick	0.29	0.275	440.00
Adhesive mortar	/	0.015	30.45
Base plaster	0.015	0.015	24.00
Alkayd paint (IN)	/	/	0.28

FOUDATION 1m²



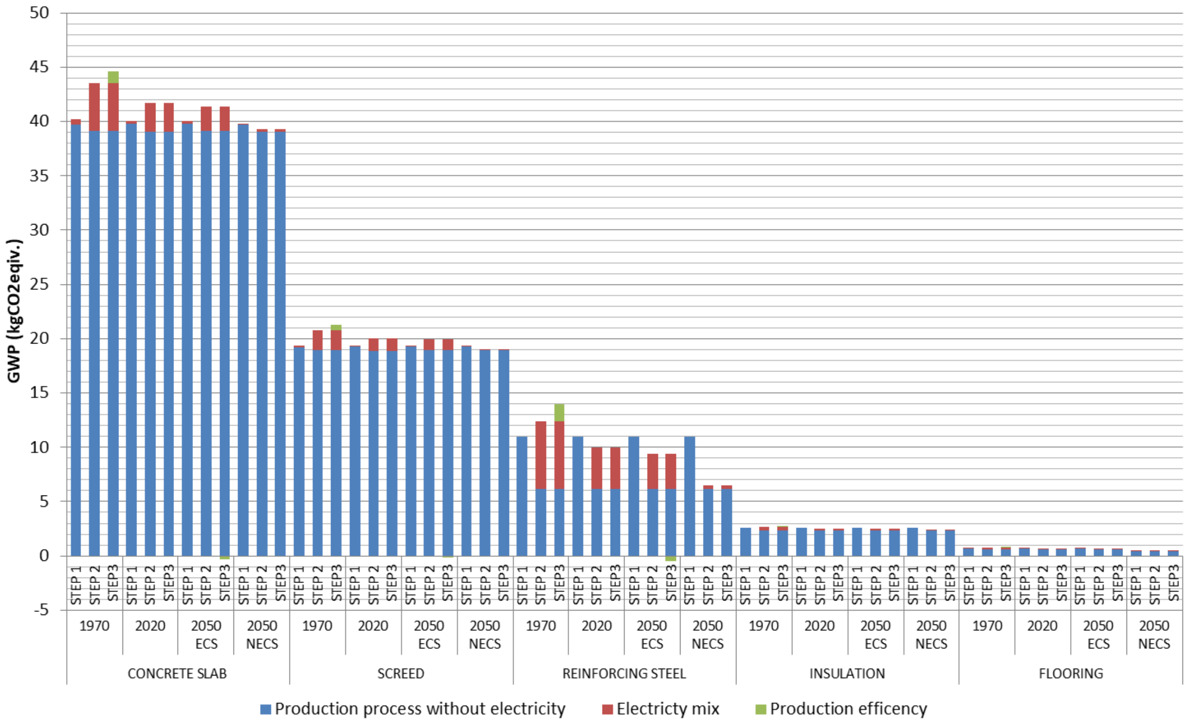
	Thickness [cm]	Mass [kg]
Sawn wood	1.5	8.40
Screed	5.0	110.00
EPS	3.0	0.60
Reinforced concrete	15.0	360.00

FLOOR 1m² (ALSO TO THE ATTIC)



	Thickness [cm]	Mass [kg]
Sawn wood	1.5	8.40
Screed	5.0	110.00
EPS	3.0	0.60
Reinforced concrete	15.0	360.00
Base plaster	1.5	24.00
Alkyd paint	/	0.28

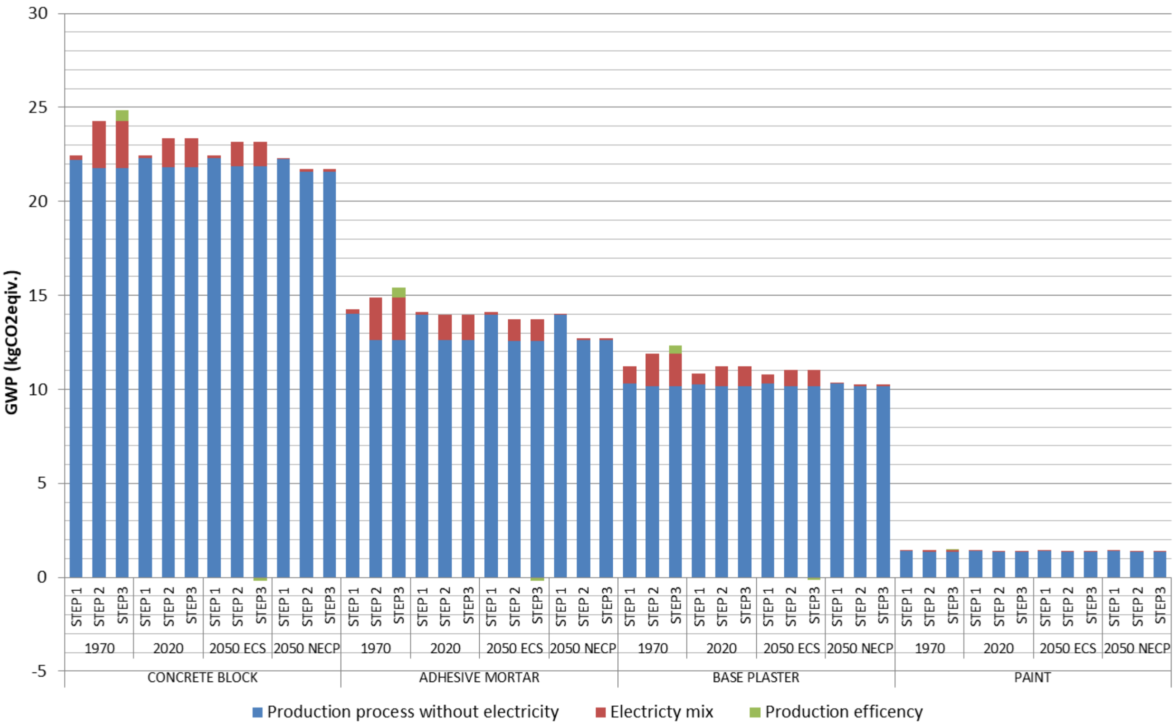
APPENDIX C



Calculated GHG emissions of 1 m^2 of foundation by materials according to the new remodelling approach

Relative contribution of the electricity mix towards the total GHG emission of the foundation materials calculated with electricity mixes for different periods and corresponding production efficiencies

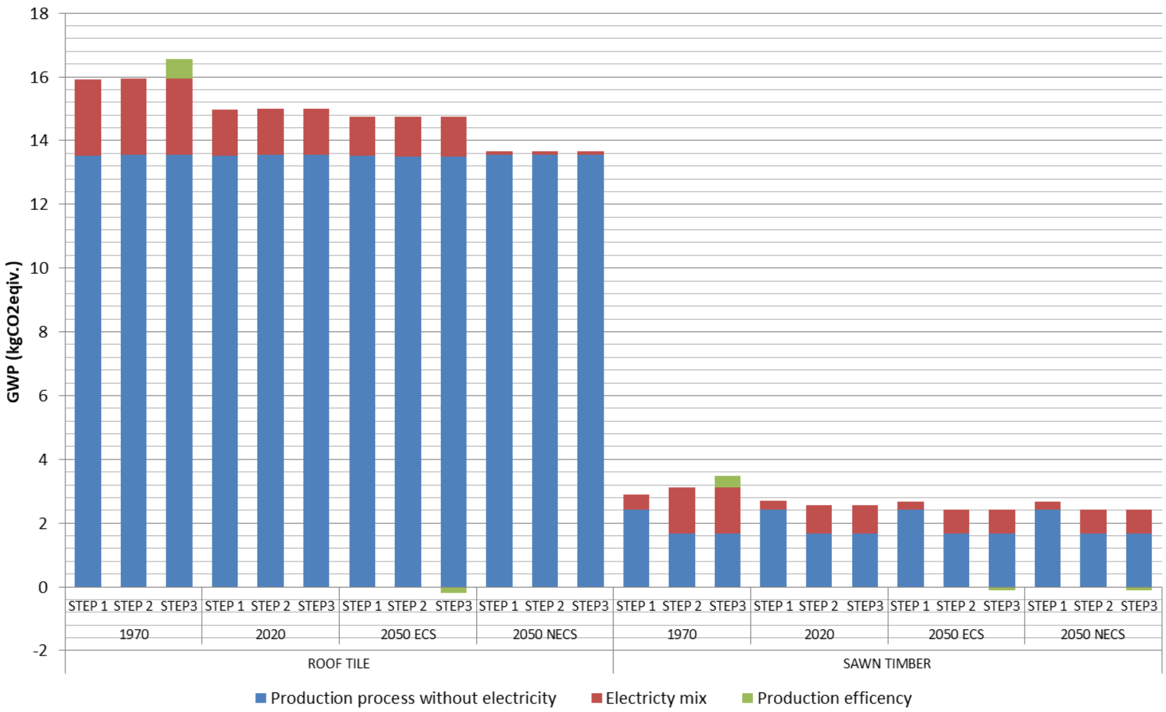
	1970			2020			2050 ECS			2050 NECP		
	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3
CONCRETE SLAB	1.12%	9.99%	12.18%	0.69%	6.33%	6.33%	0.58%	5.43%	4.66%	0.06%	0.61%	0.52%
SCREED	0.78%	8.84%	10.81%	0.48%	5.60%	5.60%	0.41%	4.72%	4.04%	0.04%	0.53%	0.45%
REINFORCING STEEL	0.00%	50.13%	55.68%	0.00%	37.99%	37.99%	0.00%	34.17%	30.61%	0.00%	5.23%	4.48%
INSULATION	0.00%	12.22%	14.82%	0.00%	7.83%	7.83%	0.00%	6.73%	5.78%	0.00%	0.76%	0.65%
FLOORING	8.58%	20.83%	24.75%	5.40%	13.86%	13.86%	4.63%	11.96%	10.36%	0.73%	2.09%	1.78%



Calculated GHG emissions of 1 m^2 of inner wall by materials according to the new remodelling approach

Relative contribution of the electricity mix towards the total GHG emission of inner wall materials calculated with electricity mixes for different periods and corresponding production efficiencies

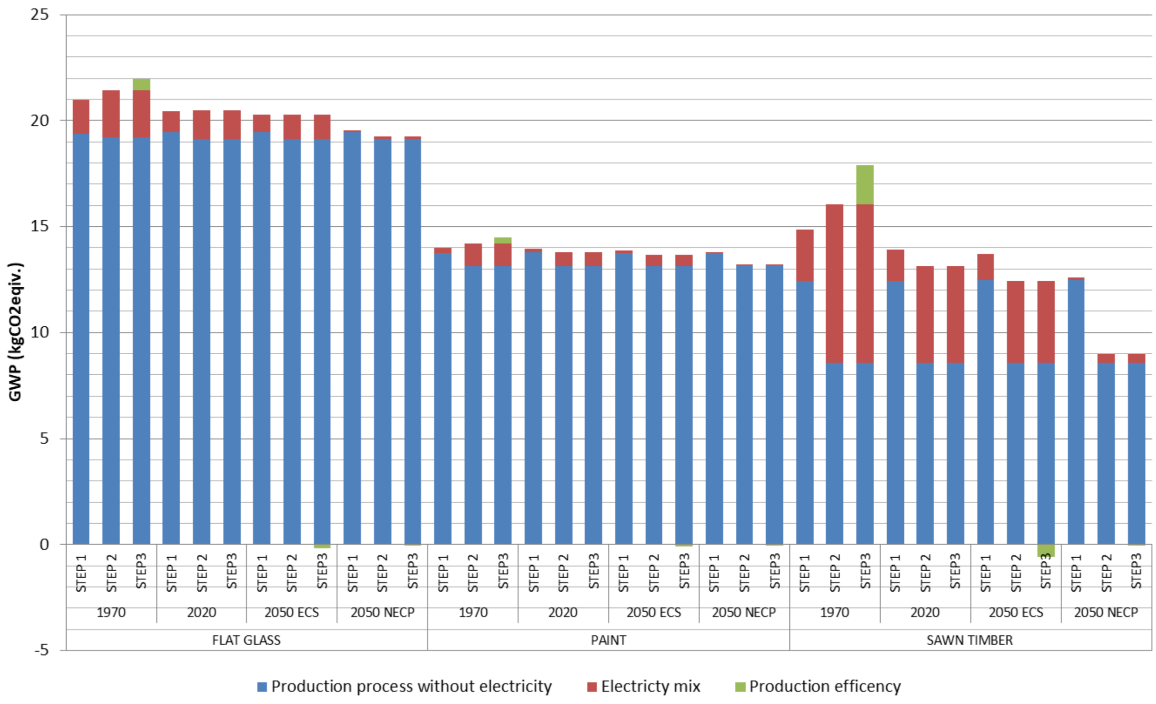
	1970			2020			2050 ECS			2050 NECP		
	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3
CONCRETE BLOCK	1.12%	10.18%	12.41%	0.69%	6.45%	6.45%	0.58%	5.52%	4.73%	0.06%	0.63%	0.53%
ADHESIVE MORTAR	1.70%	15.11%	18.20%	1.04%	9.80%	9.80%	0.89%	8.46%	7.28%	0.09%	0.97%	0.82%
BASE PLASTER	8.21%	14.52%	17.51%	5.18%	9.37%	9.37%	4.41%	8.09%	6.96%	0.49%	0.93%	0.79%
PAINT	1.75%	7.53%	9.24%	1.07%	4.74%	4.74%	0.91%	3.92%	3.35%	0.10%	0.44%	0.38%



Calculated GHG emissions of 1 m^2 of roof by materials according to the new remodelling approach

Relative contribution of the electricity mix towards the total GHG emission of roof materials calculated with electricity mixes for different periods and corresponding production efficiencies

	1970			2020			2050 ECS			2050 NECP		
	STEP 1	**STEP 2**	**STEP3**	**STEP 1**	**STEP 2**	**STEP3**	**STEP 1**	**STEP 2**	**STEP3**	**STEP 1**	**STEP 2**	**STEP3**
ROOF TILE	14,95%	15,07%	18,15%	9,68%	9,77%	9,77%	8,34%	8,43%	7,25%	0,95%	0,97%	0,82%
SAWN TIMBER	16,31%	46,58%	52,15%	10,61%	34,73%	34,73%	9,15%	31,07%	27,70%	9,15%	31,07%	27,70%



Calculated GHG emissions of 1 m^2 of window by materials according to the new remodelling approach

Relative contribution of the electricity mix towards the total GHG emission of window materials calculated with electricity mixes for different periods and corresponding production efficiencies

	1970			2020			2050 ECS			2050 NECP		
	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3	STEP 1	STEP 2	STEP3
FLAT GLASS	7,67%	10,39%	12,66%	4,81%	6,64%	6,64%	4,11%	5,68%	4,87%	0,45%	0,64%	0,54%
PAINT	1,75%	7,53%	9,24%	1,07%	4,74%	4,74%	0,91%	3,92%	3,35%	0,10%	0,44%	0,38%
SAWN TIMBER	16,31%	46,58%	52,15%	10,61%	34,73%	34,73%	9,15%	31,07%	27,70%	1,06%	4,58%	3,92%

APPENDIX D

The inputs for the calculation of the allocation of the EI for the floor

		Evirgin 1970	Evirgin 2020	E virgin m^3	E*virgin (substituted material)	Ereuse	Erecycling	E*rec.eol	Edisposal	Qsin/Qp	Qsout/Qp	A	R0	R1 (LC1)	R2 (LC1)	R1 (LC2)	R2 (LC2)
reinforcing steel	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	0.0000011	0.00000111	0.000000857	0.00000111	0	0.000000749	0.000000749	9.4528E-08	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	28	27.7	9.83	27.7	0	5.62	5.62	0.78824	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	0.00681	0.00632	0.00669	0.00632	0	0.00493	0.00493	0.00043016	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	0.00394	0.00378	0.00246	0.00378	0	0.00178	0.00178	0.000115	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	0.692	0.666	1.36	0.666	0	1.15	1.15	0.1815104	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	1.63	1.61	0.637	1.61	0	0.374	0.374	0.05722	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	1.64	1.62	0.638	1.62	0	0.374	0.374	0.057068	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	0.579	0.566	0.968	0.566	0	0.703	0.703	0.028512	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1700	1630	1980	1630	0	1620	1620	62.0608	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	3.26E-08	3.32E-08	5.18E-08	3.32E-08	0	0.00000003	0.00000003	9.9152E-09	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	0.00131	0.00129	0.000504	0.00129	0	0.000316	0.000316	0.000044356	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	0.00501	0.00499	0.0708	0.00499	0	0.0689	0.0689	0.000196	1	1	0.2		5.00E-01	1.00E+00	1.00E+00	0.95
concrete	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	4.08E-08	4.33E-08	1.04E-04	1.92E-08	0	0	1.92E-08	1.84E-08	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	5.88E-01	5.33E-01	1.28E+03	5.96E-02	0	0	0.087	7.60E-02	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	4.46E-04	3.36E-04	8.06E-01	0.0000262	0	0	0.000105	3.64E-05	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	1.29E-04	9.38E-05	2.25E-01	0.0000103	0	0	3.35E-05	9.81E-06	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.80E-02	1.24E-02	2.97E+01	0.00169	0	0	0.00553	8.57E-04	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	1.21E-01	1.16E-01	2.78E+02	0.00443	0	0	0.00706	4.94E-03	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	1.19E-01	1.14E-01	2.74E+02	0.00439	0	0	0.00702	4.94E-03	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	2.15E-02	1.85E-02	4.44E+01	0.00399	0	0	0.00611	2.29E-03	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	4.83E+01	3.29E+01	7.90E+04	4.21E+00	0	0	14.6	1.15E+00	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	3.40E-09	3.53E-09	8.48E-06	4.89E-10	0	0	4.03E-10	9.37E-10	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2.68E-05	2.23E-05	5.35E-02	0.00000229	0	0	5.48E-06	3.76E-06	1	1	0.5		0	1	1	0.9

	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	2.53E-04	2.49E-04	5.97E-01	0.0000813	0	0	7.33E-05	1.85E-05	1	1	0.5	0	1	1	0.9
cement cast floor	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	1.13E-07	1.14E-07		1.92E-08	0	0	1.92E-08	1.81E-08	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	8.54E-01	9.17E-01		5.96E-02	0	0	0.087	7.38E-02	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	3.46E-04	5.26E-04		0.0000262	0	0	0.000105	3.53E-05	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	1.01E-04	1.54E-04		0.0000103	0	0	3.35E-05	9.49E-06	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.19E-02	2.07E-02		0.00169	0	0	0.00553	4.83E-04	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	1.76E-01	1.82E-01		0.00443	0	0	0.00706	4.78E-03	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	1.72E-01	1.78E-01		0.00439	0	0	0.00702	4.78E-03	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	2.97E-02	3.47E-02		0.00399	0	0	0.00611	2.21E-03	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	3.01E+01	5.40E+01		4.21E+00	0	0	14.6	1.02E+00	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	6.50E-09	6.34E-09		4.89E-10	0	0	4.03E-10	9.10E-10	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	3.02E-05	3.76E-05		0.00000229	0	0	5.48E-06	3.64E-06	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	5.32E-04	5.16E-04		0.0000813	0	0	7.33E-05	1.79E-05	1	1	0.5	0	0.9	0	0.9
sawn timber	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	1.14E-07	1.26E-07	7.54E-05		0	0	1.89E-07	1.15E-07	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	1.66E+00	1.41E+00	843		0	0	0.189	0.251	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	1.82E-03	1.29E-03	0.772		0	0	6.43E-05	8.56E-05	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	5.83E-04	4.13E-04	0.248		0	0	3.69E-05	9.39E-03	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	8.20E-02	5.45E-02	32.7		0	0	0.00803	0.0128	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	-1.24E+00	-1.26E+00	-755		0	0	-1.8	0.091	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	1.27E-01	1.04E-01	62.2		0	0	0.0132	0.069	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.00E-01	8.58E-02	51.5		0	0	0.00958	0.0122	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.13E+02	1.38E+02	8.27E+04		0	0	18.4	15.7	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	8.90E-09	9.55E-09	5.73E-06		0	0	1.71E-09	2.62E-09	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2.33E-04	2.12E-04	0.127		0	0	4.75E-06	2.12E-05	1	1	0.5	0	0.9	0	0.9
	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.03E-03	1.01E-03	0.603		0	0	0.0001	4.13E-04	1	1	0.5	0	0.9	0	0.9
insulation (EPS)	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	4.76E-07	5.83E-07			0	0		6.86E-09	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	9.31E+01	9.07E+01			0	0		0.0605	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	2.53E-02	2.03E-02			0	0		6.43E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	5.25E-03	3.68E-03			0	0		0.0817	1	1	0.5	0	0	0	0

	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	7.55E-01	5.00E-01	0	0	1.19	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	4.46E+00	4.24E+00	0	0	0.144	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	4.43E+00	4.22E+00	0	0	0.144	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	8.84E-01	7.51E-01	0	0	0.394	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.02E+03	1.32E+03	0	0	1.09E+03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	1.12E-07	1.18E-07	0	0	7.61E-10	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	8.19E-03	7.98E-03	0	0	3.13E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	1.32E-02	1.30E-02	0	0	0.000822	1	1	0.5	0	0	0	0
base plaster	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	4.92E-08	5.62E-08	0	0	1.27E-07	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	1.43E+00	1.27E+00	0	0	1.87E-01	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	1.14E-03	8.08E-04	0	0	4.61E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	3.38E-04	2.34E-04	0	0	1.37E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	4.94E-02	3.25E-02	0	0	0.00129	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	2.48E-01	2.34E-01	0	0	0.00764	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	2.43E-01	2.29E-01	0	0	0.00763	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	4.74E-02	3.86E-02	0	0	0.00441	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.34E+02	8.78E+01	0	0	2.65E+00	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	8.82E-09	9.21E-09	0	0	2.29E-09	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	6.68E-05	5.32E-05	0	0	4.86E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	4.35E-04	4.22E-04	0	0	3.67E-05	1	1	0.5	0	0	0	0
paint	**CML2001 - Jan. 2016. Abiotic Depletion (ADP elements) [kg Sb eq.]**	1.09E-05	1.09E-05	0	0	3.80E-08	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Abiotic Depletion (ADP fossil) [MJ]	4.66E+01	4.58E+01	0	0	0.135	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Acidification Potential (AP) [kg SO2 eq.]	2.02E-02	1.85E-02	0	0	3.12E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Eutrophication Potential (EP) [kg Phosphate eq.]	1.08E-02	1.03E-02	0	0	9.25E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.16E+00	1.07E+00	0	0	0.000672	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years) [kg CO2 eq.]	2.59E+00	2.51E+00	0	0	0.00422	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. GWP (GWP 100 years). excl. biogenic carbon [kg CO2 eq.]	2.79E+00	2.71E+00	0	0	0.00421	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016. Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.43E+00	1.38E+00	0	0	0.00224	1	1	0.5	0	0	0	0

CML2001 - Jan. 2016. Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.24E+03	1.98E+03	0	0	1.40E+00	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016. Ozone Layer Depletion Potential (ODP. steady state) [kg R11 eq.]	3.52E-07	3.54E-07	0	0	1.66E-09	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016. Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.49E-03	1.42E-03	0	0	3.34E-06	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016. Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	2.64E-02	2.63E-02	0	0	2.04E-05	1	1	0.5	0	0	0	0

The EI for the LC1 calculated with current data- floor

		IMPACT VIRGIN					IMPACT RECYCLED CONTENT					IMPACT EOL RECYCLING					IMPACT CREDIT (Evsub)					IMPACT EOL DISPOSAL				
		CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF
for m2		(1-R1)*Ev	(1-R1)*Ev	Ev	(1-R1/2)*Ev	(1-R1/2)*Ev	R1*Erec	R1*Erec	0	R1/2*Erecycled	R1/2*Erecycled	0	(R2-R1)*Erec.eol	R2*Erec.eol	R2/2*Erec.eol	R2/2*Erec.eol	0	(R2-R1)*Evsub	(-R2*Evsub)	(-R2/2*Evsub	(-(R2/2)*Evsub(Qsout/Qp))	(1-R2)*Ed	(1-R2)*Ed	(1-R2)*Ed	(1-R2/2)*Ed	(1-R1/2-R2/2)*Ed
reinforcing steel	ADP elements [kg Sb eq.]	8.69E-06	8.69E-06	1.74E-05	1.30E-05	1.30E-05	5.86E-06	5.86E-06	0.00E+00	2.93E-06	2.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.69E-06	-1.74E-05	-8.69E-06	-8.69E-06	0.00E+00	0.00E+00	0.00E+00	7.40E-07	3.70E-07
	ADP fossil [MJ]	2.17E+02	2.17E+02	4.34E+02	3.25E+02	3.25E+02	4.40E+01	4.40E+01	0.00E+00	2.20E+01	2.20E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.17E+02	-4.34E+02	-2.17E+02	-2.17E+02	0.00E+00	0.00E+00	0.00E+00	6.17E+00	3.08E+00
	AP [kg SO2 eq.]	4.95E-02	4.95E-02	9.89E-02	7.42E-02	7.42E-02	3.86E-02	3.86E-02	0.00E+00	1.93E-02	1.93E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.95E-02	-9.89E-02	-4.95E-02	-4.95E-02	0.00E+00	0.00E+00	0.00E+00	3.37E-03	1.68E-03
	EP [kg Phosphate eq.]	2.96E-02	2.96E-02	5.92E-02	4.44E-02	4.44E-02	1.39E-02	1.39E-02	0.00E+00	6.96E-03	6.96E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.96E-02	-5.92E-02	-2.96E-02	-2.96E-02	0.00E+00	0.00E+00	0.00E+00	9.00E-04	4.50E-04
	FAETP inf. [kg DCB eq.]	5.21E+00	5.21E+00	1.04E+01	7.82E+00	7.82E+00	9.00E+00	9.00E+00	0.00E+00	4.50E+00	4.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.21E+00	-1.04E+01	-5.21E+00	-5.21E+00	0.00E+00	0.00E+00	0.00E+00	1.42E+00	7.10E-01
	GWP 100 years [kg CO2 eq.]	1.26E+01	1.26E+01	2.52E+01	1.89E+01	1.89E+01	2.93E+00	2.93E+00	0.00E+00	1.46E+00	1.46E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.26E+01	-2.52E+01	-1.26E+01	-1.26E+01	0.00E+00	0.00E+00	0.00E+00	4.48E-01	2.24E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	1.27E+01	1.27E+01	2.54E+01	1.90E+01	1.90E+01	2.93E+00	2.93E+00	0.00E+00	1.46E+00	1.46E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.27E+01	-2.54E+01	-1.27E+01	-1.27E+01	0.00E+00	0.00E+00	0.00E+00	4.47E-01	2.23E-01
	HTP inf. [kg DCB eq.]	4.43E+00	4.43E+00	8.86E+00	6.64E+00	6.64E+00	5.50E+00	5.50E+00	0.00E+00	2.75E+00	2.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.43E+00	-8.86E+00	-4.43E+00	-4.43E+00	0.00E+00	0.00E+00	0.00E+00	2.23E-01	1.12E-01
	MAETP inf. [kg DCB eq.]	1.28E+04	1.28E+04	2.55E+04	1.91E+04	1.91E+04	1.27E+04	1.27E+04	0.00E+00	6.34E+03	6.34E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.28E+04	-2.55E+04	-1.28E+04	-1.28E+04	0.00E+00	0.00E+00	0.00E+00	4.86E+02	2.43E+02
	ODP. steady state [kg R11 eq.]	2.60E-07	2.60E-07	5.20E-07	3.90E-07	3.90E-07	2.35E-07	2.35E-07	0.00E+00	1.17E-07	1.17E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.60E-07	-5.20E-07	-2.60E-07	-2.60E-07	0.00E+00	0.00E+00	0.00E+00	7.76E-08	3.88E-08
	POCP [kg Ethene eq.]	1.01E-02	1.01E-02	2.02E-02	1.51E-02	1.51E-02	2.47E-03	2.47E-03	0.00E+00	1.24E-03	1.24E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.01E-02	-2.02E-02	-1.01E-02	-1.01E-02	0.00E+00	0.00E+00	0.00E+00	3.47E-04	1.74E-04
	TETP inf. [kg DCB eq.]	3.90E-02	3.90E-02	7.81E-02	5.86E-02	5.86E-02	5.39E-01	5.39E-01	0.00E+00	2.70E-01	2.70E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.90E-02	-7.81E-02	-3.90E-02	-3.90E-02	0.00E+00	0.00E+00	0.00E+00	1.53E-03	7.67E-04
concrete	ADP elements [kg Sb eq.]	1.56E-05	1.56E-05	1.56E-05	1.56E-05	1.56E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.56E-05	-1.56E-05	-7.80E-06	-7.80E-06	0.00E+00	0.00E+00	0.00E+00	3.30E-06	3.30E-06
	ADP fossil [MJ]	1.92E+02	1.92E+02	1.92E+02	1.92E+02	1.92E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.92E+02	-1.92E+02	-9.60E+01	-9.60E+01	0.00E+00	0.00E+00	0.00E+00	1.37E+01	1.37E+01
	AP [kg SO2 eq.]	1.21E-01	1.21E-01	1.21E-01	1.21E-01	1.21E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.21E-01	-1.21E-01	-6.05E-02	-6.05E-02	0.00E+00	0.00E+00	0.00E+00	6.56E-03	6.56E-03
	EP [kg Phosphate eq.]	3.38E-02	3.38E-02	3.38E-02	3.38E-02	3.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.38E-02	-3.38E-02	-1.69E-02	-1.69E-02	0.00E+00	0.00E+00	0.00E+00	1.77E-03	1.77E-03
	FAETP inf. [kg DCB eq.]	4.46E+00	4.46E+00	4.46E+00	4.46E+00	4.46E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.46E+00	-4.46E+00	-2.23E+00	-2.23E+00	0.00E+00	0.00E+00	0.00E+00	1.54E-01	1.54E-01
	GWP 100 years [kg CO2 eq.]	4.17E+01	4.17E+01	4.17E+01	4.17E+01	4.17E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.17E+01	-4.17E+01	-2.09E+01	-2.09E+01	0.00E+00	0.00E+00	0.00E+00	8.90E-01	8.90E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	4.11E+01	4.11E+01	4.11E+01	4.11E+01	4.11E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.11E+01	-4.11E+01	-2.06E+01	-2.06E+01	0.00E+00	0.00E+00	0.00E+00	8.90E-01	8.90E-01
	HTP inf. [kg DCB eq.]	6.66E+00	6.66E+00	6.66E+00	6.66E+00	6.66E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-6.66E+00	-6.66E+00	-3.33E+00	-3.33E+00	0.00E+00	0.00E+00	0.00E+00	4.11E-01	4.11E-01

	MAETP inf. [kg DCB eq.]	1.19E+04	1.19E+04	1.19E+04	1.19E+04	1.19E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.19E+04	-1.19E+04	-5.93E+03	-5.93E+03	0.00E+00	0.00E+00	0.00E+00	2.08E+02	2.08E+02
	ODP. steady state [kg R11 eq.]	1.27E-06	1.27E-06	1.27E-06	1.27E-06	1.27E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.27E-06	-1.27E-06	-6.36E-07	-6.36E-07	0.00E+00	0.00E+00	0.00E+00	1.69E-07	1.69E-07
	POCP [kg Ethene eq.]	8.03E-03	8.03E-03	8.03E-03	8.03E-03	8.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.03E-03	-8.03E-03	-4.01E-03	-4.01E-03	0.00E+00	0.00E+00	0.00E+00	6.78E-04	6.78E-04
	TETP inf. [kg DCB eq.]	8.96E-02	8.96E-02	8.96E-02	8.96E-02	8.96E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.96E-02	-8.96E-02	-4.48E-02	-4.48E-02	0.00E+00	0.00E+00	0.00E+00	3.32E-03	3.32E-03
cement cast floor	**ADP elements [kg Sb eq.]**	1.25E-05	1.25E-05	1.25E-05	1.25E-05	1.25E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-06	1.90E-06	9.50E-07	9.50E-07	0.00E+00	-1.90E-06	-1.90E-06	-9.50E-07	-9.50E-07	1.99E-07	1.99E-07	1.99E-07	1.09E-06	1.09E-06
	ADP fossil [MJ]	1.01E+02	1.01E+02	1.01E+02	1.01E+02	1.01E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.61E+00	8.61E+00	4.31E+00	4.31E+00	0.00E+00	-5.90E+00	-5.90E+00	-2.95E+00	-2.95E+00	8.11E-01	8.11E-01	8.11E-01	4.46E+00	4.46E+00
	AP [kg SO2 eq.]	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E-02	1.04E-02	5.20E-03	5.20E-03	0.00E+00	-2.59E-03	-2.59E-03	-1.30E-03	-1.30E-03	3.88E-04	3.88E-04	3.88E-04	2.13E-03	2.13E-03
	EP [kg Phosphate eq.]	1.69E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.32E-03	3.32E-03	1.66E-03	1.66E-03	0.00E+00	-1.02E-03	-1.02E-03	-5.10E-04	-5.10E-04	1.04E-04	1.04E-04	1.04E-04	5.74E-04	5.74E-04
	FAETP inf. [kg DCB eq.]	2.28E+00	2.28E+00	2.28E+00	2.28E+00	2.28E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.47E-01	5.47E-01	2.74E-01	2.74E-01	0.00E+00	-1.67E-01	-1.67E-01	-8.37E-02	-8.37E-02	5.31E-03	5.31E-03	5.31E-03	2.92E-02	2.92E-02
	GWP 100 years [kg CO2 eq.]	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.99E-01	6.99E-01	3.49E-01	3.49E-01	0.00E+00	-4.39E-01	-4.39E-01	-2.19E-01	-2.19E-01	5.26E-02	5.26E-02	5.26E-02	2.89E-01	2.89E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	1.96E+01	1.96E+01	1.96E+01	1.96E+01	1.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E-01	6.95E-01	3.47E-01	3.47E-01	0.00E+00	-4.35E-01	-4.35E-01	-2.17E-01	-2.17E-01	5.26E-02	5.26E-02	5.26E-02	2.89E-01	2.89E-01
	HTP inf. [kg DCB eq.]	3.82E+00	3.82E+00	3.82E+00	3.82E+00	3.82E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.05E-01	6.05E-01	3.02E-01	3.02E-01	0.00E+00	-3.95E-01	-3.95E-01	-1.98E-01	-1.98E-01	2.43E-02	2.43E-02	2.43E-02	1.34E-01	1.34E-01
	MAETP inf. [kg DCB eq.]	5.94E+03	5.94E+03	5.94E+03	5.94E+03	5.94E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E+03	1.45E+03	7.23E+02	7.23E+02	0.00E+00	-4.17E+02	-4.17E+02	-2.08E+02	-2.08E+02	1.12E+01	1.12E+01	1.12E+01	6.18E+01	6.18E+01
	ODP. steady state [kg R11 eq.]	6.97E-07	6.97E-07	6.97E-07	6.97E-07	6.97E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-08	3.99E-08	1.99E-08	1.99E-08	0.00E+00	-4.84E-08	-4.84E-08	-2.42E-08	-2.42E-08	1.00E-08	1.00E-08	1.00E-08	5.51E-08	5.51E-08
	POCP [kg Ethene eq.]	4.14E-03	4.14E-03	4.14E-03	4.14E-03	4.14E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-04	5.43E-04	2.71E-04	2.71E-04	0.00E+00	-2.27E-04	-2.27E-04	-1.13E-04	-1.13E-04	4.01E-05	4.01E-05	4.01E-05	2.20E-04	2.20E-04
	TETP inf. [kg DCB eq.]	5.68E-02	5.68E-02	5.68E-02	5.68E-02	5.68E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.26E-03	7.26E-03	3.63E-03	3.63E-03	0.00E+00	-8.05E-03	-8.05E-03	-4.02E-03	-4.02E-03	1.97E-04	1.97E-04	1.97E-04	1.08E-03	1.08E-03
sawn timber	**ADP elements [kg Sb eq.]**	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E-06	1.43E-06	7.14E-07	7.14E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.66E-08	9.66E-08	9.66E-08	5.31E-07	5.31E-07
	ADP fossil [MJ]	1.18E+01	1.18E+01	1.18E+01	1.18E+01	1.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+00	1.43E+00	7.14E-01	7.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-01	2.11E-01	2.11E-01	1.16E+00	1.16E+00
	AP [kg SO2 eq.]	1.08E-02	1.08E-02	1.08E-02	1.08E-02	1.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-04	4.86E-04	2.43E-04	2.43E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E-05	7.19E-05	7.19E-05	3.95E-04	3.95E-04
	EP [kg Phosphate eq.]	3.47E-03	3.47E-03	3.47E-03	3.47E-03	3.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-04	2.79E-04	1.39E-04	1.39E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.89E-03	7.89E-03	7.89E-03	4.34E-02	4.34E-02
	FAETP inf. [kg DCB eq.]	4.58E-01	4.58E-01	4.58E-01	4.58E-01	4.58E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.07E-02	6.07E-02	3.04E-02	3.04E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-02	1.08E-02	1.08E-02	5.91E-02	5.91E-02
	GWP 100 years [kg CO2 eq.]	-1.06E+01	-1.06E+01	-1.06E+01	-1.06E+01	-1.06E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.36E+01	-1.36E+01	-6.80E+00	-6.80E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.64E-02	7.64E-02	7.64E-02	4.20E-01	4.20E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	8.71E-01	8.71E-01	8.71E-01	8.71E-01	8.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.98E-02	9.98E-02	4.99E-02	4.99E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-02	5.80E-02	5.80E-02	3.19E-01	3.19E-01
	HTP inf. [kg DCB eq.]	7.21E-	7.21E-	7.21E-01	7.21E-01	7.21E-01	0.00E+0	0.00E+	0.00E+00	0.00E+00	0.00E+00	0.00E+0	7.24E-02	7.24E-02	3.62E-02	3.62E-02	0.00E+0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-	1.02E-	1.02E-02	5.64E-02	5.64E-02

		01	01				0	00				0					0					02	02			
	MAETP inf. [kg DCB eq.]	1.16E+03	1.16E+03	1.16E+03	1.16E+03	1.16E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E+02	1.39E+02	6.96E+01	6.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+01	1.32E+01	1.32E+01	7.25E+01	7.25E+01
	ODP. steady state [kg R11 eq.]	8.02E-08	8.02E-08	8.02E-08	8.02E-08	8.02E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-08	1.29E-08	6.46E-09	6.46E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-09	2.20E-09	2.20E-09	1.21E-08	1.21E-08
	POCP [kg Ethene eq.]	1.78E-03	1.78E-03	1.78E-03	1.78E-03	1.78E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E-05	3.59E-05	1.80E-05	1.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-05	1.78E-05	1.78E-05	9.79E-05	9.79E-05
	TETP inf. [kg DCB eq.]	8.44E-03	8.44E-03	8.44E-03	8.44E-03	8.44E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.56E-04	7.56E-04	3.78E-04	3.78E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.47E-04	3.47E-04	3.47E-04	1.91E-03	1.91E-03
insulation (EPS)	**ADP elements [kg Sb eq.]**	3.50E-07	3.50E-07	3.50E-07	3.50E-07	3.50E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E-09	4.12E-09	4.12E-09	4.12E-09	4.12E-09
	ADP fossil [MJ]	5.44E+01	5.44E+01	5.44E+01	5.44E+01	5.44E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.63E-02	3.63E-02	3.63E-02	3.63E-02	3.63E-02
	AP [kg SO2 eq.]	1.22E-02	1.22E-02	1.22E-02	1.22E-02	1.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.86E-05	3.86E-05	3.86E-05	3.86E-05	3.86E-05
	EP [kg Phosphate eq.]	2.21E-03	2.21E-03	2.21E-03	2.21E-03	2.21E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	4.90E-02	4.90E-02	4.90E-02	4.90E-02
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.14E-01	7.14E-01	7.14E-01	7.14E-01	7.14E-01
	GWP 100 years [kg CO2 eq.]	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-02	8.64E-02	8.64E-02	8.64E-02	8.64E-02
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	2.53E+00	2.53E+00	2.53E+00	2.53E+00	2.53E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-02	8.64E-02	8.64E-02	8.64E-02	8.64E-02
	HTP inf. [kg DCB eq.]	4.51E-01	4.51E-01	4.51E-01	4.51E-01	4.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-01	2.36E-01	2.36E-01	2.36E-01	2.36E-01
	MAETP inf. [kg DCB eq.]	7.92E+02	7.92E+02	7.92E+02	7.92E+02	7.92E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E+02	6.54E+02	6.54E+02	6.54E+02	6.54E+02
	ODP. steady state [kg R11 eq.]	7.08E-08	7.08E-08	7.08E-08	7.08E-08	7.08E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E-10	4.57E-10	4.57E-10	4.57E-10	4.57E-10
	POCP [kg Ethene eq.]	4.79E-03	4.79E-03	4.79E-03	4.79E-03	4.79E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.88E-05
	TETP inf. [kg DCB eq.]	7.80E-03	7.80E-03	7.80E-03	7.80E-03	7.80E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04
base plaster	**ADP elements [kg Sb eq.]**	1.35E-06	1.35E-06	1.35E-06	1.35E-06	1.35E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06
	ADP fossil [MJ]	3.05E+01	3.05E+01	3.05E+01	3.05E+01	3.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00
	AP [kg SO2 eq.]	1.94E-02	1.94E-02	1.94E-02	1.94E-02	1.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	1.11E-03	1.11E-03	1.11E-03	1.11E-03
	EP [kg Phosphate eq.]	5.62E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-04	3.29E-04	3.29E-04	3.29E-04	3.29E-04
	FAETP inf. [kg DCB eq.]	7.80E-01	7.80E-01	7.80E-01	7.80E-01	7.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
	GWP 100 years [kg CO2 eq.]	5.62E+00	5.62E+00	5.62E+00	5.62E+00	5.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.50E+00	5.50E+00	5.50E+00	5.50E+00	5.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01

	HTP inf. [kg DCB eq.]	9.26E-01	9.26E-01	9.26E-01	9.26E-01	9.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-01	1.06E-01	1.06E-01	1.06E-01	1.06E-01
	MAETP inf. [kg DCB eq.]	2.11E+03	2.11E+03	2.11E+03	2.11E+03	2.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E+01	6.36E+01	6.36E+01	6.36E+01	6.36E+01
	ODP. steady state [kg R11 eq.]	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-08	5.50E-08	5.50E-08	5.50E-08	5.50E-08
	POCP [kg Ethene eq.]	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-04	1.17E-04	1.17E-04	1.17E-04	1.17E-04
	TETP inf. [kg DCB eq.]	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-04	8.81E-04	8.81E-04	8.81E-04	8.81E-04
paint	**ADP elements [kg Sb eq.]**	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-08	1.06E-08	1.06E-08	1.06E-08	1.06E-08
	ADP fossil [MJ]	1.28E+01	1.28E+01	1.28E+01	1.28E+01	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-02	3.78E-02	3.78E-02	3.78E-02	3.78E-02
	AP [kg SO2 eq.]	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.74E-06	8.74E-06	8.74E-06	8.74E-06	8.74E-06
	EP [kg Phosphate eq.]	2.88E-03	2.88E-03	2.88E-03	2.88E-03	2.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	1.88E-04	1.88E-04	1.88E-04	1.88E-04
	GWP 100 years [kg CO2 eq.]	7.03E-01	7.03E-01	7.03E-01	7.03E-01	7.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	7.59E-01	7.59E-01	7.59E-01	7.59E-01	7.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	HTP inf. [kg DCB eq.]	3.86E-01	3.86E-01	3.86E-01	3.86E-01	3.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-04	6.27E-04	6.27E-04	6.27E-04	6.27E-04
	MAETP inf. [kg DCB eq.]	5.54E+02	5.54E+02	5.54E+02	5.54E+02	5.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-01	3.92E-01	3.92E-01	3.92E-01	3.92E-01
	ODP. steady state [kg R11 eq.]	9.91E-08	9.91E-08	9.91E-08	9.91E-08	9.91E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E-10	4.65E-10	4.65E-10	4.65E-10	4.65E-10
	POCP [kg Ethene eq.]	3.98E-04	3.98E-04	3.98E-04	3.98E-04	3.98E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.35E-07	9.35E-07	9.35E-07	9.35E-07	9.35E-07
	TETP inf. [kg DCB eq.]	7.36E-03	7.36E-03	7.36E-03	7.36E-03	7.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-06	5.71E-06	5.71E-06	5.71E-06	5.71E-06

The EI for the LC2 calculated with current data – floor

for m2		IMPACT VIRGIN					IMPACT RECYCLED CONTENT					IMPACT EOL RECYCLING					IMPACT CREDIT (Evsub)					IMPACT EOL DISPOSAL				
		CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50:00	PEF
		(1-R1)*Ev	(1-R1)*Ev	Ev	(1-R1/2)*Ev	(1-R1/2)*Ev	R1*Erec	R1*Erec	0	R1/2*Erecycled	R1/2*Erecycled	0	(R2-R1)*Erec.eol	R2*Erec.eol	R2/2*Erec.eol	R2/2*Erec.eol	0	(R2-R1)*Evsub	(-R2*Evsub)	(-R2/2*Evsub	(-(R2/2)*Evsub(Qsout/Qp))	(1-R2)*Ed	(1-R2)*Ed	(1-R2)*Ed	(1-R2/2)*Ed	(1-R1/2-R2/2)*Ed
reinforcing steel	ADP elements [kg Sb eq.]	0.00E+00	0.00E+00	1.74E-05	8.69E-06	8.69E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.69E-07	-1.65E-05	-8.25E-06	-8.25E-06	7.40E-08	7.40E-08	7.40E-08	7.77E-07	3.70E-08
	ADP fossil [MJ]	0.00E+00	0.00E+00	4.34E+02	2.17E+02	2.17E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.17E+01	-4.12E+02	-2.06E+02	-2.06E+02	6.17E-01	6.17E-01	6.17E-01	6.48E+00	3.08E-01
	AP [kg SO2 eq.]	0.00E+00	0.00E+00	9.89E-02	4.95E-02	4.95E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.95E-03	-9.40E-02	-4.70E-02	-4.70E-02	3.37E-04	3.37E-04	3.37E-04	3.53E-03	1.68E-04
	EP [kg Phosphate eq.]	0.00E+00	0.00E+00	5.92E-02	2.96E-02	2.96E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.96E-03	-5.62E-02	-2.81E-02	-2.81E-02	9.00E-05	9.00E-05	9.00E-05	9.45E-04	4.50E-05
	FAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	1.04E+01	5.21E+00	5.21E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.21E-01	-9.90E+00	-4.95E+00	-4.95E+00	1.42E-01	1.42E-01	1.42E-01	1.49E+00	7.10E-02
	GWP 100 years [kg CO2 eq.]	0.00E+00	0.00E+00	2.52E+01	1.26E+01	1.26E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.26E+00	-2.39E+01	-1.20E+01	-1.20E+01	4.48E-02	4.48E-02	4.48E-02	4.70E-01	2.24E-02
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0.00E+00	0.00E+00	2.54E+01	1.27E+01	1.27E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.27E+00	-2.41E+01	-1.20E+01	-1.20E+01	4.47E-02	4.47E-02	4.47E-02	4.69E-01	2.23E-02
	HTP inf. [kg DCB eq.]	0.00E+00	0.00E+00	8.86E+00	4.43E+00	4.43E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.43E-01	-8.42E+00	-4.21E+00	-4.21E+00	2.23E-02	2.23E-02	2.23E-02	2.34E-01	1.12E-02
	MAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	2.55E+04	1.28E+04	1.28E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.28E+03	-2.42E+04	-1.21E+04	-1.21E+04	4.86E+01	4.86E+01	4.86E+01	5.10E+02	2.43E+01
	ODP. steady state [kg R11 eq.]	0.00E+00	0.00E+00	5.20E-07	2.60E-07	2.60E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.60E-08	-4.94E-07	-2.47E-07	-2.47E-07	7.76E-09	7.76E-09	7.76E-09	8.15E-08	3.88E-09
	POCP [kg Ethene eq.]	0.00E+00	0.00E+00	2.02E-02	1.01E-02	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.01E-03	-1.92E-02	-9.59E-03	-9.59E-03	3.47E-05	3.47E-05	3.47E-05	3.64E-04	1.74E-05
	TETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	7.81E-02	3.90E-02	3.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.90E-03	-7.42E-02	-3.71E-02	-3.71E-02	1.53E-04	1.53E-04	1.53E-04	1.61E-03	7.67E-05
concrete	ADP elements [kg Sb eq.]	0.00E+00	0.00E+00	1.56E-05	7.80E-06	7.80E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-6.91E-07	-6.22E-06	-3.11E-06	-3.11E-06	6.61E-07	6.61E-07	6.61E-07	3.63E-06	3.30E-07
	ADP fossil [MJ]	0.00E+00	0.00E+00	1.92E+02	9.60E+01	9.60E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.15E+00	-1.93E+01	-9.66E+00	-9.66E+00	2.73E+00	2.73E+00	2.73E+00	1.50E+01	1.37E+00
	AP [kg SO2 eq.]	0.00E+00	0.00E+00	1.21E-01	6.05E-02	6.05E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-9.43E-04	-8.49E-03	-4.24E-03	-4.24E-03	1.31E-03	1.31E-03	1.31E-03	7.22E-03	6.56E-04
	EP [kg Phosphate eq.]	0.00E+00	0.00E+00	3.38E-02	1.69E-02	1.69E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.71E-04	-3.34E-03	-1.67E-03	-1.67E-03	3.53E-04	3.53E-04	3.53E-04	1.94E-03	1.77E-04
	FAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	4.46E+00	2.23E+00	2.23E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-6.08E-02	-5.48E-01	-2.74E-01	-2.74E-01	3.08E-02	3.08E-02	3.08E-02	1.70E-01	1.54E-02
	GWP 100 years [kg CO2 eq.]	0.00E+00	0.00E+00	4.17E+01	2.09E+01	2.09E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.59E-01	-1.44E+00	-7.18E-01	-7.18E-01	1.78E-01	1.78E-01	1.78E-01	9.79E-01	8.90E-02
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0.00E+00	0.00E+00	4.11E+01	2.06E+01	2.06E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.58E-01	-1.42E+00	-7.11E-01	-7.11E-01	1.78E-01	1.78E-01	1.78E-01	9.79E-01	8.90E-02
	HTP inf. [kg DCB eq.]	0.00E+00	0.00E+00	6.66E+00	3.33E+00	3.33E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.44E-01	-1.29E+00	-6.46E-01	-6.46E-01	8.23E-02	8.23E-02	8.23E-02	4.53E-01	4.11E-02

	MAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	1.19E+04	5.93E+03	5.93E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.52E+02	-1.36E+03	-6.82E+02	-6.82E+02	4.16E+01	4.16E+01	4.16E+01	2.29E+02	2.08E+01
	ODP. steady state [kg R11 eq.]	0.00E+00	0.00E+00	1.27E-06	6.36E-07	6.36E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.76E-08	-1.58E-07	-7.92E-08	-7.92E-08	3.37E-08	3.37E-08	3.37E-08	1.86E-07	1.69E-08
	POCP [kg Ethene eq.]	0.00E+00	0.00E+00	8.03E-03	4.01E-03	4.01E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.24E-05	-7.42E-04	-3.71E-04	-3.71E-04	1.36E-04	1.36E-04	1.36E-04	7.45E-04	6.78E-05
	TETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	8.96E-02	4.48E-02	4.48E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.93E-03	-2.63E-02	-1.32E-02	-1.32E-02	6.65E-04	6.65E-04	6.65E-04	3.66E-03	3.32E-04
cement cast floor	ADP elements [kg Sb eq.]	1.25E-05	1.25E-05	1.25E-05	1.25E-05	1.25E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-06	1.90E-06	9.50E-07	9.50E-07	0.00E+00	1.90E-06	-1.90E-06	-9.50E-07	-9.50E-07	1.99E-07	1.99E-07	1.99E-07	1.09E-06	1.09E-06
cement cast floor	ADP fossil [MJ]	1.01E+02	1.01E+02	1.01E+02	1.01E+02	1.01E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.61E+00	8.61E+00	4.31E+00	4.31E+00	0.00E+00	5.90E+00	-5.90E+00	-2.95E+00	-2.95E+00	8.11E-01	8.11E-01	8.11E-01	4.46E+00	4.46E+00
cement cast floor	AP [kg SO2 eq.]	5.79E-02	5.79E-02	5.79E-02	5.79E-02	5.79E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E-02	1.04E-02	5.20E-03	5.20E-03	0.00E+00	2.59E-03	-2.59E-03	-1.30E-03	-1.30E-03	3.88E-04	3.88E-04	3.88E-04	2.13E-03	2.13E-03
cement cast floor	EP [kg Phosphate eq.]	1.69E-02	1.69E-02	1.69E-02	1.69E-02	1.69E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.32E-03	3.32E-03	1.66E-03	1.66E-03	0.00E+00	1.02E-03	-1.02E-03	-5.10E-04	-5.10E-04	1.04E-04	1.04E-04	1.04E-04	5.74E-04	5.74E-04
cement cast floor	FAETP inf. [kg DCB eq.]	2.28E+00	2.28E+00	2.28E+00	2.28E+00	2.28E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.47E-01	5.47E-01	2.74E-01	2.74E-01	0.00E+00	1.67E-01	-1.67E-01	-8.37E-02	-8.37E-02	5.31E-03	5.31E-03	5.31E-03	2.92E-02	2.92E-02
cement cast floor	GWP 100 years [kg CO2 eq.]	2.00E+01	2.00E+01	2.00E+01	2.00E+01	2.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.99E-01	6.99E-01	3.49E-01	3.49E-01	0.00E+00	4.39E-01	-4.39E-01	-2.19E-01	-2.19E-01	5.26E-02	5.26E-02	5.26E-02	2.89E-01	2.89E-01
cement cast floor	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	1.96E+01	1.96E+01	1.96E+01	1.96E+01	1.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.95E-01	6.95E-01	3.47E-01	3.47E-01	0.00E+00	4.35E-01	-4.35E-01	-2.17E-01	-2.17E-01	5.26E-02	5.26E-02	5.26E-02	2.89E-01	2.89E-01
cement cast floor	HTP inf. [kg DCB eq.]	3.82E+00	3.82E+00	3.82E+00	3.82E+00	3.82E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.05E-01	6.05E-01	3.02E-01	3.02E-01	0.00E+00	3.95E-01	-3.95E-01	-1.98E-01	-1.98E-01	2.43E-02	2.43E-02	2.43E-02	1.34E-01	1.34E-01
cement cast floor	MAETP inf. [kg DCB eq.]	5.94E+03	5.94E+03	5.94E+03	5.94E+03	5.94E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E+03	1.45E+03	7.23E+02	7.23E+02	0.00E+00	4.17E+02	-4.17E+02	-2.08E+02	-2.08E+02	1.12E+01	1.12E+01	1.12E+01	6.18E+01	6.18E+01
cement cast floor	ODP. steady state [kg R11 eq.]	6.97E-07	6.97E-07	6.97E-07	6.97E-07	6.97E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-08	3.99E-08	1.99E-08	1.99E-08	0.00E+00	4.84E-08	-4.84E-08	-2.42E-08	-2.42E-08	1.00E-08	1.00E-08	1.00E-08	5.51E-08	5.51E-08
cement cast floor	POCP [kg Ethene eq.]	4.14E-03	4.14E-03	4.14E-03	4.14E-03	4.14E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-04	5.43E-04	2.71E-04	2.71E-04	0.00E+00	2.27E-04	-2.27E-04	-1.13E-04	-1.13E-04	4.01E-05	4.01E-05	4.01E-05	2.20E-04	2.20E-04
cement cast floor	TETP inf. [kg DCB eq.]	5.68E-02	5.68E-02	5.68E-02	5.68E-02	5.68E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.26E-03	7.26E-03	3.63E-03	3.63E-03	0.00E+00	8.05E-03	-8.05E-03	-4.02E-03	-4.02E-03	1.97E-04	1.97E-04	1.97E-04	1.08E-03	1.08E-03
sawn timber	ADP elements [kg Sb eq.]	1.06E-06	1.06E-06	1.06E-06	1.06E-06	1.06E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E-06	1.43E-06	7.14E-07	7.14E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.66E-08	9.66E-08	9.66E-08	5.31E-07	5.31E-07
sawn timber	ADP fossil [MJ]	1.18E+01	1.18E+01	1.18E+01	1.18E+01	1.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+00	1.43E+00	7.14E-01	7.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-01	2.11E-01	2.11E-01	1.16E+00	1.16E+00
sawn timber	AP [kg SO2 eq.]	1.08E-02	1.08E-02	1.08E-02	1.08E-02	1.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-04	4.86E-04	2.43E-04	2.43E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.19E-05	7.19E-05	7.19E-05	3.95E-04	3.95E-04
sawn timber	EP [kg Phosphate eq.]	3.47E-03	3.47E-03	3.47E-03	3.47E-03	3.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-04	2.79E-04	1.39E-04	1.39E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.89E-03	7.89E-03	7.89E-03	4.34E-02	4.34E-02
sawn timber	FAETP inf. [kg DCB eq.]	4.58E-01	4.58E-01	4.58E-01	4.58E-01	4.58E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.07E-02	6.07E-02	3.04E-02	3.04E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-02	1.08E-02	1.08E-02	5.91E-02	5.91E-02
sawn timber	GWP 100 years [kg CO2 eq.]	-1.06E+01	-1.06E+01	-1.06E+01	-1.06E+01	-1.06E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.36E+01	-1.36E+01	-6.80E+00	-6.80E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.64E-02	7.64E-02	7.64E-02	4.20E-01	4.20E-01
sawn timber	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	8.71E-01	8.71E-01	8.71E-01	8.71E-01	8.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.98E-02	9.98E-02	4.99E-02	4.99E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.80E-02	5.80E-02	5.80E-02	3.19E-01	3.19E-01
sawn timber	HTP inf. [kg DCB eq.]	7.21E-	7.21E-	7.21E-01	7.21E-01	7.21E-01	0.00E+0	0.00E+	0.00E+00	0.00E+00	0.00E+00	0.00E+0	7.24E-02	7.24E-02	3.62E-02	3.62E-02	0.00E+0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-	1.02E-	1.02E-02	5.64E-02	5.64E-02

		01	01				0	00				0					0					02	02			
	MAETP inf. [kg DCB eq.]	1.16E+03	1.16E+03	1.16E+03	1.16E+03	1.16E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E+02	1.39E+02	6.96E+01	6.96E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+01	1.32E+01	1.32E+01	7.25E+01	7.25E+01
	ODP. steady state [kg R11 eq.]	8.02E-08	8.02E-08	8.02E-08	8.02E-08	8.02E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-08	1.29E-08	6.46E-09	6.46E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-09	2.20E-09	2.20E-09	1.21E-08	1.21E-08
	POCP [kg Ethene eq.]	1.78E-03	1.78E-03	1.78E-03	1.78E-03	1.78E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E-05	3.59E-05	1.80E-05	1.80E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-05	1.78E-05	1.78E-05	9.79E-05	9.79E-05
	TETP inf. [kg DCB eq.]	8.44E-03	8.44E-03	8.44E-03	8.44E-03	8.44E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.56E-04	7.56E-04	3.78E-04	3.78E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.47E-04	3.47E-04	3.47E-04	1.91E-03	1.91E-03
insulation (EPS)	ADP elements [kg Sb eq.]	3.50E-07	3.50E-07	3.50E-07	3.50E-07	3.50E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.12E-09	4.12E-09	4.12E-09	4.12E-09	4.12E-09
	ADP fossil [MJ]	5.44E+01	5.44E+01	5.44E+01	5.44E+01	5.44E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.63E-02	3.63E-02	3.63E-02	3.63E-02	3.63E-02
	AP [kg SO2 eq.]	1.22E-02	1.22E-02	1.22E-02	1.22E-02	1.22E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.86E-05	3.86E-05	3.86E-05	3.86E-05	3.86E-05
	EP [kg Phosphate eq.]	2.21E-03	2.21E-03	2.21E-03	2.21E-03	2.21E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.90E-02	4.90E-02	4.90E-02	4.90E-02	4.90E-02
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.14E-01	7.14E-01	7.14E-01	7.14E-01	7.14E-01
	GWP 100 years [kg CO2 eq.]	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-02	8.64E-02	8.64E-02	8.64E-02	8.64E-02
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	2.53E+00	2.53E+00	2.53E+00	2.53E+00	2.53E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.64E-02	8.64E-02	8.64E-02	8.64E-02	8.64E-02
	HTP inf. [kg DCB eq.]	4.51E-01	4.51E-01	4.51E-01	4.51E-01	4.51E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-01	2.36E-01	2.36E-01	2.36E-01	2.36E-01
	MAETP inf. [kg DCB eq.]	7.92E+02	7.92E+02	7.92E+02	7.92E+02	7.92E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E+02	6.54E+02	6.54E+02	6.54E+02	6.54E+02
	ODP. steady state [kg R11 eq.]	7.08E-08	7.08E-08	7.08E-08	7.08E-08	7.08E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.57E-10	4.57E-10	4.57E-10	4.57E-10	4.57E-10
	POCP [kg Ethene eq.]	4.79E-03	4.79E-03	4.79E-03	4.79E-03	4.79E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.88E-05
	TETP inf. [kg DCB eq.]	7.80E-03	7.80E-03	7.80E-03	7.80E-03	7.80E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-04	4.93E-04	4.93E-04	4.93E-04	4.93E-04
base plaster	ADP elements [kg Sb eq.]	1.35E-06	1.35E-06	1.35E-06	1.35E-06	1.35E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06
	ADP fossil [MJ]	3.05E+01	3.05E+01	3.05E+01	3.05E+01	3.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00
	AP [kg SO2 eq.]	1.94E-02	1.94E-02	1.94E-02	1.94E-02	1.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	1.11E-03	1.11E-03	1.11E-03	1.11E-03
	EP [kg Phosphate eq.]	5.62E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-04	3.29E-04	3.29E-04	3.29E-04	3.29E-04
	FAETP inf. [kg DCB eq.]	7.80E-01	7.80E-01	7.80E-01	7.80E-01	7.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
	GWP 100 years [kg CO2 eq.]	5.62E+00	5.62E+00	5.62E+00	5.62E+00	5.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.50E+00	5.50E+00	5.50E+00	5.50E+00	5.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01

	HTP inf. [kg DCB eq.]	9.26E-01	9.26E-01	9.26E-01	9.26E-01	9.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MAETP inf. [kg DCB eq.]	2.11E+03	2.11E+03	2.11E+03	2.11E+03	2.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ODP. steady state [kg R11 eq.]	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	POCP [kg Ethene eq.]	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TETP inf. [kg DCB eq.]	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
paint	**ADP elements [kg Sb eq.]**	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ADP fossil [MJ]	1.28E+01	1.28E+01	1.28E+01	1.28E+01	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	AP [kg SO2 eq.]	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	EP [kg Phosphate eq.]	2.88E-03	2.88E-03	2.88E-03	2.88E-03	2.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	GWP 100 years [kg CO2 eq.]	7.03E-01	7.03E-01	7.03E-01	7.03E-01	7.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	7.59E-01	7.59E-01	7.59E-01	7.59E-01	7.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HTP inf. [kg DCB eq.]	3.86E-01	3.86E-01	3.86E-01	3.86E-01	3.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MAETP inf. [kg DCB eq.]	5.54E+02	5.54E+02	5.54E+02	5.54E+02	5.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ODP. steady state [kg R11 eq.]	9.91E-08	9.91E-08	9.91E-08	9.91E-08	9.91E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	POCP [kg Ethene eq.]	3.98E-04	3.98E-04	3.98E-04	3.98E-04	3.98E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	TETP inf. [kg DCB eq.]	7.36E-03	7.36E-03	7.36E-03	7.36E-03	7.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Inputs for the calculation of the allocation of the EI for exterior wall

		Evirgin 1970	Evirgin 2020	E virgin m^3	E*virgin (substituted material)	Ereuse	E recycling	E*rec,eol	Edisposal	Qsin/Qp	Qsout/Qp	A	R0	R1 (1 LC)	R2 (1 LC)	R1 (2 LC)	R2 (2 LC)
adhesive mortar	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	5.13E-06	5.16E-06			0			1.25E-07	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	2.04E+01	1.96E+01			0			2.47E-01	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	8.11E-03	6.48E-03			0			8.34E-05	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	3.69E-03	3.17E-03			0			2.34E-05	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	5.48E-01	4.65E-01			0			2.01E-03	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, GWP (GWP 100 years) [kg CO2 eq.]	1.18E+00	1.11E+00			0			1.22E-02	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, GWP (GWP 100 years), excl. biogenic carbon [kg CO2 eq.]	1.17E+00	1.10E+00			0			1.22E-02	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	7.86E-01	7.42E-01			0			6.64E-03	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.32E+03	1.09E+03			0			4.42E+00	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.57E-07	1.59E-07			0			2.93E-09	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	6.50E-04	5.82E-04			0			8.69E-06	1	1	0.5		0	1	1	0
	CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	8.46E-03	8.39E-03			0			5.76E-05	1	1	0.5		0	1	1	0
concrete brick	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	1.72E-07	1.74E-07		1.92E-08	0		5.07E-09	1.24E-07	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	7.54E-01	6.94E-01		5.96E-02	0		4.47E-02	2.38E-01	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	5.39E-04	4.15E-04		2.62E-05	0		2.46E-05	7.80E-05	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	1.71E-04	1.32E-04		1.03E-05	0		6.52E-06	2.20E-05	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	2.79E-02	2.16E-02		1.69E-03	0		2.57E-04	1.96E-03	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, GWP (GWP 100 years) [kg CO2 eq.]	1.33E-01	1.28E-01		4.43E-03	0		3.25E-03	1.15E-02	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, GWP (GWP 100 years), excl. biogenic carbon [kg CO2 eq.]	1.31E-01	1.26E-01		4.39E-03	0		3.25E-03	1.15E-02	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	4.74E-02	4.41E-02		3.99E-03	0		1.44E-03	6.35E-03	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	7.00E+01	5.25E+01		4.21E+00	0		5.29E-01	4.31E+00	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4.12E-09	4.26E-09		4.89E-10	0		5.63E-10	2.80E-09	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	3.46E-05	2.95E-05		2.29E-06	0		2.53E-06	8.14E-06	1	1	0.5		0	1	1	0.9
	CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	7.89E-04	7.84E-04		8.13E-05	0		1.11E-05	5.52E-05	1	1	0.5		0	1	1	0.9
base plaster	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	4.92E-08	5.62E-08			0			1.27E-07	1	1	0.5		0	0	0	0
	CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	1.43E+00	1.27E+00			0			1.87E-01	1	1	0.5		0	0	0	0
	CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	1.14E-03	8.08E-04			0			4.61E-05	1	1	0.5		0	0	0	0
	CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	3.38E-04	2.34E-04			0			1.37E-05	1	1	0.5		0	0	0	0
	CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	4.94E-02	3.25E-02			0			1.29E-03	1	1	0.5		0	0	0	0
	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	2.48E-01	2.34E-01			0			7.64E-03	1	1	0.5		0	0	0	0

	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), exc.l biogenic carbon [kg CO2 eq.]	2.43E-01	2.29E-01	0	7.63E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	4.74E-02	3.86E-02	0	4.41E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.34E+02	8.78E+01	0	2.65E+00	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	8.82E-09	9.21E-09	0	2.29E-09	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	6.68E-05	5.32E-05	0	4.86E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	4.35E-04	4.22E-04	0	3.67E-05	1	1	0.5	0	0	0	0
cover coat	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	3.13E-05	3.13E-05	0	1.28E-07	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	1.41E+00	1.25E+00	0	1.90E-01	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	9.84E-04	6.57E-04	0	4.69E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	2.89E-04	1.86E-04	0	1.15E-04	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	4.54E-02	2.86E-02	0	1.29E-02	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	1.11E-01	9.73E-02	0	7.87E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl. biogenic carbon [kg CO2 eq.]	1.09E-01	9.51E-02	0	7.85E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	4.17E-02	3.29E-02	0	6.37E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.25E+02	7.87E+01	0	1.67E+01	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1.03E-08	1.07E-08	0	2.32E-09	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	5.39E-05	4.04E-05	0	4.96E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	2.98E-04	2.84E-04	0	3.97E-05	1	1	0.5	0	0	0	0
paint	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	1.09E-05	1.09E-05	0	3.80E-08	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	4.66E+01	4.58E+01	0	1.35E-01	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	2.02E-02	1.85E-02	0	3.12E-05	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	1.08E-02	1.03E-02	0	9.25E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	1.16E+00	1.07E+00	0	6.72E-04	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	2.59E+00	2.51E+00	0	4.22E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl. biogenic carbon [kg CO2 eq.]	2.79E+00	2.71E+00	0	4.21E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	1.43E+00	1.38E+00	0	2.24E-03	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	2.24E+03	1.98E+03	0	1.40E+00	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	3.52E-07	3.54E-07	0	1.66E-09	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1.49E-03	1.42E-03	0	3.34E-06	1	1	0.5	0	0	0	0
	CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	2.64E-02	2.63E-02	0	2.04E-05	1	1	0.5	0	0	0	0
rock wool	CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	1.72E-06	1.77E-06	0	4.84E-08	1	1	0.5	0	0	0	0

CML2001 - Jan. 2016, Abiotic Depletion (ADP fossil) [MJ]	2.01E+01	1.92E+01	0	1.46E-01	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2 eq.]	1.29E-02	1.10E-02	0	3.81E-05	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate eq.]	3.28E-03	2.67E-03	0	1.07E-05	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB eq.]	4.92E-01	3.92E-01	0	9.86E-04	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years) [kg CO2 eq.]	1.25E+00	1.17E+00	0	5.16E-03	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Global Warming Potential (GWP 100 years), excl. biogenic carbon [kg CO2 eq.]	1.26E+00	1.18E+00	0	5.15E-03	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Human Toxicity Potential (HTP inf.) [kg DCB eq.]	7.80E-01	7.28E-01	0	2.96E-03	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.]	1.29E+03	1.01E+03	0	2.26E+00	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4.55E-08	4.78E-08	0	1.72E-09	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	7.93E-04	7.13E-04	0	4.10E-06	1	1	0.5	0	0	0	0
CML2001 - Jan. 2016, Terrestrial Ecotoxicity Potential (TETP inf.) [kg DCB eq.]	4.28E-03	4.21E-03	0	2.77E-05	1	1	0.5	0	0	0	0

The EI for the LC1 calculated with current data – exterior wall

		IMPACT VIRGIN					IMPACT RECYCLED CONTENT					IMPACT EOL RECYCLING					IMPACT CREDIT (Evsub)					IMPACT EOL DISPOSAL				
for m2		CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF
		(1-R1)*Ev	(1-R1)*Ev	Ev	(1-R1/2)*Ev	(1-R1/2)*Ev	R1*Erec	R1*Erec	0	R1/2*Erecycled	R1/2*Erecycled	0	(R2-R1)*Erec.eol	R2*Erec.eol	R2/2*Erec.eol	R2/2*Erec.eol	0	(R2-R1)*Evsub	(-R2*Evsub)	(-R2/2*Evsub	(-(R2/2)*Evsub(Qsout/Qp))	(1-R2)*Ed	(1-R2)*Ed	(1-R2)*Ed	(1-R2/2)*Ed	(1-R1/2-R2/2)*Ed
adhesive mortar	ADP elements [kg Sb eq.]	1.57E-04	1.57E-04	1.57E-04	1.57E-04	1.57E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-06	1.90E-06
	ADP fossil [MJ]	5.97E+02	5.97E+02	5.97E+02	5.97E+02	5.97E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E+00	3.76E+00
	AP [kg SO2 eq.]	1.97E-01	1.97E-01	1.97E-01	1.97E-01	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-03	1.27E-03
	EP [kg Phosphate eq.]	9.65E-02	9.65E-02	9.65E-02	9.65E-02	9.65E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.56E-04	3.56E-04
	FAETP inf. [kg DCB eq.]	1.42E+01	1.42E+01	1.42E+01	1.42E+01	1.42E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.06E-02	3.06E-02
	GWP 100 years [kg CO2 eq.]	3.38E+01	3.38E+01	3.38E+01	3.38E+01	3.38E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-01	1.86E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.35E+01	3.35E+01	3.35E+01	3.35E+01	3.35E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-01	1.86E-01
	HTP inf. [kg DCB eq.]	2.26E+01	2.26E+01	2.26E+01	2.26E+01	2.26E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-01	1.01E-01
	MAETP inf. [kg DCB eq.]	3.32E+04	3.32E+04	3.32E+04	3.32E+04	3.32E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.73E+01	6.73E+01
	ODP. steady state [kg R11 eq.]	4.84E-06	4.84E-06	4.84E-06	4.84E-06	4.84E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-08	4.46E-08
	POCP [kg Ethene eq.]	1.77E-02	1.77E-02	1.77E-02	1.77E-02	1.77E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-04	1.32E-04
	TETP inf. [kg DCB eq.]	2.55E-01	2.55E-01	2.55E-01	2.55E-01	2.55E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.77E-04	8.77E-04
concrete brick	ADP elements [kg Sb eq.]	7.66E-05	7.66E-05	7.66E-05	7.66E-05	7.66E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.45E-06	-8.45E-06	-4.22E-06	-4.22E-06	0.00E+00	0.00E+00	0.00E+00	2.73E-05	2.73E-05
	ADP fossil [MJ]	3.05E+02	3.05E+02	3.05E+02	3.05E+02	3.05E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.62E+01	-2.62E+01	-1.31E+01	-1.31E+01	0.00E+00	0.00E+00	0.00E+00	5.24E+01	5.24E+01
	AP [kg SO2 eq.]	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.15E-02	-1.15E-02	-5.76E-03	-5.76E-03	0.00E+00	0.00E+00	0.00E+00	1.72E-02	1.72E-02
	EP [kg Phosphate eq.]	5.81E-02	5.81E-02	5.81E-02	5.81E-02	5.81E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.53E-03	-4.53E-03	-2.27E-03	-2.27E-03	0.00E+00	0.00E+00	0.00E+00	4.84E-03	4.84E-03
	FAETP inf. [kg DCB eq.]	9.50E+00	9.50E+00	9.50E+00	9.50E+00	9.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.44E-01	-7.44E-01	-3.72E-01	-3.72E-01	0.00E+00	0.00E+00	0.00E+00	4.31E-01	4.31E-01
	GWP 100 years [kg CO2 eq.]	5.63E+01	5.63E+01	5.63E+01	5.63E+01	5.63E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.95E+00	-1.95E+00	-9.75E-01	-9.75E-01	0.00E+00	0.00E+00	0.00E+00	2.53E+00	2.53E+00
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.54E+01	5.54E+01	5.54E+01	5.54E+01	5.54E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.93E+00	-1.93E+00	-9.66E-01	-9.66E-01	0.00E+00	0.00E+00	0.00E+00	2.53E+00	2.53E+00
	HTP inf. [kg DCB eq.]	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.76E+00	-1.76E+00	-8.78E-01	-8.78E-01	0.00E+00	0.00E+00	0.00E+00	1.40E+00	1.40E+00
	MAETP inf. [kg DCB eq.]	2.31E+04	2.31E+04	2.31E+04	2.31E+04	2.31E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.85E+03	-1.85E+03	-9.26E+02	-9.26E+02	0.00E+00	0.00E+00	0.00E+00	9.48E+02	9.48E+02
	ODP. steady state [kg R11 eq.]	1.87E-06	1.87E-06	1.87E-06	1.87E-06	1.87E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.15E-07	-2.15E-07	-1.08E-07	-1.08E-07	0.00E+00	0.00E+00	0.00E+00	6.16E-07	6.16E-07
	POCP [kg Ethene eq.]	1.30E-02	1.30E-02	1.30E-02	1.30E-02	1.30E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.01E-03	-1.01E-03	-5.04E-04	-5.04E-04	0.00E+00	0.00E+00	0.00E+00	1.79E-03	1.79E-03
	TETP inf. [kg DCB eq.]	3.45E-01	3.45E-01	3.45E-01	3.45E-01	3.45E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.58E-02	-3.58E-02	-1.79E-02	-1.79E-02	0.00E+00	0.00E+00	0.00E+00	1.21E-02	1.21E-02
base plaster	ADP elements [kg Sb eq.]	1.35E-06	1.35E-06	1.35E-06	1.35E-06	1.35E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06
	ADP fossil [MJ]	3.05E+01	3.05E+01	3.05E+01	3.05E+01	3.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00
	AP [kg SO2 eq.]	1.94E-02	1.94E-02	1.94E-02	1.94E-02	1.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	1.11E-03	1.11E-03	1.11E-03	1.11E-03
	EP [kg Phosphate eq.]	5.62E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-04	3.29E-04	3.29E-04	3.29E-04	3.29E-04
	FAETP inf. [kg DCB eq.]	7.80E-01	7.80E-01	7.80E-01	7.80E-01	7.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
	GWP 100 years [kg CO2 eq.]	5.62E+00	5.62E+00	5.62E+00	5.62E+00	5.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.50E+00	5.50E+00	5.50E+00	5.50E+00	5.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	HTP inf. [kg DCB eq.]	9.26E-01	9.26E-01	9.26E-01	9.26E-01	9.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-01	1.06E-01	1.06E-01	1.06E-01	1.06E-01
	MAETP inf. [kg DCB eq.]	2.11E+03	2.11E+03	2.11E+03	2.11E+03	2.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E+01	6.36E+01	6.36E+01	6.36E+01	6.36E+01
	ODP. steady state [kg R11 eq.]	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-08	5.50E-08	5.50E-08	5.50E-08	5.50E-08

	POCP [kg Ethene eq.]	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-04	1.17E-04	1.17E-04	1.17E-04	1.17E-04
	TETP inf. [kg DCB eq.]	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-04	8.81E-04	8.81E-04	8.81E-04	8.81E-04
cover coat	**ADP elements [kg Sb eq.]**	8.69E-04	8.69E-04	8.69E-04	8.69E-04	8.69E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.55E-06	3.55E-06	3.55E-06	3.55E-06	3.55E-06
	ADP fossil [MJ]	3.47E+01	3.47E+01	3.47E+01	3.47E+01	3.47E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00
	AP [kg SO2 eq.]	1.82E-02	1.82E-02	1.82E-02	1.82E-02	1.82E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03
	EP [kg Phosphate eq.]	5.16E-03	5.16E-03	5.16E-03	5.16E-03	5.16E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-03	3.19E-03	3.19E-03	3.19E-03	3.19E-03
	FAETP inf. [kg DCB eq.]	7.94E-01	7.94E-01	7.94E-01	7.94E-01	7.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-01	3.58E-01	3.58E-01	3.58E-01	3.58E-01
	GWP 100 years [kg CO2 eq.]	2.70E+00	2.70E+00	2.70E+00	2.70E+00	2.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	2.64E+00	2.64E+00	2.64E+00	2.64E+00	2.64E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	HTP inf. [kg DCB eq.]	9.13E-01	9.13E-01	9.13E-01	9.13E-01	9.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-01	1.77E-01	1.77E-01	1.77E-01	1.77E-01
	MAETP inf. [kg DCB eq.]	2.18E+03	2.18E+03	2.18E+03	2.18E+03	2.18E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+02	4.63E+02	4.63E+02	4.63E+02	4.63E+02
	ODP. steady state [kg R11 eq.]	2.97E-07	2.97E-07	2.97E-07	2.97E-07	2.97E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.44E-08	6.44E-08	6.44E-08	6.44E-08	6.44E-08
	POCP [kg Ethene eq.]	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.12E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04
	TETP inf. [kg DCB eq.]	7.88E-03	7.88E-03	7.88E-03	7.88E-03	7.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03
paint	**ADP elements [kg Sb eq.]**	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-08	1.06E-08	1.06E-08	1.06E-08	1.06E-08
	ADP fossil [MJ]	1.28E+01	1.28E+01	1.28E+01	1.28E+01	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-02	3.78E-02	3.78E-02	3.78E-02	3.78E-02
	AP [kg SO2 eq.]	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.74E-06	8.74E-06	8.74E-06	8.74E-06	8.74E-06
	EP [kg Phosphate eq.]	2.88E-03	2.88E-03	2.88E-03	2.88E-03	2.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	1.88E-04	1.88E-04	1.88E-04	1.88E-04
	GWP 100 years [kg CO2 eq.]	7.03E-01	7.03E-01	7.03E-01	7.03E-01	7.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	7.59E-01	7.59E-01	7.59E-01	7.59E-01	7.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	HTP inf. [kg DCB eq.]	3.86E-01	3.86E-01	3.86E-01	3.86E-01	3.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-04	6.27E-04	6.27E-04	6.27E-04	6.27E-04
	MAETP inf. [kg DCB eq.]	5.54E+02	5.54E+02	5.54E+02	5.54E+02	5.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-01	3.92E-01	3.92E-01	3.92E-01	3.92E-01
	ODP. steady state [kg R11 eq.]	9.91E-08	9.91E-08	9.91E-08	9.91E-08	9.91E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E-10	4.65E-10	4.65E-10	4.65E-10	4.65E-10
	POCP [kg Ethene eq.]	3.98E-04	3.98E-04	3.98E-04	3.98E-04	3.98E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.35E-07	9.35E-07	9.35E-07	9.35E-07	9.35E-07
	TETP inf. [kg DCB eq.]	7.36E-03	7.36E-03	7.36E-03	7.36E-03	7.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-06	5.71E-06	5.71E-06	5.71E-06	5.71E-06
rock wool	**ADP elements [kg Sb eq.]**	5.31E-05	5.31E-05	5.31E-05	5.31E-05	5.31E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-06	1.45E-06	1.45E-06	1.45E-06	1.45E-06
	ADP fossil [MJ]	5.76E+02	5.76E+02	5.76E+02	5.76E+02	5.76E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00
	AP [kg SO2 eq.]	3.30E-01	3.30E-01	3.30E-01	3.30E-01	3.30E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-03	1.14E-03	1.14E-03	1.14E-03	1.14E-03
	EP [kg Phosphate eq.]	8.01E-02	8.01E-02	8.01E-02	8.01E-02	8.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.21E-04	3.21E-04	3.21E-04	3.21E-04	3.21E-04
	FAETP inf. [kg DCB eq.]	1.18E+01	1.18E+01	1.18E+01	1.18E+01	1.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02
	GWP 100 years [kg CO2 eq.]	3.51E+01	3.51E+01	3.51E+01	3.51E+01	3.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.54E+01	3.54E+01	3.54E+01	3.54E+01	3.54E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	HTP inf. [kg DCB eq.]	2.18E+01	2.18E+01	2.18E+01	2.18E+01	2.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.88E-02	8.88E-02	8.88E-02	8.88E-02	8.88E-02
	MAETP inf. [kg DCB eq.]	3.03E+04	3.03E+04	3.03E+04	3.03E+04	3.03E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.78E+01	6.78E+01	6.78E+01	6.78E+01	6.78E+01
	ODP. steady state [kg R11 eq.]	1.43E-06	1.43E-06	1.43E-06	1.43E-06	1.43E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.16E-08	5.16E-08	5.16E-08	5.16E-08	5.16E-08
	POCP [kg Ethene eq.]	2.14E-02	2.14E-02	2.14E-02	2.14E-02	2.14E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	1.23E-04	1.23E-04	1.23E-04	1.23E-04
	TETP inf. [kg DCB eq.]	1.26E-01	1.26E-01	1.26E-01	1.26E-01	1.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.31E-04	8.31E-04	8.31E-04	8.31E-04	8.31E-04

The EI for the LC2 calculated with current data – exterior wall

for m2		IMPACT VIRGIN					IMPACT RECYCLED CONTENT					IMPACT EOL RECYCLING					IMPACT CREDIT (Evsub)					IMPACT EOL DISPOSAL				
		CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF
		(1-R1)*Ev	(1-R1)*Ev	Ev	(1-R1/2)*Ev	(1-R1/2)*Ev	R1*Erec	R1*Erec	0	R1/2*Erecycled	R1/2*Erecycled	0	(R2-R1)*Erec.eol	R2*Erec.eol	R2/2*Erec.eol	R2/2*Erec.eol	0	(R2-R1)*Evsub	(-R2*Evsub)	(-R2/2*Evsub)	(-(R2/2)*Evsub(Qsout/Qp))	(1-R2)*Ed	(1-R2)*Ed	(1-R2)*Ed	(1-R2/2)*Ed	(1-R1/2-R2/2)*Ed
adhesive mortar	ADP elements [kg Sb eq.]	0.00E+00	0.00E+00	1.57E-04	7.86E-05	7.86E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.81E-06	3.81E-06	3.81E-06	3.81E-06	1.90E-06
	ADP fossil [MJ]	0.00E+00	0.00E+00	5.97E+02	2.98E+02	2.98E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.52E+00	7.52E+00	7.52E+00	7.52E+00	3.76E+00
	AP [kg SO2 eq.]	0.00E+00	0.00E+00	1.97E-01	9.87E-02	9.87E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-03	2.54E-03	2.54E-03	2.54E-03	1.27E-03
	EP [kg Phosphate eq.]	0.00E+00	0.00E+00	9.65E-02	4.83E-02	4.83E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.13E-04	7.13E-04	7.13E-04	7.13E-04	3.56E-04
	FAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	1.42E+01	7.08E+00	7.08E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.12E-02	6.12E-02	6.12E-02	6.12E-02	3.06E-02
	GWP 100 years [kg CO2 eq.]	0.00E+00	0.00E+00	3.38E+01	1.69E+01	1.69E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-01	3.71E-01	3.71E-01	3.71E-01	1.86E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0.00E+00	0.00E+00	3.35E+01	1.67E+01	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.71E-01	3.71E-01	3.71E-01	3.71E-01	1.86E-01
	HTP inf. [kg DCB eq.]	0.00E+00	0.00E+00	2.26E+01	1.13E+01	1.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E-01	2.02E-01	2.02E-01	2.02E-01	1.01E-01
	MAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	3.32E+04	1.66E+04	1.66E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+02	1.35E+02	1.35E+02	1.35E+02	6.73E+01
	ODP. steady state [kg R11 eq.]	0.00E+00	0.00E+00	4.84E-06	2.42E-06	2.42E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.92E-08	8.92E-08	8.92E-08	8.92E-08	4.46E-08
	POCP [kg Ethene eq.]	0.00E+00	0.00E+00	1.77E-02	8.86E-03	8.86E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.65E-04	2.65E-04	2.65E-04	2.65E-04	1.32E-04
	TETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	2.55E-01	1.28E-01	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E-03	1.75E-03	1.75E-03	1.75E-03	8.77E-04
concrete brick	ADP elements [kg Sb eq.]	0.00E+00	0.00E+00	7.66E-05	3.83E-05	3.83E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.45E-07	-7.60E-06	-3.80E-06	-3.80E-06	5.46E-06	5.46E-06	5.46E-06	3.00E-05	2.73E-06
	ADP fossil [MJ]	0.00E+00	0.00E+00	3.05E+02	1.53E+02	1.53E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.62E+00	-2.36E+01	-1.18E+01	-1.18E+01	1.05E+01	1.05E+01	1.05E+01	5.76E+01	5.24E+00
	AP [kg SO2 eq.]	0.00E+00	0.00E+00	1.83E-01	9.13E-02	9.13E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-03	-1.04E-02	-5.19E-03	-5.19E-03	3.43E-03	3.43E-03	3.43E-03	1.89E-02	1.72E-03
	EP [kg Phosphate eq.]	0.00E+00	0.00E+00	5.81E-02	2.90E-02	2.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-04	-4.08E-03	-2.04E-03	-2.04E-03	9.68E-04	9.68E-04	9.68E-04	5.32E-03	4.84E-04
	FAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	9.50E+00	4.75E+00	4.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02	-6.69E-01	-3.35E-01	-3.35E-01	8.62E-02	8.62E-02	8.62E-02	4.74E-01	4.31E-02
	GWP 100 years [kg CO2 eq.]	0.00E+00	0.00E+00	5.63E+01	2.82E+01	2.82E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-01	-1.75E+00	-8.77E-01	-8.77E-01	5.06E-01	5.06E-01	5.06E-01	2.78E+00	2.53E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0.00E+00	0.00E+00	5.54E+01	2.77E+01	2.77E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E-01	-1.74E+00	-8.69E-01	-8.69E-01	5.06E-01	5.06E-01	5.06E-01	2.78E+00	2.53E-01
	HTP inf. [kg DCB eq.]	0.00E+00	0.00E+00	1.94E+01	9.70E+00	9.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.76E-01	-1.58E+00	-7.90E-01	-7.90E-01	2.79E-01	2.79E-01	2.79E-01	1.54E+00	1.40E-01
	MAETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	2.31E+04	1.16E+04	1.16E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E+02	-1.67E+03	-8.34E+02	-8.34E+02	1.90E+02	1.90E+02	1.90E+02	1.04E+03	9.48E+01
	ODP. steady state [kg R11 eq.]	0.00E+00	0.00E+00	1.87E-06	9.37E-07	9.37E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.15E-08	-1.94E-07	-9.68E-08	-9.68E-08	1.23E-07	1.23E-07	1.23E-07	6.78E-07	6.16E-08
	POCP [kg Ethene eq.]	0.00E+00	0.00E+00	1.30E-02	6.49E-03	6.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-04	-9.07E-04	-4.53E-04	-4.53E-04	3.58E-04	3.58E-04	3.58E-04	1.97E-03	1.79E-04
	TETP inf. [kg DCB eq.]	0.00E+00	0.00E+00	3.45E-01	1.72E-01	1.72E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-03	-3.22E-02	-1.61E-02	-1.61E-02	2.43E-03	2.43E-03	2.43E-03	1.34E-02	1.21E-03
base plaster	ADP elements [kg Sb eq.]	1.35E-06	1.35E-06	1.35E-06	1.35E-06	1.35E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06
	ADP fossil [MJ]	3.05E+01	3.05E+01	3.05E+01	3.05E+01	3.05E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00
	AP [kg SO2 eq.]	1.94E-02	1.94E-02	1.94E-02	1.94E-02	1.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	1.11E-03	1.11E-03	1.11E-03	1.11E-03
	EP [kg Phosphate eq.]	5.62E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-04	3.29E-04	3.29E-04	3.29E-04	3.29E-04
	FAETP inf. [kg DCB eq.]	7.80E-01	7.80E-01	7.80E-01	7.80E-01	7.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
	GWP 100 years [kg CO2 eq.]	5.62E+00	5.62E+00	5.62E+00	5.62E+00	5.62E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.50E+00	5.50E+00	5.50E+00	5.50E+00	5.50E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	HTP inf. [kg DCB eq.]	9.26E-01	9.26E-01	9.26E-01	9.26E-01	9.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-01	1.06E-01	1.06E-01	1.06E-01	1.06E-01
	MAETP inf. [kg DCB eq.]	2.11E+03	2.11E+03	2.11E+03	2.11E+03	2.11E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E+01	6.36E+01	6.36E+01	6.36E+01	6.36E+01
	ODP. steady state [kg R11 eq.]	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-08	5.50E-08	5.50E-08	5.50E-08	5.50E-08
	POCP [kg Ethene eq.]	1.28E-03	1.28E-03	1.28E-03	1.28E-03	1.28E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-04	1.17E-04	1.17E-04	1.17E-04	1.17E-04
	TETP inf. [kg DCB eq.]	1.01E-02	1.01E-02	1.01E-02	1.01E-02	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-04	8.81E-04	8.81E-04	8.81E-04	8.81E-04

cover coat	**ADP elements [kg Sb eq.]**	8.69E-04	8.69E-04	8.69E-04	8.69E-04	8.69E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.55E-06	3.55E-06	3.55E-06	3.55E-06	3.55E-06
	ADP fossil [MJ]	3.47E+01	3.47E+01	3.47E+01	3.47E+01	3.47E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00
	AP [kg SO2 eq.]	1.82E-02	1.82E-02	1.82E-02	1.82E-02	1.82E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03
	EP [kg Phosphate eq.]	5.16E-03	5.16E-03	5.16E-03	5.16E-03	5.16E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-03	3.19E-03	3.19E-03	3.19E-03	3.19E-03
	FAETP inf. [kg DCB eq.]	7.94E-01	7.94E-01	7.94E-01	7.94E-01	7.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-01	3.58E-01	3.58E-01	3.58E-01	3.58E-01
	GWP 100 years [kg CO2 eq.]	2.70E+00	2.70E+00	2.70E+00	2.70E+00	2.70E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	2.64E+00	2.64E+00	2.64E+00	2.64E+00	2.64E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	HTP inf. [kg DCB eq.]	9.13E-01	9.13E-01	9.13E-01	9.13E-01	9.13E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-01	1.77E-01	1.77E-01	1.77E-01	1.77E-01
	MAETP inf. [kg DCB eq.]	2.18E+03	2.18E+03	2.18E+03	2.18E+03	2.18E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+02	4.63E+02	4.63E+02	4.63E+02	4.63E+02
	ODP. steady state [kg R11 eq.]	2.97E-07	2.97E-07	2.97E-07	2.97E-07	2.97E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.44E-08	6.44E-08	6.44E-08	6.44E-08	6.44E-08
	POCP [kg Ethene eq.]	1.12E-03	1.12E-03	1.12E-03	1.12E-03	1.12E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04
	TETP inf. [kg DCB eq.]	7.88E-03	7.88E-03	7.88E-03	7.88E-03	7.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03
paint	**ADP elements [kg Sb eq.]**	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-08	1.06E-08	1.06E-08	1.06E-08	1.06E-08
	ADP fossil [MJ]	1.28E+01	1.28E+01	1.28E+01	1.28E+01	1.28E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-02	3.78E-02	3.78E-02	3.78E-02	3.78E-02
	AP [kg SO2 eq.]	5.18E-03	5.18E-03	5.18E-03	5.18E-03	5.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.74E-06	8.74E-06	8.74E-06	8.74E-06	8.74E-06
	EP [kg Phosphate eq.]	2.88E-03	2.88E-03	2.88E-03	2.88E-03	2.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06
	FAETP inf. [kg DCB eq.]	3.00E-01	3.00E-01	3.00E-01	3.00E-01	3.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	1.88E-04	1.88E-04	1.88E-04	1.88E-04
	GWP 100 years [kg CO2 eq.]	7.03E-01	7.03E-01	7.03E-01	7.03E-01	7.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	7.59E-01	7.59E-01	7.59E-01	7.59E-01	7.59E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	HTP inf. [kg DCB eq.]	3.86E-01	3.86E-01	3.86E-01	3.86E-01	3.86E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-04	6.27E-04	6.27E-04	6.27E-04	6.27E-04
	MAETP inf. [kg DCB eq.]	5.54E+02	5.54E+02	5.54E+02	5.54E+02	5.54E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-01	3.92E-01	3.92E-01	3.92E-01	3.92E-01
	ODP. steady state [kg R11 eq.]	9.91E-08	9.91E-08	9.91E-08	9.91E-08	9.91E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E-10	4.65E-10	4.65E-10	4.65E-10	4.65E-10
	POCP [kg Ethene eq.]	3.98E-04	3.98E-04	3.98E-04	3.98E-04	3.98E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.35E-07	9.35E-07	9.35E-07	9.35E-07	9.35E-07
	TETP inf. [kg DCB eq.]	7.36E-03	7.36E-03	7.36E-03	7.36E-03	7.36E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-06	5.71E-06	5.71E-06	5.71E-06	5.71E-06
rock wool	**ADP elements [kg Sb eq.]**	5.31E-05	5.31E-05	5.31E-05	5.31E-05	5.31E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-06	1.45E-06	1.45E-06	1.45E-06	1.45E-06
	ADP fossil [MJ]	5.76E+02	5.76E+02	5.76E+02	5.76E+02	5.76E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00
	AP [kg SO2 eq.]	3.30E-01	3.30E-01	3.30E-01	3.30E-01	3.30E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-03	1.14E-03	1.14E-03	1.14E-03	1.14E-03
	EP [kg Phosphate eq.]	8.01E-02	8.01E-02	8.01E-02	8.01E-02	8.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.21E-04	3.21E-04	3.21E-04	3.21E-04	3.21E-04
	FAETP inf. [kg DCB eq.]	1.18E+01	1.18E+01	1.18E+01	1.18E+01	1.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02
	GWP 100 years [kg CO2 eq.]	3.51E+01	3.51E+01	3.51E+01	3.51E+01	3.51E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.54E+01	3.54E+01	3.54E+01	3.54E+01	3.54E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	HTP inf. [kg DCB eq.]	2.18E+01	2.18E+01	2.18E+01	2.18E+01	2.18E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.88E-02	8.88E-02	8.88E-02	8.88E-02	8.88E-02
	MAETP inf. [kg DCB eq.]	3.03E+04	3.03E+04	3.03E+04	3.03E+04	3.03E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.78E+01	6.78E+01	6.78E+01	6.78E+01	6.78E+01
	ODP. steady state [kg R11 eq.]	1.43E-06	1.43E-06	1.43E-06	1.43E-06	1.43E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.16E-08	5.16E-08	5.16E-08	5.16E-08	5.16E-08
	POCP [kg Ethene eq.]	2.14E-02	2.14E-02	2.14E-02	2.14E-02	2.14E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	1.23E-04	1.23E-04	1.23E-04	1.23E-04
	TETP inf. [kg DCB eq.]	1.26E-01	1.26E-01	1.26E-01	1.26E-01	1.26E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.31E-04	8.31E-04	8.31E-04	8.31E-04	8.31E-04

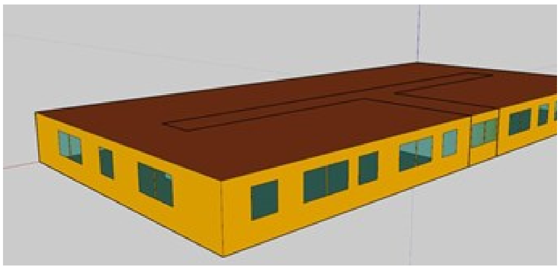
APPENDIX E

The EI for the LC1 calculated with data for 1970 – exterior wall

for m2		IMPACT VIRGIN					IMPACT RECYCLED CONTENT					IMPACT EOL RECYCLING					IMPACT CREDIT (Evsub)					IMPACT EOL DISPOSAL				
		CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF	CUT-OFF	CO-D	AVOIDED BURDEN	50:50	PEF
		(1-R1)*Ev	(1-R1)*Ev	Ev	(1-R1/2)*Ev	(1-R1/2)*Ev	R1*Erec	R1*Erec	0	R1/2*Erecycled	R1/2*Erecycled	0	(R2-R1)*Erec.eol	R2*Erec.eol	R2/2*Erec.eol	R2/2*Erec.eol	0	(R2-R1)*Evsub	(-R2*Evsub)	(-R2/2*Evsub)	(-(R2/2)*Evsub(Qsout/Qp))	(1-R2)*Ed	(1-R2)*Ed	(1-R2)*Ed	(1-R2/2)*Ed	(1-R1/2-R2/2)*Ed
adhesive mortar	ADP elements [kg Sb eq.]	1.56E-04	1.56E-04	1.56E-04	1.56E-04	1.56E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-06	1.90E-06
	ADP fossil [MJ]	6.21E+02	6.21E+02	6.21E+02	6.21E+02	6.21E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E+00	3.76E+00
	AP [kg SO2 eq.]	2.47E-01	2.47E-01	2.47E-01	2.47E-01	2.47E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-03	1.27E-03
	EP [kg Phosphate eq.]	1.12E-01	1.12E-01	1.12E-01	1.12E-01	1.12E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.56E-04	3.56E-04
	FAETP inf. [kg DCB eq.]	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.06E-02	3.06E-02
	GWP 100 years [kg CO2 eq.]	3.59E+01	3.59E+01	3.59E+01	3.59E+01	3.59E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-01	1.86E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.56E+01	3.56E+01	3.56E+01	3.56E+01	3.56E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-01	1.86E-01
	HTP inf. [kg DCB eq.]	2.39E+01	2.39E+01	2.39E+01	2.39E+01	2.39E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-01	1.01E-01
	MAETP inf. [kg DCB eq.]	4.02E+04	4.02E+04	4.02E+04	4.02E+04	4.02E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.73E+01	6.73E+01
	ODP. steady state [kg R11 eq.]	4.78E-06	4.78E-06	4.78E-06	4.78E-06	4.78E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E-08	4.46E-08
	POCP [kg Ethene eq.]	1.98E-02	1.98E-02	1.98E-02	1.98E-02	1.98E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-04	1.32E-04
	TETP inf. [kg DCB eq.]	2.58E-01	2.58E-01	2.58E-01	2.58E-01	2.58E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.77E-04	8.77E-04
concrete brick	ADP elements [kg Sb eq.]	7.57E-05	7.57E-05	7.57E-05	7.57E-05	7.57E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-8.45E-06	-8.45E-06	-4.22E-06	-4.22E-06	0.00E+00	0.00E+00	0.00E+00	2.73E-05	2.73E-05
	ADP fossil [MJ]	3.32E+02	3.32E+02	3.32E+02	3.32E+02	3.32E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.62E+01	-2.62E+01	-1.31E+01	-1.31E+01	0.00E+00	0.00E+00	0.00E+00	5.24E+01	5.24E+01
	AP [kg SO2 eq.]	2.37E-01	2.37E-01	2.37E-01	2.37E-01	2.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.15E-02	-1.15E-02	-5.76E-03	-5.76E-03	0.00E+00	0.00E+00	0.00E+00	1.72E-02	1.72E-02
	EP [kg Phosphate eq.]	7.52E-02	7.52E-02	7.52E-02	7.52E-02	7.52E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.53E-03	-4.53E-03	-2.27E-03	-2.27E-03	0.00E+00	0.00E+00	0.00E+00	4.84E-03	4.84E-03
	FAETP inf. [kg DCB eq.]	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.44E-01	-7.44E-01	-3.72E-01	-3.72E-01	0.00E+00	0.00E+00	0.00E+00	4.31E-01	4.31E-01
	GWP 100 years [kg CO2 eq.]	5.85E+01	5.85E+01	5.85E+01	5.85E+01	5.85E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.95E+00	-1.95E+00	-9.75E-01	-9.75E-01	0.00E+00	0.00E+00	0.00E+00	2.53E+00	2.53E+00
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.76E+01	5.76E+01	5.76E+01	5.76E+01	5.76E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.93E+00	-1.93E+00	-9.66E-01	-9.66E-01	0.00E+00	0.00E+00	0.00E+00	2.53E+00	2.53E+00
	HTP inf. [kg DCB eq.]	2.09E+01	2.09E+01	2.09E+01	2.09E+01	2.09E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.76E+00	-1.76E+00	-8.78E-01	-8.78E-01	0.00E+00	0.00E+00	0.00E+00	1.40E+00	1.40E+00
	MAETP inf. [kg DCB eq.]	3.08E+04	3.08E+04	3.08E+04	3.08E+04	3.08E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.85E+03	-1.85E+03	-9.26E+02	-9.26E+02	0.00E+00	0.00E+00	0.00E+00	9.48E+02	9.48E+02
	ODP. steady state [kg R11 eq.]	1.81E-06	1.81E-06	1.81E-06	1.81E-06	1.81E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.15E-07	-2.15E-07	-1.08E-07	-1.08E-07	0.00E+00	0.00E+00	0.00E+00	6.16E-07	6.16E-07
	POCP [kg Ethene eq.]	1.52E-02	1.52E-02	1.52E-02	1.52E-02	1.52E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.01E-03	-1.01E-03	-5.04E-04	-5.04E-04	0.00E+00	0.00E+00	0.00E+00	1.79E-03	1.79E-03
	TETP inf. [kg DCB eq.]	3.47E-01	3.47E-01	3.47E-01	3.47E-01	3.47E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.58E-02	-3.58E-02	-1.79E-02	-1.79E-02	0.00E+00	0.00E+00	0.00E+00	1.21E-02	1.21E-02
base plaster	ADP elements [kg Sb eq.]	1.18E-06	1.18E-06	1.18E-06	1.18E-06	1.18E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06
	ADP fossil [MJ]	3.43E+01	3.43E+01	3.43E+01	3.43E+01	3.43E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00	4.49E+00
	AP [kg SO2 eq.]	2.74E-02	2.74E-02	2.74E-02	2.74E-02	2.74E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-03	1.11E-03	1.11E-03	1.11E-03	1.11E-03
	EP [kg Phosphate eq.]	8.11E-03	8.11E-03	8.11E-03	8.11E-03	8.11E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-04	3.29E-04	3.29E-04	3.29E-04	3.29E-04
	FAETP inf. [kg DCB eq.]	1.19E+00	1.19E+00	1.19E+00	1.19E+00	1.19E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-02	3.10E-02	3.10E-02	3.10E-02	3.10E-02
	GWP 100 years [kg CO2 eq.]	5.95E+00	5.95E+00	5.95E+00	5.95E+00	5.95E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	5.83E+00	5.83E+00	5.83E+00	5.83E+00	5.83E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	1.83E-01	1.83E-01	1.83E-01	1.83E-01
	HTP inf. [kg DCB eq.]	1.14E+00	1.14E+00	1.14E+00	1.14E+00	1.14E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-01	1.06E-01	1.06E-01	1.06E-01	1.06E-01
	MAETP inf. [kg DCB eq.]	3.22E+03	3.22E+03	3.22E+03	3.22E+03	3.22E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E+01	6.36E+01	6.36E+01	6.36E+01	6.36E+01

	ODP. steady state [kg R11 eq.]	2.12E-07	2.12E-07	2.12E-07	2.12E-07	2.12E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.50E-08	5.50E-08	5.50E-08	5.50E-08	5.50E-08
	POCP [kg Ethene eq.]	1.60E-03	1.60E-03	1.60E-03	1.60E-03	1.60E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E-04	1.17E-04	1.17E-04	1.17E-04	1.17E-04
	TETP inf. [kg DCB eq.]	1.04E-02	1.04E-02	1.04E-02	1.04E-02	1.04E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-04	8.81E-04	8.81E-04	8.81E-04	8.81E-04
cover coat	**ADP elements [kg Sb eq.]**	8.69E-04	8.69E-04	8.69E-04	8.69E-04	8.69E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.55E-06	3.55E-06	3.55E-06	3.55E-06	3.55E-06
	ADP fossil [MJ]	3.91E+01	3.91E+01	3.91E+01	3.91E+01	3.91E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00	5.27E+00
	AP [kg SO2 eq.]	2.73E-02	2.73E-02	2.73E-02	2.73E-02	2.73E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-03	1.30E-03	1.30E-03	1.30E-03	1.30E-03
	EP [kg Phosphate eq.]	8.02E-03	8.02E-03	8.02E-03	8.02E-03	8.02E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-03	3.19E-03	3.19E-03	3.19E-03	3.19E-03
	FAETP inf. [kg DCB eq.]	1.26E+00	1.26E+00	1.26E+00	1.26E+00	1.26E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-01	3.58E-01	3.58E-01	3.58E-01	3.58E-01
	GWP 100 years [kg CO2 eq.]	3.08E+00	3.08E+00	3.08E+00	3.08E+00	3.08E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.02E+00	3.02E+00	3.02E+00	3.02E+00	3.02E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.18E-01	2.18E-01	2.18E-01	2.18E-01	2.18E-01
	HTP inf. [kg DCB eq.]	1.16E+00	1.16E+00	1.16E+00	1.16E+00	1.16E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-01	1.77E-01	1.77E-01	1.77E-01	1.77E-01
	MAETP inf. [kg DCB eq.]	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+02	4.63E+02	4.63E+02	4.63E+02	4.63E+02
	ODP. steady state [kg R11 eq.]	2.86E-07	2.86E-07	2.86E-07	2.86E-07	2.86E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.44E-08	6.44E-08	6.44E-08	6.44E-08	6.44E-08
	POCP [kg Ethene eq.]	1.50E-03	1.50E-03	1.50E-03	1.50E-03	1.50E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-04	1.38E-04	1.38E-04	1.38E-04	1.38E-04
	TETP inf. [kg DCB eq.]	8.27E-03	8.27E-03	8.27E-03	8.27E-03	8.27E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03
paint	**ADP elements [kg Sb eq.]**	3.05E-06	3.05E-06	3.05E-06	3.05E-06	3.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-08	1.06E-08	1.06E-08	1.06E-08	1.06E-08
	ADP fossil [MJ]	1.30E+01	1.30E+01	1.30E+01	1.30E+01	1.30E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.78E-02	3.78E-02	3.78E-02	3.78E-02	3.78E-02
	AP [kg SO2 eq.]	5.66E-03	5.66E-03	5.66E-03	5.66E-03	5.66E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.74E-06	8.74E-06	8.74E-06	8.74E-06	8.74E-06
	EP [kg Phosphate eq.]	3.02E-03	3.02E-03	3.02E-03	3.02E-03	3.02E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.59E-06	2.59E-06	2.59E-06	2.59E-06	2.59E-06
	FAETP inf. [kg DCB eq.]	3.25E-01	3.25E-01	3.25E-01	3.25E-01	3.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	1.88E-04	1.88E-04	1.88E-04	1.88E-04
	GWP 100 years [kg CO2 eq.]	7.25E-01	7.25E-01	7.25E-01	7.25E-01	7.25E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	7.81E-01	7.81E-01	7.81E-01	7.81E-01	7.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.18E-03	1.18E-03	1.18E-03	1.18E-03	1.18E-03
	HTP inf. [kg DCB eq.]	4.00E-01	4.00E-01	4.00E-01	4.00E-01	4.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-04	6.27E-04	6.27E-04	6.27E-04	6.27E-04
	MAETP inf. [kg DCB eq.]	6.27E+02	6.27E+02	6.27E+02	6.27E+02	6.27E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-01	3.92E-01	3.92E-01	3.92E-01	3.92E-01
	ODP. steady state [kg R11 eq.]	9.86E-08	9.86E-08	9.86E-08	9.86E-08	9.86E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E-10	4.65E-10	4.65E-10	4.65E-10	4.65E-10
	POCP [kg Ethene eq.]	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.35E-07	9.35E-07	9.35E-07	9.35E-07	9.35E-07
	TETP inf. [kg DCB eq.]	7.39E-03	7.39E-03	7.39E-03	7.39E-03	7.39E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-06	5.71E-06	5.71E-06	5.71E-06	5.71E-06
rock wool	**ADP elements [kg Sb eq.]**	5.16E-05	5.16E-05	5.16E-05	5.16E-05	5.16E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-06	1.45E-06	1.45E-06	1.45E-06	1.45E-06
	ADP fossil [MJ]	6.03E+02	6.03E+02	6.03E+02	6.03E+02	6.03E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00	4.38E+00
	AP [kg SO2 eq.]	3.87E-01	3.87E-01	3.87E-01	3.87E-01	3.87E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-03	1.14E-03	1.14E-03	1.14E-03	1.14E-03
	EP [kg Phosphate eq.]	9.84E-02	9.84E-02	9.84E-02	9.84E-02	9.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.21E-04	3.21E-04	3.21E-04	3.21E-04	3.21E-04
	FAETP inf. [kg DCB eq.]	1.48E+01	1.48E+01	1.48E+01	1.48E+01	1.48E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E-02	2.96E-02	2.96E-02	2.96E-02	2.96E-02
	GWP 100 years [kg CO2 eq.]	3.75E+01	3.75E+01	3.75E+01	3.75E+01	3.75E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	3.78E+01	3.78E+01	3.78E+01	3.78E+01	3.78E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01	1.55E-01	1.55E-01	1.55E-01
	HTP inf. [kg DCB eq.]	2.34E+01	2.34E+01	2.34E+01	2.34E+01	2.34E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.88E-02	8.88E-02	8.88E-02	8.88E-02	8.88E-02
	MAETP inf. [kg DCB eq.]	3.87E+04	3.87E+04	3.87E+04	3.87E+04	3.87E+04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.78E+01	6.78E+01	6.78E+01	6.78E+01	6.78E+01
	ODP. steady state [kg R11 eq.]	1.37E-06	1.37E-06	1.37E-06	1.37E-06	1.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.16E-08	5.16E-08	5.16E-08	5.16E-08	5.16E-08
	POCP [kg Ethene eq.]	2.38E-02	2.38E-02	2.38E-02	2.38E-02	2.38E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	1.23E-04	1.23E-04	1.23E-04	1.23E-04
	TETP inf. [kg DCB eq.]	1.28E-01	1.28E-01	1.28E-01	1.28E-01	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.31E-04	8.31E-04	8.31E-04	8.31E-04	8.31E-04

APPENDIX F



Model used for the calculation of the energy reduction in TRNSYS (zoning visible)

MODEL SETTINGS	
Heating set-point	20 °C
Cooling set-point	26 °C
Indoor temperature control	ON/ OFF constant
Infiltration + natural ventilation rate	0.3/h
Internal heat gain rate and schedule (appliances)	5W/m^2 - constant
Internal heat gain rate and schedule (occupants)	ISO 7730 for living
Shading	None
Uwindow	1.06

PROPERTIES OF THE INSULATION MATERIAL

	Density	Specific heat	Thermal conductivity
	kg/m^3	J/kgK	W/mK
EPS	20	1260	0.041
Aerogel	150	1000	0.015
Phenolic foam	35	1400	0.021
Cellulos e	85	1800	0.040
Agepan	190	2000	0.045
Cover coat	1800	1050	0.700
Wood	600	2090	0.140

More vailable on:
https://www.ozs.si/datoteke/ozs/sekcije/Janko%20Rozman/Sekcija%20instalaterjev-energetikov/TSG-01-004_2010_U%C4%8Dinkovita%20raba%20energije.pdf

APPENDIX G

The EI of the insulation, adhesive, cover coat and transport for the different insulation systems

	EPS							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	2.45E-06	6.76E-05	0.000154	0.00113	4.37E-06	6.76E-05	0.000154	0.00113
ADP fossil [MJ]	381	256	22.9031	619	680	256	22.9031	619
AP [kg SO2 eq.]	0.0852	0.0716	0.014465	0.134	0.152	0.0716	0.014465	0.134
EP [kg Phosphate eq.]	0.0155	0.0384	0.003688	0.0418	0.0276	0.0384	0.003688	0.0418
FAETP inf. [kg DCB eq.]	2.1	5.55	0.90725	6.79	3.75	5.55	0.90725	6.79
GWP 100 years [kg CO2 eq.]	17.8	14.4	1.45115	41.2	31.8	14.4	1.45115	41.2
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	17.7	14.4	1.44415	41.2	31.6	14.4	1.44415	41.2
HTP inf. [kg DCB eq.]	3.13	9.39	2.481263	22.3	5.59	9.39	2.481263	22.3
MAETP inf. [kg DCB eq.]	5540	12900	2857.71	13800	9890	12900	2857.71	13800

	MW							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	5.96E-05	6.76E-05	0.000154	0.00136	8.36E-05	6.76E-05	0.000154	0.001358
ADP fossil [MJ]	350	256	22.9031	743	597	256	22.9031	742.6701
AP [kg SO2 eq.]	0.18174	0.0716	0.014465	0.161	0.31674	0.0716	0.014465	0.160607
EP [kg Phosphate eq.]	0.04408	0.0384	0.003688	0.0501	0.07618	0.0384	0.003688	0.050111
FAETP inf. [kg DCB eq.]	6.954	5.55	0.90725	8.15	11.654	5.55	0.90725	8.146043
GWP 100 years [kg CO2 eq.]	20.78	14.4	1.45115	49.5	35.78	14.4	1.45115	49.49778
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	20.88	14.4	1.44415	49.5	35.98	14.4	1.44415	49.49002
HTP inf. [kg DCB eq.]	13.51	9.39	2.481263	26.7	22.71	9.39	2.481263	26.71407
MAETP inf. [kg DCB eq.]	17290	12900	2857.71	16500	29290	12900	2857.71	16522.79

	CL							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	0.004792	6.76E-05	0.000154	0.00158	0.010034	6.76E-05	0.000153	0.001585
ADP fossil [MJ]	161.6	256	22.9031	866	277.7996	256	22.90728	866.4485
AP [kg SO2 eq.]	0.09366	0.0716	0.014465	0.187	0.167952	0.0716	0.014461	0.187375
EP [kg Phosphate eq.]	0.0418	0.0384	0.003688	0.0585	0.076655	0.0384	0.003693	0.058463
FAETP inf. [kg DCB eq.]	17.862	5.55	0.90725	9.5	35.14322	5.55	0.907175	9.503717
GWP 100 years [kg CO2 eq.]	-15.641	14.4	1.45115	57.7	-30.961	14.4	1.450788	57.74741
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	10.785	14.4	1.44415	57.7	19.04439	14.4	1.444105	57.73835
HTP inf. [kg DCB eq.]	23.625	9.39	2.481263	31.2	45.10339	9.39	2.48529	31.16642
MAETP inf. [kg DCB eq.]	58350	12900	2857.71	19300	116680.1	12900	2858.163	19276.58

	PF							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	1.08E-05	6.76E-05	0.000154	0.00113	1.94E-05	6.76E-05	0.000154	0.00113
ADP fossil [MJ]	246.1	256	22.9031	619	441.6	256	22.9031	619
AP [kg SO2 eq.]	0.015408	0.0716	0.014465	0.134	0.027648	0.0716	0.014465	0.134
EP [kg Phosphate eq.]	0.001862	0.0384	0.003688	0.0418	0.003341	0.0384	0.003688	0.0418
FAETP inf. [kg DCB eq.]	0	5.55	0.90725	6.79	0	5.55	0.90725	6.79
GWP 100 years [kg CO2 eq.]	8.2497	14.4	1.45115	41.2	14.8032	14.4	1.45115	41.2
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0	14.4	1.44415	41.2	0	14.4	1.44415	41.2
HTP inf. [kg DCB eq.]	0	9.39	2.481263	22.3	0	9.39	2.481263	22.3
MAETP inf. [kg DCB eq.]	0	12900	2857.71	13800	0	12900	2857.71	13800

	PF INT							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	1.08E-05	6.76E-05	0.000467	0.00113	1.94E-05	6.76E-05	0.000467	0.00113
ADP fossil [MJ]	246.1	256	71.3831	619	441.6	256	71.3831	619
AP [kg SO2 eq.]	0.015408	0.0716	0.034165	0.134	0.027648	0.0716	0.034165	0.134
EP [kg Phosphate eq.]	0.001862	0.0384	0.014248	0.0418	0.003341	0.0384	0.014248	0.0418
FAETP inf. [kg DCB eq.]	0	5.55	2.07435	6.79	0	5.55	2.07435	6.79
GWP 100 years [kg CO2 eq.]	8.2497	14.4	7.95915	41.2	14.8032	14.4	7.95915	41.2
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0	14.4	8.03815	41.2	0	14.4	8.03815	41.2
HTP inf. [kg DCB eq.]	0	9.39	5.545963	22.3	0	9.39	5.545963	22.3
MAETP inf. [kg DCB eq.]	0	12900	5869.71	13800	0	12900	5869.71	13800

	AG							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	0.000377	6.76E-05	0.000154	0.00113	0.00067	6.76E-05	0.000467	0.00113
ADP fossil [MJ]	705.1583	256	22.9031	619	1254.632	256	71.3831	619
AP [kg SO2 eq.]	0.465003	0.0716	0.014465	0.134	0.827343	0.0716	0.034165	0.134
EP [kg Phosphate eq.]	0.047786	0.0384	0.003688	0.0418	0.085022	0.0384	0.014248	0.0418
FAETP inf. [kg DCB eq.]	0	5.55	0.90725	6.79	0	5.55	2.07435	6.79
GWP 100 years [kg CO2 eq.]	96.096	14.4	1.45115	41.2	170.976	14.4	7.95915	41.2
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0	14.4	1.44415	41.2	0	14.4	8.03815	41.2
HTP inf. [kg DCB eq.]	0	9.39	2.481263	22.3	0	9.39	5.545963	22.3
MAETP inf. [kg DCB eq.]	0	12900	2857.71	13800	0	12900	5869.71	13800

	AG int							
	0.17				**0.10**			
	Insulation*	**Adhesive**	**Cover coat ****	**Transport**	**Insulation***	**Adhesive**	**Cover coat ****	**Transport**
ADP elements [kg Sb eq.]	0.000377	6.76E-05	0.000467	0.00113	0.00067	6.76E-05	0.000467	0.00113
ADP fossil [MJ]	705.1583	256	71.3831	619	1254.632	256	71.3831	619
AP [kg SO2 eq.]	0.465003	0.0716	0.034165	0.134	0.827343	0.0716	0.034165	0.134
EP [kg Phosphate eq.]	0.047786	0.0384	0.014248	0.0418	0.085022	0.0384	0.014248	0.0418
FAETP inf. [kg DCB eq.]	0	5.55	2.07435	6.79	0	5.55	2.07435	6.79
GWP 100 years [kg CO2 eq.]	96.096	14.4	7.95915	41.2	170.976	14.4	7.95915	41.2
GWP 100 years. excl. biogenic carbon [kg CO2 eq.]	0	14.4	8.03815	41.2	0	14.4	8.03815	41.2
HTP inf. [kg DCB eq.]	0	9.39	5.545963	22.3	0	9.39	5.545963	22.3
MAETP inf. [kg DCB eq.]	0	12900	5869.71	13800	0	12900	5869.71	13800

ODP. steady state [kg R11 eq.]	POCP [kg Ethene eq.]	TETP inf. [kg DCB eq.]
4.95E-07	0.0335	0.0548
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
7.56E-06	0.0142	0.173
8.84E-07	0.0599	0.0978
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
7.56E-06	0.0142	0.173
1.45E-06	0.012148	0.0824
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
9.07E-06	0.017	0.208
2.09E-06	0.021148	0.1365
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
9.07E-06	0.017032	0.208111
1.05E-06	0.009637	0.21188
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
1.06E-05	0.0199	0.243
1.8E-06	0.016937	0.392141
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012992
1.06E-05	0.01987	0.242796
2.09E-08	0.00489	0
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
7.56E-06	0.0142	0.173
3.74E-08	0.008774	0
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
7.56E-06	0.0142	0.173
2.09E-08	0.00489	0
2.1E-06	0.00709	0.111
4.4E-07	0.002567	0.037473
7.56E-06	0.0142	0.173
3.74E-08	0.008774	0
2.1E-06	0.00709	0.111
4.4E-07	0.002567	0.037473
7.56E-06	0.0142	0.173
2.63E-05	0.032009	0
2.1E-06	0.00709	0.111
1.4E-07	0.000954	0.012996
7.56E-06	0.0142	0.173
4.68E-05	0.056951	0
2.1E-06	0.00709	0.111
4.4E-07	0.002567	0.037473
7.56E-06	0.0142	0.173
2.63E-05	0.032009	0
2.1E-06	0.00709	0.111
4.4E-07	0.002567	0.037473
7.56E-06	0.0142	0.173
4.68E-05	0.056951	0
2.1E-06	0.00709	0.111
4.4E-07	0.002567	0.037473
7.56E-06	0.0142	0.173

*Insulation+ seals ** Cover coat including reinfrocing mesh, disperison and cover coat