A comparative study of Product Environmental Footprint (PEF) and EN 15804 in the construction sector concentrating on the End-of-Life stage and reducing subjectivity in the formulas

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En jämförande studie av Product Environmental Footprint (PEF) och EN 15804 inom byggsektorn med fokus på slutet av livscyklern och att minska subjektiviteten i formlerna

Keywords: LCA, EN 15804, PEF, Circular Footprint Formula, Recyclability Assessment, Circular Economy, End of life, recycling rate, construction, building, Energy margin

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Degree project course: Strategies for sustainable development, Second Cycle AL250X, 30 credits

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Acknowledgments

This master thesis has been conducted at the Royal Institute of Technology (KTH), division of industrial ecology (SEED) in collaboration with IVL Swedish Environmental Research Institute. The master thesis was directly supervised by Dr. Martin Erlandsson (IVL) and Dr. Anna Björklund (KTH). I wish to thank Anna Björklund and Martin Erlandsson for their guidance during the development of this thesis. It was a great opportunity for me to work with them, and I am very grateful for their support and supervision. They have always made time for my questions and discussions.

I should mention special thanks to Dr. Tomas Ekvall for the open-loop recycling calculation tool and his support by answering my questions. I learned a lot from his work.

I want to also thank my friends at IVL, who created a wonderful working environment and answered my questions whenever I had a problem in the middle of the work.

Lastly, I should thank my family for their great support in every stage of my life. They have been always supporters especially, my father, the main man in my life.
Abstract

One of the main polluting industries in the world with high environmental impact is the construction industry which also generates a huge amount of waste. To overcome these burdens, we need to reduce the impact through new solutions, technologies and by injecting circular economy concept into the industry. Construction and building material industry are responsible for nearly 11% of all GHG emissions and the usage of residential/commercial buildings is contributing to 28% of all GHG emissions globally. The construction industry is also responsible for 35% of the total wastes in the European Union. Both linear economy and emissions of the construction sector are becoming more important in recent years that led to the development of many standards, frameworks and innovations.

Reporting environmental burdens of the construction elements, products and construction works or construction projects is one of the ways for emissions accounting. Therefore, a report on environmental impacts of goods or services is called environmental product claims which can be based on a single criterion (like CO₂ emission or % of recycled content) or based on a complete LCA study with multiple impacts. These reports have been classified by ISO 14020 series in three types, Type I (third-party certified label), Type II (self-declared claims) and Type III (the third party verified declaration based on LCA study). The third type is known as Environmental Product Declaration (EPD).

To make the LCA results in EPD:s comparable, Product Category Rules (PCR) are developed. The regulations for the construction materials are defined in EN 15804 so the declarations of the building materials and construction works according to these regulations are compliant with EN 15804. Another framework for environmental declarations called, Product Environmental Footprint (PEF) is developed in Europe. Besides Business to Business declarations that are the target group for EN 15804, PEF also includes environmental labelling (type I) with consumers as the target group. The PCR:s from the updated version of EN 15804:2012+A2:2019 can be regarded as the parallel methodology specification for the construction materials in the PEF system. Other product groups' rules and specifications are based on the PEF guidance document.

The overall aims of this study are to compare the EN 15804 and PEF formulas concentrating on credits at the end of life and after the end of life stage and to reduce the subjectivity of two variables, energy margin, and recycling rate in the assessment of recycling alternatives after the end-of-life stage.

Calculated credits can be included differently in the environmental declarations depending on the methodological approach. PEF includes the End-of-Life (EoL) credits into the Life Cycle Assessment (LCA) study and adds them to the product's performance results, while EN 15804 mandates to report the credits from recycling/recovery separately as supplementary information to the products environmental performance. To compare the credits that are calculated according to PEF and EN 15804, a separate indicator is virtually defined for PEF in order to calculate all the credits separately and compare the results with EN 15804 Module D results to give the reader an overview of the most beneficial uses of the construction waste according to PEF and EN 15804.

Reducing subjectivity of choosing recycling rate has been addressed by developing more transparent and less subjective tool by integrating and using DGNB (German Sustainable Building Council) and BRE (center for building research in the UK) methods. For energy margin, this has been done by integrating energy margin calculation tool by CDM (Clean Development Mechanism, United Nations) and find the contribution of different materials to the environmental benefits in and after the end of life stage of the building lifecycle. However,
the DGNB and BRE methods require further development, since they are not originally developed for LCA studies and just used as the only current options available in order to make recyclability assessment methods compatible with LCA studies. Other methods, specifically for LCA, can also be developed in the future.

Based on an inventory of the components and materials used in a real building, the most environmental benefits (credits) from downstream recycling/recovery considering all materials are generated for the wooden products when using the EN 15804 formula, while aluminium is in the second place. On the other hand, aluminium is in the first place and wood is second using the PEF formula. Aluminium has by far the most benefits (credits) considering the credits per kg of each material, due to the huge recycling potential that aluminium has and will replace primary aluminium in the future. Unlike PEF, EN 15804 reports all credits separately outside of the LCA system boundary. This is very beneficial since the correct verified LCA will not be affected by the credits that are given based on current technologies when the end of life of the building components are between 40 to 120 years away from today.

Keywords

LCA, EN 15804, PEF, Circular Footprint Formula, Recyclability Assessment, Circular Economy, End of life, Recycling rate, Construction, Building, Energy margin
Sammanfattning

En av de industrier i världen med högst miljöpåverkan är byggbranschen som också genererar en enorm mängd avfall. För att hantera detta måste vi minska effekterna genom nya lösningar, teknologier och genom att använda konceptet cirkulär ekonomi i byggbranschen. Bygg- och byggnadsmaterialindustrin är ansvarig för nästan 11% av alla växthusgasutsläpp och användningen av bostäder / kommersiella byggnader bidrar till 28% av alla växthusgasutsläpp globalt. Byggbranschen ansvarar också för 35% av det totala avfallet i EU. Både linjär ekonomi och utsläpp från byggsektorn har blivit viktigare under de senaste åren vilket har lett till utveckling av många standarder, ramverk och innovationer.


De övergripande syftena med denna studie är att jämföra formulerna EN 15804 och PEF som koncentrarar sig på krediter i slutet av livscykeln och att minska subjektiviteten för två variabler, energimarginal och återvinningsgrad vid bedömningen av återvinningsalternativ i slutet av livscykeln.

Beräknade krediter kan inkluderas olika i miljödeklarationerna beroende på den valda metoden. PEF inkluderar slutet av livscykeln (EoL)-krediter i livscykelen (LCA)-studien och lägger dem till produktens resultat, medan EN 15804 kräver att kreditera från återvinning rapporteras separat som kompletterande information till produkternas miljöprestanda. För att jämföra krediter som beräknas enligt PEF och EN 15804, definieras en virtuell separat indikator för PEF för att beräkna alla krediter separat och jämföra resultaten med EN 15804 Modul D-resultat för att ge läsaren en översikt över de mest fördelaktiga användning av byggavfall enligt PEF och EN 15804.

Olika sätt att minska subjektiviteten i valet av återvinningsgrad behandlas genom att utveckla mer transparenta och mindre subjektiva verktyg med hjälp av metoder från DGNB (German Sustainable Building Council) och BRE (Center for building research, UK). Energimarginal behandlas genom att integrera ett verktyg för energimarginaler från CDM (Clean Development Mechanism, FN) och hitta bidraget från olika material till miljöfördelarna i och efter livscykeln för byggnaden. DGNB och BRE metoderna kräver emellertid ytterligare utveckling, eftersom de inte ursprungligen är utvecklade för LCA-studier och bara används som de enda tillgängliga alternativen för att göra utvärderingsmetoder för återvinningsbarhet
kompatibla med LCA-studier. Andra metoder, speciellt för LCA, kan också utvecklas i framtiden.

Baserat på en inventering av komponenter och material som används i en riktig byggnad, genereras de största miljömässiga fördelarna (krediter) av nedströms återvinning av träprodukter när man använder EN 15804-formeln, medan aluminium ligger på andra plats. Å andra sidan är kommer aluminium i första hand och trä kommer på andra plats med PEF-formeln. Aluminium har överlägset flest fördelar (krediter) per kg av varje material, på grund av den enorma återvinningspotentialen som aluminium har och kommer att ersätta primärt aluminium i framtiden. Till skillnad från PEF rapporterar EN 15804 alla krediter separat utanför LCA-systemgränsen. Detta är mycket fördelaktigt eftersom den korrekt verifierade LCAn inte kommer att påverkas av de krediter som ges baserat på nuvarande teknik när byggnadskomponenternas livslängd är mellan 40 och 120 år från idag.

Nykelord

LCA, EN 15804, PEF, Formulär för cirkulär fotavtryck, bedömning av återvinningsbarhet, cirkulär ekonomi, livslängd, återvinningsgrad, konstruktion, byggnad, Bygg, LCA,
Nomenclature

LCA – Life Cycle Assessment
GHG – Green House Gases
CO2 – Carbon Dioxide
EPD – Environmental Product Declaration
PCR – Product Category Rules
PEF – Product Environmental Footprint
CFF – Circular Footprint Formula
EoL – End of Life
DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen, German Sustainable Building Council

BRE – Building Research Establishment (center for building research in the UK)
CDM – Clean Development Mechanism, United nations
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1 Introduction

European Union has been working with environmental issues for a long time, trying to propose new suggestions and solutions to reduce emissions to the air, water, and soil. One of the main polluting industries with high environmental impact is the construction industry which also generates a huge amount of waste. To overcome these burdens, we need to reduce the impacts through new solutions, technologies and by injecting circular economy concept into the industry. Circular economy in business means to reduce waste and the use of virgin materials by increasing reuse and recycling. (Martin Geissdoerfer, 2017). Construction and building material industry is responsible for nearly 11% of all GHG emissions globally, which is rapidly growing, while the usage of residential/commercial buildings are contributing to 28% of all GHG emissions globally, which is declining over time. (Architecture2030, 2018) Both linear economy and emissions of the construction sector are becoming more important in recent years that led to the development of many standards, frameworks, and innovations.

The first step of impact reduction is to calculate them. Reporting environmental burdens of the construction elements, products and construction works or construction projects is one of the ways for emission accounting. Therefore, a report on environmental impacts of goods or services is called environmental product claims which can be based on a single criterion (like CO2 emission or % of recycled content) or based on a complete study with multiple impacts. There are different frameworks for impacts reporting. According to ISO framework, These reports have been classified into three types (ISO 14020 series), Type I (third-party certified), Type II (self-declared) and Type III (the third party verified based on LCA study). (Curran, 2015) The third type, also known as Environmental Product Declaration (EPD), is the one that is used in this study. There are standards developed to regulate EPDs in the industry and make them comparable, for construction materials the standard is EN 15804. Another framework for environmental declaration is Product Environmental Footprint (PEF) which has a wider range of material types including building materials. These two are becoming the main frameworks for declaration in the construction industry.

These two frameworks and standards have detailed formulas to include incentives in them that encourage or force the industries toward a more circular and greener market. A part of the formulas in these frameworks can be known as End of Life (EoL) formulas in which they account for burdens/benefits of having a material or component at the end of life stage. These burdens/benefits include the possibility of recycling (i. e. Steel profiles are recyclable while wooden products are mostly being incinerated after the use phase.), being substituted fuel for energy production (wood emits less in incineration plants comparing to oil and coal that are currently being burnt to produce energy/electricity in many countries), etc. These benefits/credits are reported separately and are known as “Module D” in EN 15804, while they are part of the non-modular single environmental performance result according to PEF. The amount of credits and how they will be reported have an influence on the users and decision-makers choices therefore it is important to discover the strength and weaknesses while comparing two methods. In this study, the detailed calculations are shown and the results are presented to indicate how much burden or benefit each material type has in and after the end of life stage according to two different formulas, one according to EN 15804 formula and the other one according to PEF Circular Footprint Formula (CFF). Two variables (recycling rate, and energy margin) in these formulas are identified as controversial since they can be chosen subjectively. Therefore, three methods used to calculate them with less subjectivity.
The versions of the equations from EN 15804 and PEF:
- EN 15804 Amendment 2:2019 (European Committee for Standardization, 2019)
- PEF CFF formula (Zampori L, 2019)

The recycling rate calculations are based on rules and component categorization of the following methods:
- TEC 1.6, Ease of Recovery and Recycling evaluation (DGNB Gmbh, 2018)
- Design For Deconstruction (DFD) method (BRE Trust, 2015)

The method that is used for Energy Margin (Eer average) calculations is as follow:
- CDM (Clean Development Mechanism, United nations) Tool to calculate the emission factor for an electricity system (UNFCCC, CDM – Executive Board, 2008)

2 Project aim

The main goal of this study is to evaluate and compare the environmental credits calculated according to EN 15804 “End of life formula” and PEF “Circular Footprint Formula” (CFF). This is achieved by following common boundary settings extracted from EN 15804 by developing virtual credit-based formulas from the PEF CFF to make it comparable with EN 15804 formula, concentrating on the end of life and after the end of life stage. Sub-goals are to handle two controversial variables; recycling rate and energy margin (Eer average in EN 15804 formula). Reducing subjectivity of choosing recycling rate by developing more transparent and less subjective tool using DGNB (German Sustainable Building Council) and BRE (center for building research in the UK) methods and energy margin by integrating energy margin calculation tool by CDM (Clean Development Mechanism, United Nations) and find the contribution of different materials to the environmental benefits in and after the end of life stage of the building lifecycle.

All emission variables in the formulas will be addressed to GHG emissions since GHG emission reduction is in the highest demand and is also the only required impact category in the forthcoming mandatory climate declaration for all new buildings in Sweden.

The expected impacts of this study are a slight reduction in the subjectivity of LCA studies. It also reflects the methodological differences of the PEF and EN 15804 approaches, while concentrating on the formulas and interpretations, rather than their suggestions for different variables. The results of this study indicate how different choices (choosing recycling rates, energy margin and choosing which framework to use for declaration) can lead to a different environmental declaration, which means less comparability. Other impacts can be:

- Changes in PEF and EN 15804 formulas/approaches in the future versions
- Development of a precise and less flexible tool by Building certification systems to connect their systems to LCA standards, concentrating on recycling rates.
- Publishing a new handbook for the declarations of long-lasting products

2.1 Research questions

1- What are the methodological and reporting differences concerning downstream recycling/recovery credits in order to assess different recycling alternatives between Environmental Product Declarations (EPD)s that are EN 15804 compliant and declarations according to Product Environmental Footprint (PEF)?
2- Based on the data from a plus energy building, which materials earn more environmental benefits/credits in and after the end of life stage of the buildings, both in gross and per kg of material according to:
   a. EN 15804:2012+A2:2019, Module D
   b. PEF latest pilot version, 2019, a translation of Circular Footprint Formula to be reported as a separate information module

3- How to reduce subjectivity in calculating energy margin (Eer average in Module D formula)?

4- How to reduce the subjectivity of choosing the recycling rates that are needed for calculations in the EoL formulas? (in building and construction sector)

2.2 Limitations and delimitations

A complete LCA study contains a large number of impact categories. It reports all different environmental impacts. However, for having more understandable and concentrated results, Global Warming Potential (GWP) is the only impact category used in this study. GWP represents the amount of equivalent CO₂ emissions by the processes in the system that is direct or indirect (for example from CH₄, methane emissions) contribution to global warming. Therefore, from this part until the end of the report, the word “emission” may be used instead of “impact”.

One of the credits in the formulas is to use energy from waste incineration (wooden chips) instead of incinerating virgin material (oil, coal) in the production phase of material (i.e. using wood chips to produce enough heat for windows manufacturing site). For simplifying the understanding of the results, this value is assumed to be zero. In other words, using energy recovery from recycled material assumed to be 0 for all material groups. It means that in the production of the materials, the energy consumption is from commercial fuel or electricity, but not secondary fuel directly being incinerated to produce the material. However, at the end of life stage, the credit of exporting waste as fuel is considered.

3 Background

Nowadays one of the main global issues to tackle is global warming. The awareness of environmental issues has been among scientists from the 19th century, but the consensus between countries as an international agreement started from Kyoto-protocol regarding greenhouse gas (GHG) emissions and global warming. This protocol resulted in energy consumption regulations for energy usage reduction and to build more efficient buildings. This path started in Europe with Energy Performance of Buildings Directive in 2003 and is continued with new regulations regarding net/near-zero energy buildings and building certifications for certifying sustainable buildings. These certificates are broader than just certifying energy consumption, different systems cover ecological, economical and social aspects besides environmental issues. (Buyle, 2018) In recent years, since the energy consumption per building is going down and the overall lifetime performance of the buildings, at least those that are built recently, is very good, the awareness regarding environmental impacts of the building materials, construction works, demolition and waste handling that are called “embodied environmental burdens” is increasing. The embodied GHG emissions of the buildings are now responsible for nearly one-third of the whole building emission on average while the operational phase responsible for the rest globally. The embodied burdens will grow
because of the current trend in the global construction, so developing standards and regulations for controlling and reducing embodied environmental impact, specifically GHG emissions, are now vital to achieving the global warming goals in time. (Architecture2030, 2018)

There had been many tools, systems, and methods in the industry for environmental accounting, but the main tool that has been used for building materials is Life Cycle Assessment (LCA) since this tool is much more detailed comparing to other methods such as building certifications and can be used to investigate the burdens of products or services by evaluating the whole lifetime. (Buyle, 2018) There are different LCA studies in terms of lifetime such as cradle to gate (from material extraction until and excluding product use) cradle to grave (from material extraction until the end of the waste handling process) and gate to gate (looks just to one or a few value-added processes in the production chain). (Curran, 2015)

When LCA studies conducted, decision-makers and product users will start using such studies as reference for their choices by trying to find a product with lower environmental impacts but, Lifecycle assessment tool is not developed for comparison. In 1997, International Organization for Standardization (ISO) published the first version of ISO 14040 aiming at harmonization of the LCA methods and procedures. Even after all efforts on ISO 14040 series, LCA studies are still not comparable since ISO 14040 series are mostly concentrated on developing frameworks for conducting such studies, rather than remove flexibility and restrict researchers, stated that “there is no single method for conducting LCA”. (Buyle, 2018)

The same as the comparability problem, there are a few methodological problems in LCA that are addressed by (Curran, 2015) both as a problem and the possible solutions. The way that researchers treat these problems and their choice of solution influence the comparability negatively. Development of harmonized rules for Environmental Product Declarations (EPD) for buildings and materials is still progressing with the new version of EN 15804, amendment 2:2019 which the first version was published in 2012 with the aim of harmonizing building materials and construction works LCA studies and make them comparable. Another framework that has comparability and harmonization as its aim is Product Environmental Footprint (PEF) which is developed in the European Union.

This chapter contains Life Cycle Assessment (LCA) definition, The ISO 14040 framework for LCA studies, the methodological problems (allocation problems) in LCA and the solutions. Then, the Environmental Product Declaration (EPD) compliant with the EN 15804 standard is described as well as the Product Environmental Footprint (PEF) framework. Moreover, the methodological differences between these two methods are explained so that the reader can follow the calculations and methodology of this study.

3.1 Life Cycle Assessment (LCA)

Life Cycle Assessment is an environmental approach that provides a comprehensive view of the environmental aspects of a product or service throughout its life cycle. LCA standardized and defined by ISO standards in ISO 14040 group. (ISO 14040, 2006) A typical life cycle study consists of four different parts:

1. Goal and Scope

Goal and Scope is the starting point of an LCA. In this part, the purpose of the study and the details of the product or service are presented. In detail, Goals include application, reasons for the study's implementation, target group and how the results are intended to be used. Scope includes the functional unit _the product's quantified description of the service provided by the product system_ and system boundaries. The scope section also includes a determination of
environmental impact categories and environmental impact assessment method as well as description of data types, data sources and data quality requirements (Curran, 2015)

2. Life Cycle Inventory

LCI consists of flows to and from the natural environment. Includes data collection, calculation, and validation of data as well as reporting of allocation procedure. It provides the basis of the impact assessment and is critically important to be complete, unbiased and correct. (Curran, 2015)

3. Life Cycle Impact Assessment

In this part, the quantity of the materials or energy that has been used to produce a product or provide a service will convert to environmental impacts. Standards and methods have requirements and recommendations for the choice of impact categories, indicators and characterization models. Nowadays there are lots of free or commercial tools/software that make LCIA easy to conduct but there is always a matter of choice between tools. (Curran, 2015)

4. Interpretation and results

Interpretation is where the results of the inventory and impact modelling are analysed. This part includes also the identification of key issues, evaluation of completeness, sensitivity, and compliance. Conclusions, limitations and recommendations are also included in the life-cycle interpretation. Interpretation is important to give credibility to the study and present the results in a useful manner for decision making. (Curran, 2015)

Environmental impact reports have many types and formulations but the product environmental impact reports have been classified by ISO 14020 series in three types, Type I (third-party certified), Type II (self-declared) and Type III (the third party verified based on LCA study). (Curran, 2015) The third type, also known as Environmental Product Declaration (EPD), is now widely used in the construction industry.

3.1.1 Attributional and Consequential LCA

The two main methods of doing lifecycle assessment studies are attributional and consequential. Attributional LCA is a holistic study in the system boundary, it means that like accounting, the model contains every process of the system and count the impacts of each process and report the total impacts. On the other hand, Consequential LCA is change-oriented. It describes the consequences of a change in the chain of processes. In other words, attributional LCA determines the potential environmental impacts of the products/services while consequential LCA determines the positive or negative impact of choosing an alternative, comparing to the primary system. (Curran, 2015)

3.1.2 Methodological (Allocation) problems

Allocation problems occur when there are processes or products that are shared between different systems. It happens when products other than the main product are produced, more than one input material used or when the input of the current system is an output of the previous one. In the Life Cycle Assessment, there are three categorized allocation problems that should be solved by the practitioner. The choice of solution for these problems should be according to the standards or be justified by the practitioner. The allocation problems are:

- Multi-input
- Multi-output
- Open-loop recycling
Multi-input and multi-output allocation problems occur when a product system has multiple inputs or co-products (outputs) which are a part of other systems. For example, if the system produces wooden chips at the end of life stage, these wood chips are now having a value and will be used in energy production plants and can be substituted with a more polluting fuel such as coal. It means that there is a benefit in having wooden waste at the end of life stage of the building for another user (power plant) which is not part of the current system. Allocation problem arises in this situation, “who should earn these benefits? Is it a benefit for the builder that has a greener waste or the power plant that has greener fuel, or maybe both?” (considering that building producer could have used alternative materials such as concrete, steel, etc. which means that power plant would have polluter fuel, coal). These problems appear in fuel export and incineration calculations of this study. A common solution in standards is avoiding burdens. It means that if the product is going to be incinerated for energy generation after its lifetime, the burdens that are avoided by the reduction of burning other fuels for the same purpose (e.g. heat production) will be accounted which in the example means that all benefits from burning wood instead of coal will be for the building producer. Another solution is so-called “polluter pays”. It means that the burdens of the waste generation are for the first user and burdens of incineration are for the second user, which in the example means that all benefits from burning wood instead of coal will be for the power plant. (Curran, 2015)

Open-Loop Recycling describes a system that a product will be recycled after the end of life stage and the recovered component or material will be used in other systems of products. This loop will typically close after this stage by disposing of the product, but some materials may go through several loops. The total number of useful lives of the material is addressed with ‘n’. In the case of disposal after recycling once, this number is equal to 2 ’n=2’. (Curran, 2015) The problem in open-loop recycling arises when LCA practitioners will try to allocate burdens. Should we allocate all burdens to the first user of the material? or allocate half of them to the first user and half of them to the second user? This allocation problem has multiple solutions in different standards. There is a list of recycling modelling methods to solve the open-loop recycling problem that is addressed in detail. (Tomas Ekvall, 2019) The schematic flow of this problem can be seen in Figure 1.

![Open Loop recycling](https://example.com/flowchart.png)

**Figure 1** Open Loop recycling, Green boxes are shared between two products

In general, the approaches can be grouped into two main categories, economic approaches, and physical approaches. The economic approaches are based on the prices or supply and demand of the materials in the market. Both EN 15804 standard and Product Environmental Footprint (PEF) are not related to the economic approaches directly. EN 15804 standard is based on physical relations and follow a simple “polluter pays” or “cut-off” or “100/0” method. (European Committee for Standardization, 2019) Circular Footprint Formula proposed by Product Environmental Footprint (PEF) allocates the burdens with a suggested percentage between the first and the second user of the material. The suggested percentage is listed in “Annex C” of the standard and will be updated regularly. (Zampori, 2019) the detail descriptions of how these standards solve Open-Loop Recycling are in the next section, after describing each of them in detail.
3.2 Environmental Declaration

3.2.1 EPD

An Environmental Product Declaration (EPD) reports the environmental impacts of the products or any construction works based on the same LCA methodology settings that are designed to make EPDs comparable. Comparability can be achieved if the EPD follows the same common Product Category Rules (PCR). PCRs are rules, requirements, and guidelines for writing an EPD for a specific product group, depending on their applications which improve the transparency of the declarations. EPDs can be either reported based on a declared unit or functional unit. Declared unit is typically mass or other preferable units for the forthcoming LCA study of construction works or construction products, while EPD based on the functional unit can be used for comparison within the products group. (European Committee for Standardization, 2019) However, it should be noticed that two EPDs of two products with different PCRs may not be comparable. This could be caused by differences in the system boundary or other specifications that are different between PCRs used for the LCA studies. Nevertheless, the cradle-to-gate (A1-3 in Figure 2) EPDs that are formatted according to EN 15804, are designed to be comparable and modular in order to be used for LCA studies of any construction works (e.g. buildings).

3.2.2 EN 15804

EN 15804 is a reference standard for developing reliable and verifiable LCA studies reported as EPD:s. EN 15804 provides the product category rules (PCR) for harmonized Environmental Declarations of building materials and construction works so that the declarations can be comparable. In this standard, construction works life cycle is defined and several possible scenarios for reporting the EPD have been mentioned. The four major Modules that this standard defines are Product and construction process stage (A), use stage (B) and End of life stage (C) while the benefits or loads beyond the system boundary is also defined as Module D. Module D aims to provide transparency in the analysis regarding environmental impacts and environmental savings linked to reusable and recyclable products, materials or fuels that will be used outside the building’s system boundaries (after the end of life). Module D is a separate commentary result of the products’ environmental lifecycle performance from Module A to C. In this module, the potential environmental benefits of avoiding the use of primary materials and fuels by recycling and reuse are reported. This can refer also to the situation where the use of secondary materials is for energy generation. (Technical Committee CEN/TC 350 “Sustainability of construction works”, 2019)

EN 15804 classified the entire life of a building into 4 modules shown in Figure 2.
The current version in use is EN 15804 2012 amendment 1 that is published in 2013 (A1:2013). This version does not contain formulas for the assessment and has just regulations and descriptions. The recent EN 15804 (amendment 2 to be published in 2019, A2:2019) is regulating all modules including module D (benefits and loads beyond the system boundary) calculation in detail, by adding a sort of formulas which should be used for calculation and reporting. The result of Module D calculation can be addressed as a “recycling and recovery declaration”, which helps users to understand the consequences of their choices among waste handling alternatives and their input material. However, it is not always useful for product comparison. In other words, the formulas sum up in an indicator “Module D result” which indicates the environmental burdens/benefits of the product related to the use of recycled material and recyclability of the studying material in the future based on the net flow from the products lifecycle (A4 to C in Figure 2). (European Committee for Standardization, 2019) (Nicholas Dodd, 2017)

With the detailed analysis of the writer, the only methodological difference in calculations between A1:2013 version and A2:2019 version is in the substitution impact. In the calculations, there is a part of the formula that compares the burdens from using the virgin material to be substituted with recycled material ($E_{VM \ sub \ out}$) with the burdens from recycling material ($E_{MR \ after \ EoW \ out}$) and report the difference as the benefit of recycling. The A2:2019 version added a line to the definition of ($E_{VM \ sub \ out}$), asking for using the average input material (a combination of recycled and virgin material) if virgin material is not used in the production phase of the product. The A1:2013 version does not consider the average input and just uses the virgin material. It means that for example, if in the Copper industry in a country, nearly all products are now being produced on average from 40% recycled material and 60% virgin material, no matter what are these rates for the current producer, the credit of using recycled material in the production will be given to the substitution of that 60% virgin, not to the total 100% input material. There are some other differences (such as updated impact categories) that are not in the scope of this study.

3.2.3 PEF

PEF is a life cycle assessment (LCA) based method which is an initiative from the European Commission for testing the environmental footprint rules and quantifying the environmental impacts of the goods/services. It provides a set of rules that are intended to make studies comparable and verifiable. It has developed sector-specific rules and provides and updates a list of default parameters that are needed in the calculations. The Circular Footprint Formula (CFF) represents the environmental footprint (impact) of the product according to the PEF standard. (Zampori, 2019) PEF reports contain the impacts and credits summed and presented in the same result. It is not possible to separate the credits from the real impacts in the reports according to the PEF framework.

3.2.4 EN 15804 and PEF CFF formula

EN 15804 provides formulas for all four Modules (A, B, C, D) presented in Figure 2. But two formulas are related to the End of Life of the products, Module C and D formulas. The precise definition of each variable is listed after the formulas, but a description of what each formula stands for is written below. Two problems in the EN 15804:2012 A2:2019 formulas identified by the writer that are addressed in appendix 1. Since the reference of this study is the draft version, these problems may be fixed in the future.

\[ e_{\text{module C}} = M_{MR \ out} \cdot E_{MR \ before \ EoW \ out} + M_{ER \ out} \cdot E_{ER \ before \ EoW \ out} + M_{INC \ out} \cdot E_{INC} + M_{LF} \cdot E_{LF} \]  

(1)
Module C has four parts, part one represents the emissions of the material recovery process before the end of life. As two examples, emissions from the demolition of the building and the emissions of separating steel from concrete are in this category. The second part is the emissions of the process that transforms waste materials to an energy source to be used for energy production in subsequent system, for example, producing wooden chips by the building owner is in this category. The third part is emissions from incinerating waste. The difference between incineration and the second part is that $E_{ER \text{ before } EoW\text{ out}}$ represents the emissions of producing fuel from waste, while incineration represents the emissions of the burning the product, neither necessarily a fuel, nor a source of energy generation. The future emissions from burning fuel are addressed in Module D. The fourth part is emissions from landfilling.

After module C, the end of waste phase reaches. After this intellectual line, any calculation will be out of the official lifecycle analysis and should be reported as a separate indicator as it is already explained. Module D is the only Module after this line. The line can be seen in Figure 3 and the full flowchart is available in appendix 1 in which the schematic definition of each important variable is also indicated.

$$e_{\text{module D}} = e_{\text{module D1}} + e_{\text{module D2}} + e_{\text{module D3}} + e_{\text{module D4}}$$

Module D divided into four submodules, D1 contains all emissions based on materials. it represents the emissions of the material recovery process after the end of life. D2 contains all emissions based on energy. It represents the emissions of the process of energy recovery by burning the fuels produced from the waste of the current system after the end of life. For example, burning wood chips in another system that are produced from the materials of the current system is in this category. D3 represents the benefits of the incineration process if it has energy recovery. Some incineration facilities have an energy recovery system and use the heat, while others just burn the waste to get rid of it. D4 represents the benefits of the landfilling process if it has energy recovery. Some landfilling facilities have an energy recovery system in which they take methane emitted from the waste and burn them for heat generation. It rarely happens for construction wastes and is more for biodegradable materials. Wood can be the only candidate for this sub-module in this study.
\[ e_{\text{module D1}} = \sum_{i} (M_{\text{MR out} | i} - M_{\text{MR in} | i}) \times \left( E_{\text{MR after EoW out} | i} - E_{\text{VMsub out} | i} \cdot Q_{\text{R out} | i} \right) \]  

Module D1 subtracts the mass of recycled input to prevent double accounting of the credits for using them in the first parentheses. In the second parentheses, the emissions of recycling processes minus quality-adjusted emissions from production out of virgin materials are calculated. Quality adjusting helps to consider that the product from recycled material after the recycling process may not have the same quality as the product from virgin material.

\[ e_{\text{module D2}} = \sum_{i} (M_{\text{ER out} | i} - M_{\text{ER in} | i}) \times \left( E_{\text{ER after EoW out} | i} - E_{\text{ER average}} \right) \]  

In which \( E_{\text{ER average}} = \text{LHV} \cdot X_{\text{ER heat}} \cdot E_{\text{SE heat}} + \text{LHV} \cdot X_{\text{ER elec}} \cdot E_{\text{SE elec}} \)  

Module D2 subtracts the mass of energy recovered input to prevent double accounting of the credits for using them in the first parentheses. In the second parentheses, the emissions of average energy margin (\( E_{\text{ER average}} \)) are subtracted from emissions of the burning of the exported fuel (for example wooden chips). The formula for calculating (\( E_{\text{ER average}} \)) is given by the standard as it is shown (5). The detailed calculation is conducted later in this report.

\[ e_{\text{module D3}} = -M_{\text{INC out}} \times (\text{LHV} \cdot X_{\text{INC heat}} \cdot E_{\text{SE heat}} + \text{LHV} \cdot X_{\text{INC elec}} \cdot E_{\text{SE elec}}) \]  

\[ e_{\text{module D4}} = -M_{\text{LF}} \times (\text{LHV} \cdot X_{\text{LF heat}} \cdot E_{\text{SE heat}} + \text{LHV} \cdot X_{\text{LF elec}} \cdot E_{\text{SE elec}}) \]  

Modules D3 and D4 multiply the mass of the material that goes for either incineration or landfill, to the parentheses after. In the parentheses, the emissions from average substituted fuel for heat or electricity generation per unit of analysis should be calculated. These Modules result in benefits of using the energy recovered from these activities to substitute for the energy produced in normal power plants.

\( Q_{\text{R out}} \): quality of the outgoing recovered material (recycled and reused), i.e. quality of the recycled material at the point of substitution;

\( Q_{\text{Sub}} \): quality of the substituted material, i.e. quality of primary material or quality of the average input material if primary material is not used;

\( M_{\text{MR in}} \): amount of input material to the product system that has been recovered (recycled or reused) from a previous system (determined at the system boundary);

\( M_{\text{MR out}} \): the amount of material exiting the system that will be recovered (recycled and reused) in a subsequent system. This amount is determined at end of waste point and is therefore equal to the output flow of “materials to recycling [kg]” reported for modules A4, A5, B and C;

\( M_{\text{ER in}} \): the amount of material entering the product system that has reached the end of waste status before incineration in a previous system and enters the product system as secondary fuel. This amount equals the output flow of “materials for energy recovery [kg]” of a previous system;

\( M_{\text{ER out}} \): the amount of material leaving the product system where it has reached the end of waste status before incineration and leaves the product system as secondary fuel. This
amount equals to the value reported for the indicator output flow of “materials for energy recovery [kg]”;

\( M_{\text{INC out}} \): the amount of waste that will be incinerated with efficiency of energy recovery lower than 60 % or that is used for energy recovery with energy efficiency greater than 60 % but which has not reached the end of waste status;

\( M_{\text{LF}} \): the amount of material in the product that will be landfilled.

\( E_{\text{VMSub out}} \): specific emissions and resources consumed per unit of analysis arising from acquisition and pre-processing of the primary material, or average input material if primary material is not used, from the cradle to the point of functional equivalence where it would substitute secondary material that would be used in a subsequent system

\( E_{\text{MR before EoW out}} \): specific emissions and resources consumed per unit of analysis arising from material recovery (recycling and reusing) processes of the current system until the end of waste status is reached

\( E_{\text{MR after EoW out}} \): specific emissions and resources consumed per unit of analysis arising from material recovery (recycling and reusing) processes of a subsequent system after the end of waste status

\( E_{\text{ER before EoW out}} \): specific emissions and resources consumed per unit of analysis arising from processing of waste destined to be used as material for energy recovery of a subsequent system before the end of waste status (after this processing, waste is no longer considered as waste but as secondary fuel)

\( E_{\text{ER after EoW out}} \): specific emissions and resources consumed per unit of analysis arising from processing and combustion of secondary fuels in a subsequent system after the end of waste status (where waste is no longer considered as waste but as secondary fuel)

\( E_{\text{INC}} \): specific emissions and resources consumed per unit of analysis arising from incineration of waste

\( E_{\text{LF}} \): specific emissions and resources consumed per unit of analysis arising from landfill

\( E_{\text{SE heat}} \): specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: heat

\( E_{\text{SE elec}} \): specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: electricity

\( E_{\text{ER average}} \): specific emissions and resources per unit of analysis that would have arisen from specific current average substituted energy source: heat and electricity

\( X_{\text{ER heat}} \): efficiency of the energy recovery process for heat

\( X_{\text{ER elec}} \): efficiency of the energy recovery process for electricity

\( X_{\text{INC,heat}} \): efficiency of the incineration process for heat

\( X_{\text{INC,elec}} \): efficiency of the incineration process for electricity

\( X_{\text{LF,heat}} \): efficiency of the landfilling process for heat

\( X_{\text{LF,elec}} \): efficiency of the landfilling process for electricity

\( LHV \): Lower Heating Value of the material in the product that is used for energy recovery.

PEF CFF formula is a formula that classified the lifecycle impacts based on three pillars, material formula, energy formula and disposal formula. These three divisions are representative
of the impacts with the source from Material use/recycle, Energy usage/production and Disposal processes, respectively. So the impacts of different lifecycle stages (as it can be seen in EN 15804 such as production impacts, waste handling impacts and use phase) cannot be found in an environmental report according to PEF. The three divisions of the CFF formula are as follow:

**Material**

\[
(1 - R_1)E_v + R_1 \times \left( AE_{\text{recycled}} + (1 - A)E_v \times \frac{Q_{\text{in}}}{Q_p} \right) + (1 - A)R_2 \times \left( E_{\text{recycling EoL}} - E_v \times \frac{Q_{\text{out}}}{Q_p} \right)
\]

**Energy**

\[
(1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,\text{heat}} \times E_{SE,\text{heat}} - LHV \times X_{ER,\text{elec}} \times E_{SE,\text{elec}})
\]

**Disposal**

\[
(1 - R_2 - R_3) \times E_D
\]

**E_v**: specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material.

**E^* v**: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.

**E_{\text{recycled}}**: specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.

**E_{\text{recycling EoL}}**: specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.

**E_{ER}**: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.).

**E_D**: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.

**E_{SE,\text{heat & elec}}**: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.

**X_{ER,\text{heat & elec}}**: the efficiency of the energy recovery process for both heat and electricity.

**Q_{\text{in}}**: quality of the ingoing secondary material

**Q_{\text{out}}**: quality of the outgoing secondary material

**R_1**: it is the proportion of material in the input to the production that has been recycled from a previous system.

**R_2**: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.

**LHV**: Lower Heating Value of the material in the product that is used for energy recovery.

**B**: allocation factor of energy recovery processes. It applies both to burdens and credits. (it is equal to 0 by default.)
A: allocation factor of burdens and credits between supplier and user of recycled materials.

Variable A defines how much burdens will be on the shoulders of the recycling supplier (virgin material user) and user of recycled material and “it aims to reflect market realities”. If the A=0, it means that 100% of the credits go for recyclable materials at the end of life (0/100 approach and credits are for the second user) and if A=1, 100% of credits would be allocated to having recycled content (100/0 approach and credits are for the first user). In PEF, the A value should always be between 0.2 and 0.8. (Zampori, 2019) It means:

- “A=0.2. Low offer of recyclable materials and high demand: the formula focuses on recyclability at end of life.
- A=0.8. High offer of recyclable materials and low demand: the formula focuses on recycled content.
- A=0.5. Equilibrium between offer and demand: the formula focuses both on recyclability at end of life and recycled content”. (Zampori, 2019)

The process of how to determine A factor is clearly described by PEF. Users are not free to choose the A parameter, they should first try to find them in PEF documents and if there is no default A suggested by PEF, they must choose 0.5. The process of determining A is:

1- “Check in Annex C the availability of an application-specific A value which fits the PEF study,
2- If an application-specific A value is not available, the material-specific A value in Annex C shall be used,
3- If a material-specific A value is not available, the A value shall be set equal to 0.5.” (Zampori, 2019)

A two-row example from the PEF Annex C file can be seen in Figure 4.

<table>
<thead>
<tr>
<th>Category</th>
<th>Material</th>
<th>Application</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>Copper</td>
<td>MATERIAL</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>building - sheet</td>
<td>0.2</td>
</tr>
</tbody>
</table>

(Figure 4 Sample Data from Annex C file, PEF initiative (Zampori, 2019)

3.2.5 Methodological difference between EN 15804 and PEF

Both methods have similar formulas but there is a fundamental methodological difference that is necessary to be described. PEF method has a more flexible allocation of the burdens and benefits considering the market by having parameter “A” with which PEF is regulating the burden division itself. The process of how to determine A is mentioned in 3 steps already, so the practitioner is not free to decide the value of A. While both methods solve the open-loop recycling allocation problem, PEF aims to have fairer division of burdens regarding recycling between first and second user while at the same time encourages the usage of recycled material or having recycling potential in the future depending on the market (PEF defines A values in annex C according to the market situation). This division variable varies between 0.2 and 0.8 depending on the product group, for example, the A value is equal to 0.5 for construction wooden products in annex C. This means that half of the burdens/credits from using recycled content by the first user will be allocated to the first user, and the other half is for the second user in the future. The division is the same for recycling process burdens/credits. On the other hand, EN 15804 solves the open-loop allocation problem with a simple cut-off or 100/0 approach. It means that all the burdens of the virgin material and recycled materials used
in the product will be counted as burdens of the current product. In other words, if a product is produced with 100% virgin material, all burdens are for the first user, then if it recycles, all burdens from the recycling process will be allocated to the second user in the chain. For having a system to encourage the market toward a more sustainable one, EN 15804 defines a recycling and recovery indicator parameter “Module D” which its value indicates how environmentally friendly the product will be in the future if there is a potential of recycling/recovering material at the end of life stage. Hence, the nature of the CFF formula and module D formulas are not the same. The Module D formula gives environmental points while CFF formula adds credits to the LCA results for reporting the burdens and allocate them according to the “A” value. But in this study, The part of the PEF CFF that is giving credits regarding the end of life and after the end of life stage is translated to a point/credit giving indicator to be able to compare both methods in the same context. It means that the results of this study are credits/points that will be given to the first user by these two methods, but in the real world, Module D value is identifiable in EPD documents while PEF credits/points are added up to other numbers and are difficult to be separated. (Zampori, 2019) (European Committee for Standardization, 2019)

Table 1 EN 15804 vs. PEF brief comparison

<table>
<thead>
<tr>
<th>Methodology specification</th>
<th>Modelling approach</th>
<th>Results meaning</th>
<th>Open-loop recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 15804 A1 and A2, stage A-C</td>
<td>Attributional</td>
<td>environmental impact of the product. ‘real-world impact’ that may be used for comparison with environmental targets</td>
<td>The cut-off method (100/0) approach</td>
</tr>
<tr>
<td>EN 15804 A2:2019 module D</td>
<td>Consequential</td>
<td>What happens if the recycling material is recovered and replace another material or energy source?</td>
<td>Substitution and thereby avoided impact compared to a baseline</td>
</tr>
<tr>
<td>PEF</td>
<td>Attributional¹</td>
<td>Environmental performance of the product from cradle to grave considering avoided impacts of recycling/recovery in the future</td>
<td>Substitution and thereby avoided impact compared to a baseline</td>
</tr>
</tbody>
</table>

From the Attributional Vs. Consequential LCA point of view, EN 15804 follows the attributional LCA basics from Module A to Module C and reports the Module D result as a separate number from the LCA study, since it answers another (consequential based) question. Module D calculation is based on consequential LCA principles². PEF CFF formula is based

¹ Since it uses this approach both for process allocation and Open Loop Recycling.
² The principles of consequential LCA and using avoided burden approach in attributional LCA are different since for consequential LCA marginal data should be used while average data is the input of attributional LCA. Marginal data is however not required in all parts of Module D
on attributional LCA and reports a single non-modular result. A summary of these differences can be seen in Table 1.

Other differences exist such as data requirements, the type of the products for standard application and impact categories that are not related to the comparison of nature and results of the formulas, the main purpose of this study.

3.2.6 Controversial variables in the EoL formulas

Recycling rate:

Recycling rate is the amount of material that is going out from the product system for recycling in the future divided by the total amount of material going into the system for production. In EN 15804 formula, it is not divided (which is addressed as a problem in Appendix 1) but there is no difference since determining the amount of material that will be recycled in the future is the purpose. EN 15804 has no default values or suggested procedure for “how to” determine this amount. PEF formula has a list of default suggested values that are not complete in which some construction components/materials are missing. Both standards mentioned that practitioners should determine and then justify the value they used. This way of determining variable is subjective (and maybe arbitrary) and can lead to a high amount of uncertainty, while uncertainty analysis is still not a part of the standards.

Amount of material going out of the system for recycling in the future in EN 15804, Module D:

\[ e_{\text{module } D1} = \sum \left( M_{MR \text{ out } i} - M_{MR \text{ in } i} \right) \times \left( E_{MR \text{ after EoW out } i} - E_{VM\text{ sub out } i} \times \frac{Q_{R \text{ out } i}}{Q_{\text{sub } i}} \right) \]

Recycling rate in PEF formula:

Material

\[ (1 - R_1)E_\nu + R_1 \times \left( A_{E\text{recycled}} + (1 - A)E_\nu \times \frac{Q_{\text{in } i}}{Q_p} \right) \]

Energy

\[ (1 - B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) \]

Disposal

\[ (1 - R_2 - R_3) \times E_D \]

In this study as a secondary aim, a recycling rate calculation tool for buildings is developed to assess if there is any potential to have lower subjectivity by using the recyclability assessment methods that will be mentioned in the next part. Using such a tool can result in less subjectivity in specifying the recycling rate which can lead to lower subjectivity of the studies in this sector while encouraging building developers to use recycling/reuse technologies.

Eer average:

Eer average is specific emissions and resources per unit of analysis that would have arisen from specific current average substituted energy sources: heat and electricity. In other words, This variable value is the average amount of emissions for producing heat and electricity in a country. The formula for calculating this according to EN 15804 is not correct and this issue and the solution are addressed in Appendix 1. Module D compares the emissions from the burning of exported fuel in the future (like wooden chips) to the average emissions of the energy system in a country in the Module D formula. It means that it will not be always positive to burn fuels from waste, especially if electricity and energy production is from renewable
sources. PEF did not include such credit/burden in its formula and combines both exported fuel for the future burning and incineration at the end of life stage which always gives positive credit for energy production by burning such fuel.

\[
e_{\text{module D2}} = \sum (M_{\text{ER out}|i} - M_{\text{ER in}|i}) \times (E_{\text{ER after EoW out}|i} - E_{\text{ER average}})
\]

Determining this variable is not subjective but can lead to wrong decisions. Since the formula for calculating Eer average is as follow, it is important to understand two emissions for heat and electricity. LHV is the lower heating value and X is the efficiency of energy production.

\[
E_{\text{ER average}} = \text{LHV} \times X_{\text{ER heat}} \times E_{\text{SE heat}} + \text{LHV} \times X_{\text{ER elec}} \times E_{\text{SE elec}}
\]

\[E_{\text{SE heat,elec}}\]: specific emissions and resources consumed per unit of analysis that would have arisen from specific current average substituted energy source: heat and electricity respectively.

Determining such “average substituted energy source” for Eer average calculation can become both subjective and leads to unreal numbers for Eer average when exported fuel be transported and stored for future use. In this study, by using a tool from CDM (UNFCCC, CDM – Executive Board, 2008), these variables are calculated according to the rules of the CDM tool handbook which leads to far less subjectivity and clearer determination.

### 3.3 Recyclability assessment methods

The recyclability assessment methods are the methods for evaluating the potentiality of recycling/reusing of the building materials/components at the end of life of the components or building. Since recycling rate in both PEF and EN 15804 can be subjective due to lack of regulation, integrating these methods to LCA can help studies to be less subjective and less dependent on the practitioner choices as well as encouraging new innovations for sustainable construction by providing a tool for recycling/reuse rate calculation with clear set of rules and methodology to prevent burden shifting in this industry. There are not that many recyclability assessment methods in the market, while some of them are based on scores for green building certifications. (Olugbenga O. Akinade, 2017) some of them connect Building Information Models (BIM) to the scoring system (Akinade, 2015) which cannot be used in Sweden since the current practice of using the BIM models are far from the guidelines of these tools. For this study, two methods have been chosen, a method developed by DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen, German Sustainable Building Council) and a method from BRE (Building Research Establishment _center for building research in the UK_).

#### 3.3.1 DGNB

DGNB is the broadest certificate among building certification competitors in terms of environmental consideration. building certifications are environmental labels that have several levels to indicate how much a building is environmentally friendly. DGNB’s weightings of the criteria are in a table transparently which gives the reader a broad concept of how important each criterion is according to DGNB. DGNB system document consists of many criteria related to green buildings and construction. (DGNB GmbH, 2018) The recyclability assessment tool can be found under the criterion:

- TEC1.6 Ease of recovery and recycling (DGNB GmbH, 2018)

The ease of recovery and recycling criterion is a part of a set of criteria that reflects the final score of the building in terms of being green according to DGNB definition. This criterion
should be determined based on a list of scores and rules. A project can earn a total of 100 points for TEC 1.6 criterion which is the sum of 3 parts, ease of recycling (45 points), ease of recovery (45 points) and ease of recovery, conversion, and recycling in the planning process (10 points). The list of the standard components according to DGNB TEC 1.6 is shown in Table 2.

<table>
<thead>
<tr>
<th>Component Group</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External walls (m²)</strong></td>
<td>Non-load-bearing or prefabricated</td>
</tr>
<tr>
<td></td>
<td>Cladding units and internal linings (of external walls)</td>
</tr>
<tr>
<td></td>
<td>External doors and windows</td>
</tr>
<tr>
<td><strong>Internal walls (m²)</strong></td>
<td>Non-load-bearing or prefabricated</td>
</tr>
<tr>
<td></td>
<td>Internal linings</td>
</tr>
<tr>
<td></td>
<td>Internal doors and windows</td>
</tr>
<tr>
<td><strong>Floors and ceilings (m²)</strong></td>
<td>Floorings</td>
</tr>
<tr>
<td></td>
<td>Ceiling linings</td>
</tr>
<tr>
<td><strong>Roofs (m²)</strong></td>
<td>Roof coverings and roof linings</td>
</tr>
<tr>
<td><strong>Load-bearing structures (m²)</strong></td>
<td>Load-bearing external walls</td>
</tr>
<tr>
<td></td>
<td>External columns</td>
</tr>
<tr>
<td></td>
<td>Load-bearing internal walls</td>
</tr>
<tr>
<td></td>
<td>Internal columns</td>
</tr>
<tr>
<td></td>
<td>Floor structures</td>
</tr>
<tr>
<td></td>
<td>Roof structures</td>
</tr>
<tr>
<td><strong>Foundations (m²)</strong></td>
<td>Shallow or deep foundations</td>
</tr>
<tr>
<td></td>
<td>Subsoil and base slabs and sealing of buildings</td>
</tr>
<tr>
<td></td>
<td>Floorings</td>
</tr>
</tbody>
</table>

In the recyclability assessment tool that is developed for this study, ease of recycling (45 points) and ease of recovery (45 points) scoring system are used and the third part is not considered. To briefly describe, the components of the building will be grouped according to Table 2 and each component will be scored by the practitioner according to a set of rules from the DGNB system. The list of the rules can be found in Appendix 3.

3.3.2 BRE

BRE is a research and development company in the UK. The most famous product of BRE is BREEAM, a building certification system. They have developed a tool called Design For Deconstruction (DFD) which indicates the potentiality of recycling or reusing of the building components in the future. Same as DGNB tool, the components should be categorized according to the list of the components provided in DFD tool. After listing, the scoring should
be done by the practitioner according to a set of rules that can be found in Appendix 4. The tool will be described in detail in the methodological approach section.

List of building components according to DFD tool is as follow:
- Foundations and floors
- External walls (m²)
- Internal walls (m²)
- load-bearing (not mentioned by BRE DFD tool, added by the writer for the integrity of the tool)
- Roof
- Windows and doors
- floor finish
- building services
- sanitary ware

4 Research Methods and Design

In this part, the methods that are developed for answering the research questions and the way in which the project is constructed are presented. The methodology of this study is divided into several phases. For a brief description, in this project, the aim is to compare the end of life and after the end of life burdens/credits that will be assigned to the construction products by the PEF method and EN 15804 method in order to evaluate the differences between the two methods. The evaluation and comparison of these two can lit up the awareness regarding the high amounts of credits/burdens attributed to the products based on assumptions with uncertainties in the environmental declarations and reports, while uncertainty analysis and statistical reporting are not included in them, uncertainties are even more in the credits given to a long-lasting product like building. Moreover, the question “which product will have more credits according to each method” can be answered by presenting the credit results.

All amounts of the materials are based on a real project, an extraction of components used in a multi-story plus energy building developed by Skanska AB in Sweden. this makes it possible to indicate the proportions and therefore the importance of different materials in terms of generating environmental benefits/burdens. The list of the 217 components can be found in Appendix 6. The flow of answering each research question can be seen in Figure 5. For the evaluation, there will be 5 phases in this project:
Phase 1: grouping materials

This phase is for grouping 217 components (like walls, beam, column, etc.) in a list of 17 material groups (precast concrete, steel rebar, glass, etc.) to make the calculations simpler.

Phase 2: Determining the Global warming impact (GWP)

This phase exists to determine the emissions of the different stages of the materials/products life cycle. This is important since the emission variables should be determined in PEF and EN 15804 formulas.

Phase 3: developing PEF vs. 15804 approach

After having the list of materials and their emissions in different life stages, we need to calculate PEF and EN 15804 for comparison. Since they are different in nature, a few variable definitions, and variable names, a list of equivalent variables for common use in both formulas generated for this study in which variables from both formulas can be replaced with them.

Phase 4: Using recyclability assessment methods for recycling rate determination

As it is described in the background part, there are two controversial variables. One of them is the recycling rate at the end of life. In the 4th phase, recycling rates will be determined according to recyclability assessment methods from DGNB and BRE. In the results part, however, 4 different scenarios for recycling rate determination have been used for reporting statistical errors, one is PEF default numbers, another one is from literature and the other two are from DGNB and BRE recyclability assessment tools in order to indicate the amount of uncertainty of the EoL and after EoL credits/burdens by having different choice for determining the recycling rate. It follows with a conclusion of how helpful the recyclability assessment method would be for all stakeholders if one method is developed for the construction sector and be used by all practitioners, without any exception.

As it is mentioned, For comparing and evaluating different approaches for determining the materials rate of recycling, 4 scenarios have been developed in this project. Each scenario used in both formulas at the same time. It means that PEF default suggested numbers are also used in EN 15804 formulas in the first scenario. The scenarios are as follow:

- The “PEF suggestions in annex C + literature for missing ones” case – Main Scenario
- The “DGNB results of the developed recycling rate calculation tool” case
- The “BRE results of the developed recycling rate calculation tool” case
- The “Recycling rate based on Literature” case

For the second and third scenarios, a guideline for how to use recyclability assessment methods in this context is developed; this is a result of developing a way to connect them to the EoL formula’s rate of recycling (R2).

Phase 5: determining Eer average for EN 15804

As it is described in the background part, there are two controversial variables. The second one is Eer average. In the 5th phase, an energy margin calculation tool from CDM will be used to calculate Eer average for Sweden instead of the standard definition “average substituted fuel emissions for energy production”.
4.1 Phase 1: grouping materials

The list of the components of the case study consists of 217 rows. This list can be found in appendix 6. They first classified in a preliminary material/component-based list and some assumptions about some components were made. The assumptions and preliminary groups are addressed in Table 3.

*Table 3* preliminary groups of materials calculated from the 217 components of the real project which can be found in appendix 6 and assumptions regarding the materials used in the components.

<table>
<thead>
<tr>
<th>groups</th>
<th>mass kg</th>
<th>assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete elements</td>
<td>2639600</td>
<td>assume 5% rebars</td>
</tr>
<tr>
<td>concrete inplace</td>
<td>617809</td>
<td>assume 2% rebars</td>
</tr>
<tr>
<td>mortar</td>
<td>5261</td>
<td>Will be in the same group with Block (LECA) and tiles</td>
</tr>
<tr>
<td>inner walls</td>
<td>1810846</td>
<td>assume 95% concrete, 3% insulation, 2% rebar, excluding steel studs</td>
</tr>
<tr>
<td>outer walls</td>
<td>570768</td>
<td>assume 93% concrete, 5% insulation, 2% rebar</td>
</tr>
<tr>
<td>steel (frame)</td>
<td>42383</td>
<td></td>
</tr>
<tr>
<td>steel (rebar)</td>
<td>5809</td>
<td></td>
</tr>
<tr>
<td>steel (studs)</td>
<td>39540</td>
<td></td>
</tr>
<tr>
<td>steel (other)</td>
<td>34873</td>
<td></td>
</tr>
<tr>
<td>steel (plates)</td>
<td>8501</td>
<td></td>
</tr>
<tr>
<td>wood</td>
<td>120201</td>
<td></td>
</tr>
<tr>
<td>oil-based, recovery</td>
<td>62592</td>
<td>All oil-based components that will be recycled/incinerated</td>
</tr>
<tr>
<td>oil-based, landfilled</td>
<td>1715</td>
<td>All oil-based components that should be landfilled</td>
</tr>
<tr>
<td>block</td>
<td>43649</td>
<td></td>
</tr>
<tr>
<td>insulation</td>
<td>20037</td>
<td></td>
</tr>
<tr>
<td>cement</td>
<td>18035</td>
<td></td>
</tr>
<tr>
<td>aluminium</td>
<td>11530</td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>100870</td>
<td></td>
</tr>
<tr>
<td>gypsum</td>
<td>48917</td>
<td></td>
</tr>
<tr>
<td>tiles</td>
<td>149579</td>
<td></td>
</tr>
<tr>
<td>furniture</td>
<td>99638</td>
<td>assume 90% wood and 10% steel</td>
</tr>
<tr>
<td>stone</td>
<td>1466</td>
<td></td>
</tr>
<tr>
<td>windows</td>
<td>16047</td>
<td>assume 80% glass, 4% steel, 6% aluminium and 10% wood</td>
</tr>
<tr>
<td>doors</td>
<td>4678</td>
<td>assume 100% wood</td>
</tr>
</tbody>
</table>
Then the assumed values are allocated to the main material groups and the components have been classified into 17 different material groups listed in Table 4:

<table>
<thead>
<tr>
<th>groups</th>
<th>mass kg</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete elements (concrete)</td>
<td>4 758 738</td>
<td>58%</td>
</tr>
<tr>
<td>gravel, cement (shotcrete included)</td>
<td>1 667 285</td>
<td>20%</td>
</tr>
<tr>
<td>concrete inplace (concrete)</td>
<td>605 452</td>
<td>7%</td>
</tr>
<tr>
<td>mortar, blocks and bricks, tiles</td>
<td>198 488</td>
<td>2.4%</td>
</tr>
<tr>
<td>steel (rebar)</td>
<td>197 778</td>
<td>2.4%</td>
</tr>
<tr>
<td>steel (studs and plates)</td>
<td>48 041</td>
<td>0.6%</td>
</tr>
<tr>
<td>steel (frame, structural elements)</td>
<td>42 383</td>
<td>0.5%</td>
</tr>
<tr>
<td>steel (other)</td>
<td>45 479</td>
<td>0.6%</td>
</tr>
<tr>
<td>wood</td>
<td>211 480</td>
<td>2.6%</td>
</tr>
<tr>
<td>glass</td>
<td>113 707</td>
<td>1.4%</td>
</tr>
<tr>
<td>oil based, recoverable</td>
<td>62 592</td>
<td>0.8%</td>
</tr>
<tr>
<td>oil based, landfilled</td>
<td>1 715</td>
<td>0.02%</td>
</tr>
<tr>
<td>gypsum</td>
<td>48 917</td>
<td>0.6%</td>
</tr>
<tr>
<td>copper</td>
<td>29 121</td>
<td>0.4%</td>
</tr>
<tr>
<td>insulation (mineral based)</td>
<td>102 901</td>
<td>1.3%</td>
</tr>
<tr>
<td>aluminium</td>
<td>12 493</td>
<td>0.2%</td>
</tr>
<tr>
<td>natural imported stone</td>
<td>1 466</td>
<td>0.02%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8 152 714</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

### Table 4 The amounts of 17 material groups used in the real building project

4.2 Phase 2: Determining the Global warming impact (GWP)

Determining the GHG emissions of each material group was in phase 2. Since concrete, gravel, and cement constitute more than 70% of the total weight of the building, a detailed LCA study conducted using Gabi educational software and Database to determine different emission variables in the formulas. Finding and determining emissions of concrete from literature is not that easy since each company and project has its own concrete mixture and production plant. The concrete mixture is according to an EPD (Skanska industrial solutions AB, 2019) for green concrete in the Stockholm area from Skanska AB and the emissions are compared and validated.
with that report. All transportations for waste handling (from deconstruction to landfill/recycling plant) in this LCA assumed to be 100 km.

Table 5 Concrete mix used in the study (Skanska industrial solutions AB, 2019)

<table>
<thead>
<tr>
<th>Concrete mix 1m3</th>
<th>kg</th>
<th>percentage</th>
<th>for one tonne</th>
<th>recyclate</th>
</tr>
</thead>
<tbody>
<tr>
<td>gravel</td>
<td>1102</td>
<td>49%</td>
<td>490</td>
<td>992</td>
</tr>
<tr>
<td>sand</td>
<td>692</td>
<td>31%</td>
<td>308</td>
<td>623</td>
</tr>
<tr>
<td>cement</td>
<td>225</td>
<td>10%</td>
<td>100</td>
<td>11</td>
</tr>
<tr>
<td>water</td>
<td>203</td>
<td>9%</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>absorbed water</td>
<td>24</td>
<td>1%</td>
<td>11</td>
<td>-</td>
</tr>
<tr>
<td>additives</td>
<td>1</td>
<td>0%</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>total</td>
<td>2247</td>
<td>100%</td>
<td>1000</td>
<td>1626</td>
</tr>
</tbody>
</table>

The emissions of the demolition process of the concrete are according to a study conducted for Boverket and Energimyndigheten. (Erlandsson & Pettersson, 2015) The detailed inputs and calculations are in Table 6Table 7.

Table 6 Input numbers from the report used in this study (Erlandsson & Pettersson, 2015)

<table>
<thead>
<tr>
<th>energy calculations</th>
<th>consumed</th>
<th>kwh/m2 BTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>making things ready for crushing</td>
<td>El</td>
<td>0.1</td>
</tr>
<tr>
<td>Diesel</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>crushing of the frame regardless of the frame type</td>
<td>El</td>
<td>8</td>
</tr>
<tr>
<td>Diesel</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>process consumed</td>
<td>kwh/ton</td>
<td></td>
</tr>
<tr>
<td>frame type consumption added to above (concrete frame) + over 6 meter height decks</td>
<td>Diesel</td>
<td>12.05</td>
</tr>
<tr>
<td>refining for secondary use of the concrete</td>
<td>Diesel</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 7 Results of the consumed energy for the demolition of the concrete calculated based on table 6 data

<table>
<thead>
<tr>
<th>Consumed</th>
<th>MJ</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>El used during crushing</td>
<td>106.9236</td>
<td>-</td>
</tr>
<tr>
<td>Diesel used during crushing general</td>
<td>145.2049</td>
<td>3.22677639</td>
</tr>
<tr>
<td>Diesel used during crushing for frame type</td>
<td>99.29682</td>
<td>2.206596</td>
</tr>
<tr>
<td>total diesel used for crushing</td>
<td>244.5018</td>
<td>5.4337239</td>
</tr>
<tr>
<td>diesel for refining</td>
<td>15.6888</td>
<td>0.34864</td>
</tr>
</tbody>
</table>

For the rest of the material groups, different articles, LCA studies and EPDs have been used. R2 (recycling rates) would differ depending on the scenarios but the literature-based scenario numbers are derived from the references in Table 8.

Table 8 References for Lifecycle results and variables in formulas, including literature-based scenario

<table>
<thead>
<tr>
<th>groups</th>
<th>Emissions references</th>
<th>R1, R2, R3, Qout</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete elements</td>
<td>Gabi Educational Database</td>
<td>(NATURVÅRDSVERKET, 2014)</td>
</tr>
<tr>
<td>gravel, cement (shotcrete included)</td>
<td>Gabi Educational Database</td>
<td>(NATURVÅRDSVERKET, 2014)</td>
</tr>
<tr>
<td>Material</td>
<td>Database</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Concrete inplace</td>
<td>Gabi Educational Database</td>
<td>(NATURVÅRDSVERKET, 2014)</td>
</tr>
<tr>
<td>Mortar, blocks and bricks, tiles</td>
<td>(votorantim cimentos, 2016) (Leca International, 2019) (Minera Skifer AS, 2018)</td>
<td>assumptions for R1, R2, R3</td>
</tr>
<tr>
<td>Steel (studs and plates)</td>
<td>Gabi Educational Database</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Steel (frame, structural elements)</td>
<td>Gabi Educational Database, (Norstal Steel Structures, 2018)</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Steel (other)</td>
<td>Gabi Educational Database, (Ferrometall AS, 2018)</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Wood</td>
<td>Gabi Educational Database</td>
<td>PEF annex C numbers + assumptions for fuel export percentage</td>
</tr>
<tr>
<td>Glass</td>
<td>Gabi Educational Database</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Oil-based, recoverable</td>
<td>(Danosa, 2015) (Davani, 2018)</td>
<td>(Dahlbo, 2007)</td>
</tr>
<tr>
<td>Oil-based, landfilled</td>
<td>Gabi Educational Database, Eurobitume Lifecycle Inventory, (Vinidex systems and solutions, 2016)</td>
<td>0 assumed for R1, R2, R3</td>
</tr>
<tr>
<td>Insulation (mineral based)</td>
<td>Gabi Educational Database</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Aluminium</td>
<td>(Purso Oy, 2018) (Purso Oy [2], 2018)</td>
<td>PEF annex C numbers</td>
</tr>
<tr>
<td>Natural imported stone</td>
<td>(Minera Skifer, 2018)</td>
<td>0 assumed for R1, R2, R3</td>
</tr>
</tbody>
</table>

4.3 Phase 3: developing PEF vs. 15804 approach

4.3.1 Methodology description

The implementation of investigation of the differences between PEF CFF formula and EN 15804 End of life equations consists of several steps:

- In the first step, due to the methodological differences that are already discussed in the introduction part, the PEF CFF is rewritten into virtual formulas to be comparable with the EN 15804 formulas. It means that the PEF formula is categorized into four modules.
according to EN 15804 (A, B, C, D) and then all formula parts that give credits and burdens in the C and D modules are derived for this study. To clarify this in an example, there is no impact of sourcing virgin material directly in the formula since this process belongs to module A in EN 15804. But the credit of avoiding virgin material has been considered since it is categorized in the benefits beyond the system boundary in Module D.

- To be able to use the same inventory for both formulas, variables of both approaches are translated into equivalent variables in a list. For the material part, the interpretation of the study conducted for the Swedish lifecycle center (Tomas Ekvall, 2019) is used. This list of equivalent variables is in Table 9.

### Table 9 Definitions of parameters and equivalence

<table>
<thead>
<tr>
<th>Equivalent parameters used in the study</th>
<th>description (eq CO2 kg per unit of analysis arising from)</th>
<th>PEF parameter</th>
<th>EN 15804 parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV</td>
<td>emissions of acquisition and pre-processing of virgin material</td>
<td>EV</td>
<td>Evm in</td>
</tr>
<tr>
<td>E*V</td>
<td>emissions of acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.</td>
<td>E*V</td>
<td>Evmsub out</td>
</tr>
<tr>
<td>Erecycled</td>
<td>emissions of the recycling process of the recycled (reused) material (for PEF, it, includes collection, sorting, and transportation process.)</td>
<td>Erecycled</td>
<td>Emr after EoW in</td>
</tr>
<tr>
<td>Erecycling EoL (after EoW out)</td>
<td>emissions of the recycling process of the material after the end of life stage (for PEF, it, includes collection, sorting, and transportation process.)</td>
<td>Erecycling EoL</td>
<td>Emr after EoW out</td>
</tr>
<tr>
<td>ED</td>
<td>emissions of disposal of waste material at the EoL of the analyzed product, without energy recovery.</td>
<td>ED</td>
<td>ELF</td>
</tr>
<tr>
<td>R1</td>
<td>it is the proportion of material in the input to the production that has been recycled from a previous system.</td>
<td>R1</td>
<td>Mmr in/Mtotal</td>
</tr>
<tr>
<td>R2</td>
<td>it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system.</td>
<td>R2</td>
<td>Mmr out/Mtotal</td>
</tr>
<tr>
<td>Mer in/M tot</td>
<td>it is the amount of the material from the previous system that used as secondary fuel, divided by the total amount of material in the current system (it is assumed to be 0 in this study to reduce unimportant complexity</td>
<td>defined in the description, not as a single variable</td>
<td>Mer in/Mtotal</td>
</tr>
<tr>
<td>Equivalent parameters used in the study</td>
<td>description (eq CO2 kg per unit of analysis arising from)</td>
<td>PEF parameter</td>
<td>EN 15804 parameter</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>---------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>% incinerate</td>
<td>amount of waste that will be incinerated which has not reached the end of waste status.</td>
<td>-</td>
<td>Minc out/Mtotal</td>
</tr>
<tr>
<td>% as fuel</td>
<td>amount of material leaving the product system where it has reached the end of waste status before incineration and leaves the product system as secondary fuel.</td>
<td>-</td>
<td>Mer out/Mtotal</td>
</tr>
<tr>
<td>R3</td>
<td>it is the proportion of the material in the product that is used for energy recovery at EoL. (%incineration+%fuel)</td>
<td>R3</td>
<td>-</td>
</tr>
<tr>
<td>QP (sub)</td>
<td>quality of the substituted material, i.e. quality of primary material or quality of the average input material if primary material is not used</td>
<td>Qp</td>
<td>Qsub</td>
</tr>
<tr>
<td>QRin</td>
<td>quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.</td>
<td>Qs in</td>
<td>Does not take it into account</td>
</tr>
<tr>
<td>QRout</td>
<td>quality of the outgoing secondary material (recycled and reused), i.e. quality of the recycled material at the point of substitution</td>
<td>Qs out</td>
<td>Qrout</td>
</tr>
<tr>
<td>Ese heat, elec</td>
<td>specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity respectively.</td>
<td>Ese heat, elec</td>
<td>Ese heat, elec</td>
</tr>
<tr>
<td>Einc</td>
<td>emissions of incineration</td>
<td>Does not take it into account</td>
<td>Einc</td>
</tr>
<tr>
<td>Eer (after EoW out)</td>
<td>emissions of the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, ...).</td>
<td>Eer</td>
<td>Eer after EoW out</td>
</tr>
<tr>
<td>Eer average</td>
<td>emissions of specific current average substituted energy sources: heat and electricity.</td>
<td>Does not take it into account</td>
<td>Eer average</td>
</tr>
<tr>
<td>LHV</td>
<td>Lower Heating Value of the material in the product that is used for energy recovery.</td>
<td>LHV</td>
<td>LHV</td>
</tr>
<tr>
<td>XLF se heat, elec</td>
<td>the efficiency of the energy recovery process from landfill for both heat and electricity.</td>
<td>X se heat, elec</td>
<td>XLF se heat, elec</td>
</tr>
</tbody>
</table>
Equivalent parameters used in the study | description (eq CO2 kg per unit of analysis arising from) | PEF parameter | EN 15804 parameter
---|---|---|---
Xinc se heat, elec | the efficiency of the energy recovery process from incineration for both heat and electricity. | Xinc se heat, elec

- For a clear comparison, the translation will be finished by dividing the PEF formula into the same life stages as EN 15804. For that, there will be two modules based on EN 15804, impacts that belong to Module A-C (lifecycle) and Module D (beyond the system boundary) and equivalent Modules for PEF. To understand which stage contributes to benefits/burdens of each Module, a list of life cycle stages that are credit givers has been developed:

1) **Avoiding virgin**: The credits that are achieved through less virgin material use
2) **Recycled content**: The credits/burdens that are achieved through using recycled material
3) **Recycling EoL**: The credits/burdens that can be achieved by having the possibility of recycling in the future
4) **Energy recovery EoL (fuel)**: The credits/burdens that can be achieved by exporting waste as fuel in the future after the End of Life
5) **Energy recovery (energy export, incineration, and landfill)**: The credits/burdens that will be achieved through energy recovery from waste directly in the End of Life
6) **Disposal**: The burdens that will be achieved by waste landfilling procedure

These Modules will be grouped into two groups according to the EN 15804 standard. In this stage, the end of life-related parts of the PEF CFF formula is completely translated to a credit-based formula that is comparable with EN 15804. Groups will be as follow:

1- **Module A-C**, credits/burdens from recycled content in production and the end of life stage, included in LCA according to EN 15804:
   - Avoiding virgin
   - Recycled content
   - Disposal
2- **Module D**, after the end of life, should be reported separately according to EN 15804:
   - Recycling EoL
   - Energy recovery (energy export, incineration, and landfill)
   - Energy recovery EoL (fuel export)

Then the credits/burdens that are allocated in these two stages will be presented as results, the amount of the credits or burdens from each stage are reported regardless of the Modules in Appendix 2 so that the results of each module can be visible.

### 4.3.2 EoL formulas

As it is already been discussed, Module D result from EN 15804 is more like a recycling and recovery indicator than a number related to lifecycle assessment study. In this project, a part of the PEF CFF formula has been translated to be calculated according to life cycle stages presented by EN 15804. This leads to having a recycling indicator for PEF (representative of Module D related stages) to be comparable with EN 15804 Module D formula. The rest will be aligned with the lifecycle stages that are included in LCA studies according to EN 15804, these stages will be grouped as Module C results for both standards.
A positive number in the table means that the row had environmental burdens and a negative number in the table is environmental credit/point. Detailed formulas for each column of the tables presented in the result section are in Table 10 and Table 11. The description of the variables can be found in Table 9.

**Table 10 Calculation Formulas for credits/burdens in EoL and after EoL related life cycle stages, derived from EN 15804**

<table>
<thead>
<tr>
<th>Lifecycle stage</th>
<th>Module A-C</th>
<th>Module D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoiding virgin</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recycled content</td>
<td>( R_1 \times E_{recycled} )</td>
<td>-</td>
</tr>
<tr>
<td>Recycling EoL</td>
<td>-</td>
<td>((R_1 - R_2) \times \left( \frac{E_{recEoL} - E \times V \times Q_R}{Q_P} \right))</td>
</tr>
<tr>
<td>energy recovery (export of fuel)</td>
<td>-</td>
<td>( \left( %<em>{fuel} - \frac{M</em>{er}}{M_{total}} \right) \times \left( E_{er} - E_{er\ average} \right) )</td>
</tr>
<tr>
<td>energy recovery (export of energy, incineration, and landfill)</td>
<td>( %<em>{incineration} \times E</em>{inc} )</td>
<td>(-M_{INC} \times (LHV \times X_{INC\ heat} \times E_{SE\ heat} + LHV \times X_{INC\ elec} \times E_{SE\ elec}) - M_{LF} \times (LHV \times X_{LF\ heat} \times E_{SE\ heat} + LHV \times X_{LF\ elec} \times E_{SE\ elec}))</td>
</tr>
<tr>
<td>Disposal</td>
<td>((1 - R_2) \times E_D)</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>Sum Module A-C</td>
<td>Sum Module D</td>
</tr>
</tbody>
</table>

**Table 11 Calculation Formulas for credits/burdens in different Module D related stages, derived from PEFCFF formula**

<table>
<thead>
<tr>
<th>Lifecycle stage</th>
<th>End of Life (EoL) virtual stage</th>
<th>After EoL virtual stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoiding virgin</td>
<td>(-(1 - A) \times R_2 \times \frac{Q_{R\ out}}{Q_P} \times E_V)</td>
<td>-</td>
</tr>
<tr>
<td>Recycled content</td>
<td>( A \times R_1 \times E_{recycled} + ) ((1 - A) \times R_1 \times \frac{Q_{R\ in}}{Q_P} \times E_V)</td>
<td>-</td>
</tr>
<tr>
<td>Recycling EoL</td>
<td>-</td>
<td>((1 - A) \times R_2 \times E_{recycling\ EoL})</td>
</tr>
<tr>
<td>energy recovery EoL</td>
<td>( R_3 \times E_{inc} )</td>
<td>-</td>
</tr>
<tr>
<td>energy recovery (export of energy, incineration, and landfill)</td>
<td>-</td>
<td>(-R_3 \times M_{total} ) ( (LHV \times X_{INC\ heat} \times E_{SE\ heat} + LHV \times X_{INC\ elec} \times E_{SE\ elec}))</td>
</tr>
<tr>
<td>Disposal</td>
<td>((1 - R_2) \times E_D)</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>Sum of EoL credits/burdens</td>
<td>Sum of after EoL credits/burdens</td>
</tr>
</tbody>
</table>
4.4 Phase 4: Using recyclability assessment methods for recycling rate determination

4.4.1 Recycling Score according to DGNB

DGNB TEC 1.6 tool is a tool for scoring the recyclability and reusability of the buildings. This section asks practitioners to group components in the groupings they provide. The grouping should be based on the area (m²) but since the data of the case study are all weights (kg), weights have been used in this study. After grouping according to DGNB vertically, the material grouping from the previous section (17 material groups) will be listed horizontally. Then the percentage of how much of each component is from each material group will be written in the material column. For example, concrete external columns of the building are precast concrete elements that contain 95% concrete element and 5% steel rebar and 0% for the rest 15 groups. Groupings and percentages can be seen in Figure 6.

<table>
<thead>
<tr>
<th>Component</th>
<th>Total mass used in the project (kg)</th>
<th>concrete elements (concrete)</th>
<th>gravel &amp; cement (shotcrete included)</th>
<th>concrete inplace (concrete)</th>
<th>mortar, blocks and bricks, tiles</th>
<th>steel (rebar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-load-bearing or prefabricated</td>
<td>47587</td>
<td>99%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Cladding units and internal linings, (external walls)</td>
<td>20830</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>External doors and windows</td>
<td>10000</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Non-load-bearing or prefabricated</td>
<td>118566</td>
<td>99%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Internal linings, (internal walls)</td>
<td>77880</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Internal doors and windows</td>
<td>10000</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Floorings</td>
<td>323430</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Roofing</td>
<td>13317</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Roof coverings and roof linings</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Load-bearing external walls</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>External columns</td>
<td>22200</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Load-bearing internal walls</td>
<td>40930</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Internal columns</td>
<td>77330</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Floor structures</td>
<td>2668549</td>
<td>99%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Roof structures</td>
<td>10498</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Subfloor or deep foundations</td>
<td>1071970</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Subfloor and slabsl and sealing of buildings</td>
<td>481790</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 6 Grouping components according to DGNB and determined material percentages. Tables are continuous and divided into two tables to make them readable.

After determining the percentages, the recyclability potential score and reusing potential score must be determined. For specifying these scores, DGNB has a classification system for quality levels and scoring charts. (DGNB GmbH, 2018) The descriptions for quality levels and scoring charts can be found in appendix 3. For this study, another criterion has been added to the already mentioned scoring points. This criterion is:

- Will the components be reused? If not, Does 90% of the component is at least in Quality Level 2 (QL2)?

Answering this question will lead to multiplying a correction factor to the final score. This exists to make sure that the numbers are more accurate since DGNB considers a higher level (i.e. the component is fully recyclable) by having just 60% of the total amount at that level (i.e. 65% of the material is recyclable). The resulting multipliers will be as follow:
• Reused; 1
• More than 90% of the component at least in Quality Level 2; 0.95
• Default: Less than 90% of the component is in Quality Level 2; 0.75

The scoring final chart is indicated in Figure 7. It is important to mention again that detailed scoring criteria are in appendix 3.

4.4.2 Recycling score according to BRE

BRE Design for Deconstruction (DFD) tool is a detailed tool for different aspects of the deconstruction, not just reusing and recyclability. Unlike DGNB, it just provides the scoring criteria based on considerations in the design phase.

The four scored criteria according to DFD are:

• Reuse and recycling potential of the key elements and components within
• The connections between the elements and components (a checklist approach is used for connections for the first stages of design followed by the scoring approach)
• The accessibility of elements and components
• The deconstruction processes.

Depending on the design process considerations, each of these criteria should be scored either 1, 0.5 or 0. If it is fully (1) partially (0.5) or not (0) considered. The score for each criterion is then aggregated across the elements and presented as a percentage. (BRE group, 2019)
This section asks practitioners to group components in the groupings they provide. After grouping according to BRE vertically, the material grouping from the previous section (17 material groups) will be listed horizontally. Then, the percentage of how much of each component is from each material group will be written in the material column. The four criteria of the DFD tool will be listed for scoring each component group according to the rules mentioned above. The groupings, percentages and scores can be seen in Figure 8.

| BRE Design for Deconstruction simple method (DFD) | List of Components based on BRE | reusing and recycling potential | connection | accessibility | deconstruction optimization | DFD score according to BRE | total mass used in the project (kg) | concrete elements (concrete) | gravel & cement (shotcrete) | concrete infill (concrete) | mortar, blocks and bricks, tiles | steel (rebar) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |
| Foundations and floors | 61% | 0% | 0% | 0% | 15% | 2133343.507 | 0% | 78% | 23% | 0% | 2% | 157778 |
| External walls (m²) | 0% | 0% | 100% | 0% | 25% | 206634.948 | 88% | 0% | 0% | 0% | 2% | 197778 |
| Internal walls (m²) | 48% | 48% | 100% | 0% | 4% | 194833.347 | 90% | 1% | 0% | 0% | 2% | 197778 |
| Load bearing (not mentioned by the BRE, added by the writer) | 50% | 0% | 4% | 0% | 13% | 282989.654 | 89% | 0% | 4% | 0% | 2% | 197778 |
| Roof | 50% | 0% | 100% | 0% | 38% | 133147.775 | 0% | 0% | 0% | 0% | 0% | 197778 |
| Windows and doors | 50% | 75% | 100% | 0% | 98% | 2153334.507 | 0% | 0% | 0% | 0% | 0% | 197778 |
| Floor finish | 50% | 0% | 100% | 0% | 38% | 32437.382 | 0% | 0% | 0% | 0% | 0% | 197778 |
| Building services | 100% | 100% | 100% | 0% | 79% | 26278.981 | 0% | 0% | 0% | 0% | 0% | 197778 |
| Sanitary ware | 50% | 0% | 100% | 0% | 50% | 218488 | 0% | 0% | 0% | 0% | 0% | 197778 |
| Steel (studs and plates) | steel (other) | wood | glass | oil based, recyclable | | | | | | | | | |
| | 48041 | 42383 | 45479 | 211480 | 113707 | 62592 | 1715 | 48917 | 29121 | 102901 | 12493 | 1466 |
| | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 2% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

Figure 8 Grouping components and scores according to BRE DFD tool and determined material percentages. Tables are continuous and divided into two tables to make them readable.

After determining the “DFD score” according to BRE, we should send the recyclability score to the calculation tool. For this study, the maximum number between “reusing and recycling potential” and “DFD score” is considered as Si for the calculation tool. The reason behind this decision is to reduce the unreality behind the recyclability score since DFD considers connection, accessibility and deconstruction optimization for the scoring system. While they are positive for recycling/reusing if they are considered, they are not always negative if designers did not consider them in the design phase.

### 4.4.3 Calculating recycling rates

This tool developed for this study. The results of this tool may not be accurate since DGNB and BRE tools purposes were not to be used in a Lifecycle Assessment project but can be a good start for creating recyclability assessment tools for LCA studies of the buildings to make recycling rate determination transparent and less subjective in the future. The Si parameter in the formula can be determined using other tools or by the practitioner from literature. In this way of specifying the recycling rate, the practitioner is determining this rate for the specific component used in the specific building, not a general number for a geographical area from literature. The tool formula for recyclability rate calculation is formula (8):
Recyclability rate of material \( j \) = \( \sum_{i=1}^{n} \frac{S_i \times M_i \times P_i}{S_{\text{max}}^j} \) \( M_j \) \( (8) \)

\( S_i \): Average mass-weighted recyclability score of each component group. In this study, according to DGNB or BRE.

\( M_i \): Total mass of the same component used in the building (i.e. floorings). \( \sum_{k=1}^{n} m_k \) in which \( m_k \) is the mass of each component in the same category (i.e. parquets of 2\textsuperscript{nd} floor)

\( P_i \): the amount of material used in a component divided by the total mass of the component.

\( S_{\text{max}}^i \): the maximum score that the component can earn according to DGNB rules.

\( M_j \): The total amount of material used in the building (i.e. total steel rebar).

As a descriptive calculation of the formula, \( S_i \) should be determined, for this study two tools from DGNB and BRE used. After \( S_i \) determination, we should divide them to the highest possible score which results in the final recyclability/reusability score in percentage. This number in each row then will be multiplied with each component material percentages under the material column to result in the recyclability/reusability of the material inside the component. The resulted number then will be multiplied with the total mass of the component. The sum of the column under each material group will result in the desired rates of that material.

After grouping materials, the calculation tool which is developed for this study will automatically calculate the recycling rates according to the formula (8). The results are presented in Table 12.

The two first rows are the results of a method that is developed to make recycling rate calculation restricted with a set of rules and formulas in which there will be far less subjective choices comparing to current business as usual cases. Adding to these two rows, another two recycling rate rows will be added to this study. One from the Annex C of PEF standard that consists of default numbers for this rate and another row from the literature that is currently the case for many studies. These 4 numbers will be used simultaneously in the formulas developed for the PEF vs EN 15804 methodology. The results will show how sensitive the formulas are to the recycling rate determination. In other words, it reflects how subjective choices of recycling rate can lead to different results in these standards which may result in wrong environmental decisions in the industry.

**Table 12 Recycling rates of the 4 scenarios used in this study**

<table>
<thead>
<tr>
<th>Material groups</th>
<th>Concrete elements (concrete)</th>
<th>Gravel &amp; cement (shotcrete included)</th>
<th>Concrete replay (concrete)</th>
<th>Mortar, blocks and bricks, tiles</th>
<th>Steel (rebar)</th>
<th>Steel (studs and plates)</th>
<th>Steel (frame, structural elements)</th>
<th>Steel (other)</th>
<th>Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario DGNB</td>
<td>81%</td>
<td>74%</td>
<td>78%</td>
<td>20%</td>
<td>83%</td>
<td>75%</td>
<td>82%</td>
<td>41%</td>
<td>15%</td>
</tr>
<tr>
<td>Scenario BRE</td>
<td>47%</td>
<td>61%</td>
<td>59%</td>
<td>50%</td>
<td>49%</td>
<td>49%</td>
<td>50%</td>
<td>56%</td>
<td>25%</td>
</tr>
<tr>
<td>Scenario Highest tech</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Scenario PEF default</td>
<td>60%</td>
<td>50%</td>
<td>60%</td>
<td>0%</td>
<td>95%</td>
<td>95%</td>
<td>85%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material groups</th>
<th>Glass</th>
<th>Oil based, recoverable</th>
<th>Oil based, landfilled</th>
<th>Gypsum</th>
<th>Copper</th>
<th>Insulation (mineral based)</th>
<th>Aluminium</th>
<th>Natural imported stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario DGNB</td>
<td>11%</td>
<td>24%</td>
<td>0%</td>
<td>18%</td>
<td>0%</td>
<td>56%</td>
<td>91%</td>
<td>19%</td>
</tr>
<tr>
<td>Scenario BRE</td>
<td>12%</td>
<td>49%</td>
<td>0%</td>
<td>48%</td>
<td>85%</td>
<td>38%</td>
<td>99%</td>
<td>49%</td>
</tr>
<tr>
<td>Scenario Highest tech</td>
<td>87%</td>
<td>60%</td>
<td>95%</td>
<td>65%</td>
<td>100%</td>
<td>66%</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>Scenario PEF default</td>
<td>1%</td>
<td>2%</td>
<td>0%</td>
<td>40%</td>
<td>91%</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>
4.5 Phase 5: determining Eer average for EN 15804

Eer average, a variable in formula (5), is the amount of emissions that are emitted for energy production from specific current average substituted energy sources for both heat and electricity. It is already discussed in detail in the background section. This variable can be named as “energy margin” because of its nature. In this phase, the energy margin will be calculated according to EN 15804 formula and CDM calculation tool.

EN 15804 formula: 
\[ E_{ER\, average} = LHV \times X_{ER\, heat} \times E_{SE\, heat} + LHV \times X_{ER\, elec} \times E_{SE\, elec} \]  

As it can be seen in the formula, \( E_{SE\, heat} \) and \( E_{SE\, elec} \) are used to calculate \( E_{ER\, average} \). There is a fundamental definition problem that is addressed in Appendix 1. In this section, these two emissions are corrected according to the suggestion in Appendix 1 and a tool from CDM is used for the calculation of these parameters. This tool is:

- CDM suggestion for electricity grids (will be expanded to heat production too)  
  (UNFCCC, CDM – Executive Board, 2008)

The EN 15804 suggestion for calculating energy margin is to use the average substituted fuel for both \( E_{SE\, heat} \) & \( E_{SE\, elec} \). In Sweden, biofuel is widely used, mostly in the shape of wooden chips or biomass. But CDM calculation tool is more complex and can lead to a more accurate energy margin, which may lead to fairer credits/points comparing to the standard’s suggestion. After describing CDM tool, the calculation makes it clear.

4.5.1 CDM tool

CDM describes in detail how to calculate the operational energy margin in the calculation methods. There are four methods in CDM report (UNFCCC, CDM – Executive Board, 2008):

- Simple method
- Simple adjusted method
- Dispatch data analysis method
- Average method

For this study, the simple method is used. For calculating marginal emission per MWH for heat and electricity production according to CDM simple method, a few important factors should be taken into account. (UNFCCC, CDM – Executive Board, 2008)

- the practitioner should not consider low-cost / must-run resources in the calculation.
- Based on data on fuel consumption and net electricity generation of each power plant/unit (Option A), or Based on data on net electricity generation, the average efficiency of each power unit and the fuel type(s) used in each power unit (Option B)

Low-cost / must-run resources are defined by CDM calculation tool guidelines: “Low-cost/must-run resources are defined as power plants with low marginal generation costs or power plants that are dispatched independently of the daily or seasonal load of the grid. They typically include hydro, geothermal, wind, low-cost biomass and solar generation. If coal is
obviously used as must-run, it should also be included in this list, i.e. excluded from the set of plants.” (UNFCCC, CDM – Executive Board, 2008)

Option A data availability was not public. Hence, in this study, Option B has been chosen. Option A should always be used if there are data available. (UNFCCC, CDM – Executive Board, 2008)

The total energy use in the industrial sector in Sweden is presented in Figure 9. The list of biofuels with the amounts used in power generation, the detailed list of electricity sources and district heating sources will be analysed. The emission of natural gas is reported by the Swedish energy agency and an average emission will be taken into account for both petroleum products and other fuel categories.

Electricity production by source type is reported in Figure 10. While hydropower, wind-power, solar power and the green part of the chart are among Low-cost/must-run sources, the energy plants that should be used in this calculation are thermal power plants. thermal power plants have a wide range of technologies and resource types. These power plants, according to Figure 11, are working based on 10 different resource categories, the fuels that should be considered according to CDM method are:

- Wood fuel
- Black liquor and tall oil
- Fuel oils
- Natural gas
- Coal
- Furnace gas

District heating which represents just 2% of the heat used in the industrial sector, have a variety of resource according to Figure 12. The fuels that will be in the category of analysis are:

- Wood fuels
- Oil and oil products
- Natural gas
- Coal
- Peat

After identifying the energy sources according to CDM, the amount of energy produced using those sources and the environmental impacts (CO2 equivalent emissions in this study) must be found in statistics. In Sweden, the energy production and its sources can be found in (Swedish Energy Agency, 2019) and (SCB, 2018) and the environmental impact can be found in (Swedish Environmental Protection Agency, 2019) which reports emissions factors of
different energy sources in Sweden. The summary of these data is presented in \( \text{Pi:} \) The amount of energy production using each fuel type in MWH.

\( \text{Ei:} \) Emission factor of each fuel in \( \left( \frac{\text{kg CO}_2}{\text{MWH}} \right) \).

The emission factor of heat production depends on the emission factor of district heating. Since district heating has another list of fuels, first we should present district heating values and calculate the emission factor of it, then write it in the data for heat production and calculate 2 emission factors, one for electricity and one for heat.

Table 13 District heating supply by the types of fuels and their emission factor in Sweden

<table>
<thead>
<tr>
<th>fuel burnt for supply district heating</th>
<th>GJ</th>
<th>kg CO2 per GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood fuel</td>
<td>20.82</td>
<td>96</td>
</tr>
<tr>
<td>Oil and oil products</td>
<td>1.17</td>
<td>74.26</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1.98</td>
<td>57</td>
</tr>
<tr>
<td>Peat</td>
<td>0.91</td>
<td>105.20</td>
</tr>
<tr>
<td>Coal</td>
<td>1.47</td>
<td>93</td>
</tr>
</tbody>
</table>

Emission factor of district heating = 92.26 kg CO2/GJ = 332.13 kg CO2/MWH

Table 14 to Table 15. The equivalent emission factor for each list is calculated in Table 16. The equivalent emission factors are calculated according to simple weighting formula, formula (9).

\[
\text{Equivalent CO}_2 \left( \frac{\text{kg CO}_2}{\text{MWH}} \right) = \frac{\sum_i P_i \times E_i}{\sum_i P_i} \quad (10)
\]

\( \text{Pi:} \) The amount of energy production using each fuel type in MWH.

\( \text{Ei:} \) Emission factor of each fuel in \( \left( \frac{\text{kg CO}_2}{\text{MWH}} \right) \).

The emission factor of heat production depends on the emission factor of district heating. Since district heating has another list of fuels, first we should present district heating values and calculate the emission factor of it, then write it in the data for heat production and calculate 2 emission factors, one for electricity and one for heat.
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<tr>
<td>Peat</td>
<td>0.91</td>
<td>105.20</td>
</tr>
<tr>
<td>Coal</td>
<td>1.47</td>
<td>93</td>
</tr>
</tbody>
</table>

Emission factor of district heating = 92.26 kg CO2/GJ = 332.13 kg CO2/MWH

Table 14 Electricity generation in power plants by the type of fuel and their emission factor in Sweden (Swedish Energy Agency, 2019) (Swedish Environmental Protection Agency, 2019)

<table>
<thead>
<tr>
<th>fuel consumed in power plants to generate electricity</th>
<th>TWH</th>
<th>kg CO2 per MWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood fuel</td>
<td>5.13</td>
<td>345.60</td>
</tr>
<tr>
<td>Black liquor and tall oil</td>
<td>4.16</td>
<td>271.08</td>
</tr>
<tr>
<td>Fuel oils</td>
<td>0.35</td>
<td>274.32</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.70</td>
<td>205.20</td>
</tr>
<tr>
<td>Peat</td>
<td>0.18</td>
<td>378.72</td>
</tr>
<tr>
<td>Coal</td>
<td>0.26</td>
<td>334.80</td>
</tr>
<tr>
<td>Furnace gas</td>
<td>0.75</td>
<td>1148.66</td>
</tr>
</tbody>
</table>

Table 15 Heat generation in the industry by the types of sources and their emission factor in Sweden (Swedish Energy Agency, 2019) (Swedish Environmental Protection Agency, 2019)

<table>
<thead>
<tr>
<th>heat energy use industry in Sweden 2017</th>
<th>TWH</th>
<th>kg CO2 emission per MWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuels</td>
<td>56</td>
<td>345.60</td>
</tr>
<tr>
<td>electricity</td>
<td>50</td>
<td>15.00</td>
</tr>
<tr>
<td>petroleum</td>
<td>10</td>
<td>267.34</td>
</tr>
<tr>
<td>other fuels</td>
<td>6</td>
<td>216.00</td>
</tr>
<tr>
<td>natural gas</td>
<td>4</td>
<td>205.20</td>
</tr>
<tr>
<td>district heating</td>
<td>3</td>
<td>332.13</td>
</tr>
</tbody>
</table>
Table 16 The emission factors of electricity and heat produced from alternative sources in Sweden

<table>
<thead>
<tr>
<th>Emission factor, Equivalent CO2</th>
<th>kg CO2 per MWH</th>
<th>kg CO2 per MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity from Power plants</td>
<td>360.29</td>
<td>0.10</td>
</tr>
<tr>
<td>Heat production plants in the industry</td>
<td>200.70</td>
<td>0.06</td>
</tr>
</tbody>
</table>

The two calculated emission factors can be used as $E_{SE\text{ heat}}$ & $E_{SE\text{ elec}}$ in Formula (9). This will result in the final Eer average that is indicated in Table 17.

Table 17 Parameters and calculation of Eer average from the calculated emission factors according to CDM

<table>
<thead>
<tr>
<th>Eer from formula</th>
<th>Wood waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>average electricity material</td>
<td></td>
</tr>
<tr>
<td>LHV</td>
<td>16.9</td>
</tr>
<tr>
<td>$E_{se\text{ elec}}$ (kg Co2/MJ) (from CDM simple method)</td>
<td>0.10</td>
</tr>
<tr>
<td>$X_{er\text{ elec}}$ (assumed)</td>
<td>0.3</td>
</tr>
<tr>
<td>average heat material</td>
<td></td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>16.9</td>
</tr>
<tr>
<td>$E_{se\text{ heat}}$ (kg Co2/MJ) (from CDM simple method)</td>
<td>0.06</td>
</tr>
<tr>
<td>$X_{er\text{ heat}}$ (assumed)</td>
<td>0.85</td>
</tr>
<tr>
<td>Eer average (kg Co2/unit of analysis)</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Just for comparison, if the recommendation from EN 15804 being used for the calculation, the $E_{se\text{ heat}}$ and $E_{se\text{ elec}}$ variables must be from specific current average substituted energy sources. If we assume that the corrections mentioned in Appendix 1 are considered, in Sweden, these numbers are 0.08 kg CO2/MJ and 0.09 kg CO2/MJ for $E_{se\text{ heat}}$ & $E_{se\text{ elec}}$ respectively. (SCB, 2018) so the formula results in (Eer average = 1.7 kgCO2/unit of analysis). As we can see, this number is higher than the calculated number according to CDM which means more credit for burning fuel from waste. Giving more credit to this process while the emission factors based on all alternative fuels give lower Eer average does not seem to be justifiable.

5 Results and Analysis

5.1 Main scenario results

In this part, the results of calculating formulas that were developed for PEF vs 15804 comparison will be presented based on the main scenario the PEF suggested default numbers and literature for missing ones that is the most probable reference in such studies. Then, the
sensitivity of the recycling rate determination will be presented based on the 4 different recycling rate determination scenarios that are mentioned in the methods part. The detailed results of each scenario and their values are listed in appendix 2. The formulas show credits less than 0 and burdens more than 0. Therefore, the charts representing points/credits with the values less than 0, and burdens are those with the value of more than 0.

![Points/credits for total material group for the whole building (PEF default Scenario)](image)

**Figure 13** Burdens/Credits for each material group for the whole building in EoL and after EoL stages. NOTE: PEF does not have after EoL stage. But the PEF formula is virtually divided into these stages to make comparison possible.

**Credits for the end of life stage:**

As it can be seen in Figure 13, the CO₂ equivalent credits of Aluminium are by far the highest following steel products according to the PEF formula. These credits come from the possibility of recycling at the end of life that means avoiding virgin material in the future. According to EN 15804, the highest credits are for those with 0 credit, since EN 15804 just allocate burdens in this stage and does not have “avoiding virgin material” credit in its methodology.

**Credits for after the end of life stage:**

As is indicated in Figure 13, the CO₂ equivalent credits from incinerating wood are the highest among other credits according to EN 15804, and the highest is aluminium according to PEF. The incineration and burning credits are higher in EN 15804 (it is visible in both wood and plastic recoverable results). That is due to the extra points EN 15804 gives for the avoiding burdens in substituted energy production, connected to Eer average that is already calculated. In other words, EN 15804 gives extra points for having so-called “greener fuel” for burning power plants compared to the fuels that are already being used.

Another interesting result is for aluminium. While aluminium is not used massively comparing to other major materials, this material has also earned high credits, mostly due to the fact that producing aluminium from virgin material is nearly 80 times more CO₂ intensive, comparing to the production out of the secondary (recycled) materials. Moreover, recycled content in the production phase is low and the recycling rate at EoL is high both in literature and PEF default numbers. In Figure 14, where the analysis is per kg of material instead of the
total amount used in the building, aluminium credit is the highest by far according to both standards that also reflects the fact mentioned.

As can be seen in Figure 13Figure 14, the CO₂ equivalents calculated for the oil-based materials are positive which means that they have actually burdens after the End of Life stage. This burden comes from the fact that emissions from burning such materials are too high compared to their contribution to the Swedish Energy production. Therefore, it is important to support concepts/inventions for recycling/reusing all plastics used in the construction sector.

Aluminium results make copper credits more interesting. Comparing copper with aluminium, the current technology for recycling are able to have the same rates of recycling for both input and output of a production line, but the aluminium profiles are still mostly produced from virgin aluminium, while copper used in different parts of the building has currently recycled content in their production. This is the reason that copper does not earn that many points.

Something that is more important than comparing EoL and after EoL credits is the total credits the standards give to the products. Since PEF does not have after the end of life stage in methodology, all credits/burdens will be summed up with the LCA results. On the other hand, after EoL credits should be reported separately in LCA studies according to EN 15804 and it is important not to consider them as real credit, rather consider them as separate “future potential” indicator. If we go back to the basic methodologies of both standards, the results will be as Figure 15.
Figure 15 Credits/burdens that must be reported in environmental reports. EN 15804 has two credit types, one is included in LCA studies one should be report separately not to be given as “real credit” rather an indicator.

Although concrete used in this building is more than 70% of the total mass of the building, and it is usually between 50% to 80% in concrete structured buildings, the gross credits are very low compared to other materials. This is because of the fact that the cement content of the concrete is still not recyclable in industry, while there are some pilot projects that are developed in the EU and East Asia for cement recycling. Cement is responsible for more than 90% of the GHG emissions of the concrete while constitutes just 10% to 15% of it. Nowadays there are technologies that recycle more than 80% of the concrete, but the resulting material is just low/normal quality aggregates, not cement. The low credits are not just for concrete based groups but also for mortar and brick, block, tiles, stone, glass, gypsum and insulation materials.
These are due to the fact that there is no potential in recycling for stone, block, brick and tiles while the recycling process for gypsum and glass can be positive economically than be positive environmentally. The reuse gap can be seen here since such materials do not have recycling potential. Technologies for increasing the reusability by easy non-destructive deconstruction methods can help the industry to become greener. Initiating and supporting projects around the world that are working on design and build for disassembly and reuse can help the construction industry to become greener.

As it can be interpreted from Figure 15, the total credits that EN 15804 gives to the products are generally higher than what PEF gives but, EN 15804 mandate reporters to report most of the credits as an indicator out of the system boundary of the LCA study. It means that they are not credits anymore, but just an indicator to help decision-makers having a general figure about the future. In other words, these kinds of points are an answer to “how sustainable this product can be in the future?”. In fact, the real credits that PEF gives to the products are higher than EN 15804 most of the time since it sums up and include all credits in the LCA study.

The sensitivity analysis for result changes according to the other 3 scenarios is presented in Figure 16.

<table>
<thead>
<tr>
<th>Material groups</th>
<th>Pre-cycly stage</th>
<th>EN 15804</th>
<th>PEF</th>
<th>BRE DFD</th>
<th>Literature based error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete elements (concrete)</td>
<td>After EoL</td>
<td>12%</td>
<td>21%</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>Gravel &amp; cement</td>
<td>After EoL</td>
<td>10%</td>
<td>35%</td>
<td>42%</td>
<td>35%</td>
</tr>
<tr>
<td>Concrete inplace (concrete)</td>
<td>After EoL</td>
<td>61%</td>
<td>55%</td>
<td>42%</td>
<td>47%</td>
</tr>
<tr>
<td>Mortar, blocks and bricks, tiles</td>
<td>After EoL</td>
<td>20%</td>
<td>30%</td>
<td>42%</td>
<td>42%</td>
</tr>
<tr>
<td>Steel (rebar)</td>
<td>After EoL</td>
<td>94%</td>
<td>2%</td>
<td>47%</td>
<td>10%</td>
</tr>
<tr>
<td>Steel (studs and plates)</td>
<td>After EoL</td>
<td>28%</td>
<td>4%</td>
<td>30%</td>
<td>9%</td>
</tr>
<tr>
<td>Steel (frame, structural elements)</td>
<td>After EoL</td>
<td>3%</td>
<td>17%</td>
<td>12%</td>
<td>6%</td>
</tr>
<tr>
<td>Steel (other)</td>
<td>After EoL</td>
<td>3%</td>
<td>3%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Wood</td>
<td>After EoL</td>
<td>0%</td>
<td>64%</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td>Glass</td>
<td>After EoL</td>
<td>1%</td>
<td>13%</td>
<td>21%</td>
<td>21%</td>
</tr>
<tr>
<td>Oil based, recoverable</td>
<td>After EoL</td>
<td>105%</td>
<td>0%</td>
<td>200%</td>
<td>0%</td>
</tr>
<tr>
<td>Oil based, landfilled</td>
<td>After EoL</td>
<td>0%</td>
<td>0%</td>
<td>35%</td>
<td>35%</td>
</tr>
<tr>
<td>Gypsum</td>
<td>After EoL</td>
<td>60%</td>
<td>7%</td>
<td>7%</td>
<td>65%</td>
</tr>
<tr>
<td>Copper</td>
<td>After EoL</td>
<td>55%</td>
<td>45%</td>
<td>42%</td>
<td>42%</td>
</tr>
<tr>
<td>Insulation (mineral based)</td>
<td>After EoL</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>After EoL</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Natural imported stone</td>
<td>After EoL</td>
<td>19%</td>
<td>19%</td>
<td>42%</td>
<td>42%</td>
</tr>
</tbody>
</table>

Figure 16 Percentage error for Life Cycle stages results from 3 alternative scenarios comparing to the main scenario.

Since determining recycling rates (R2) in the formulas can be subjective, especially in EN 15804 which does not have default numbers, it is important to restrict the choices of practitioners using some means from suggesting a list of default numbers to mandating practitioners to use a specific tool which two of them have been presented in this study to increase the transparency and comparability of the LCA studies in construction sector. However, as the percentage error rates are shown, there is a huge error for some of the indicators that need to be fixed in future studies.
6 Discussion

The credits for wood and aluminium have been shown as the highest, one from incineration and the second one from recycling. If we accept recycling as a good act for both environmental impact reduction and circular economy, the incineration of the wooden products is not always this much positive as it is calculated, rather it has negative impacts. Standards decided to give a huge amount of credits to the incineration of materials. To better describe, EN 15804 give extra points for having so-called “greener fuel” for burning power plants compared to the fuels that are already being used. However, this is not the case in PEF. A question that can arise after seeing the wood credits is that how much these credits will be real and how they affect/shape the future since the technology is on the way to generate green energy from renewable resources? What we can see in the construction sector is that standards are giving positive credits to something that will not be positive in the far future. On the other hand, it should be considered that asking practitioners to work according to the future technologies in all aspects can lead to biased data from recycling technologies of the future that are in the concept phase. Therefore, considering just the energy market of the future and suggesting numbers for different geographical areas considering future technologies and the lifespan of the buildings can make studies more realistic since the current mandate of EN 15804 is to do the studies according to the current widely spread technology of the specific geographical area.

As it is mentioned, Module D, after the end of life, credits are more like points and exist to be an answer for “how sustainable this product can be in the future?” rather than real burden/credit in the lifecycle stage. However, the answer to this question is rather more complex than how EN 15804 treats it. Answering this question needs detailed and comprehensive knowledge of the new inventions and contains a high amount of uncertainty while there is no mandatory sensitivity or uncertainty analysis on this indicator.

As the main negative aspect of each standard, it can be mentioned that the LCA studies according to PEF are not reflecting all the real burdens that are already emitted due to the fact that it combines them with the credits of the future processes, which are not still happened. It means that people will not be able to realize what are the real impacts and then decide according to their priorities and their choices will be based on a time-traveled number that PEF reports. On the other hand, calculating, using and finding variables for EN 15804 formulas (especially Module D) is more time and resource consuming, which can end up choosing general or wrong numbers by the practitioner.

Two controversial variables have been investigated in this study, recycling rate and Energy margin (Eer average). The recycling rate can be quite subjective and depending on the practitioner’s decisions and choices while Eer average is controversial inherently due to its definition by EN 15804. The ways to calculate recycling rates for the construction industry were developed and presented, and the sensitivity analysis of the results can be seen in Figure 16.

In the DGNB tool and BRE tool scenarios for recycling rate calculation, this rate is completely restricted to a set of rules and formulas, where the practitioner has to follow a list of rules and determine formula values accordingly, and then the tools suggest recycling rates. The problem with these two tools is the fact that component groups and material groups are not completely matched with the purpose of the LCA studies, and this can be fixed by inventing a new tool with a similar approach or starting the discussion of connecting Green Building Certifications and Life Cycle Assessment studies in the future.
For Eer average, a tool from CDM has been used and the result seems to be more logic than what EN 15804 asks practitioners to do. The choice of whether it is good enough or a special tool must be created for this variable depends on the practitioner's point of view. Using CDM tool is more time and resource-consuming while the EN 15804 suggestion is very easy and simple. Another controversial variables in formulas are efficiencies. Determining the efficiencies of incineration and landfill is one of the hardest parts while they affect directly the credits. Calculating and determining efficiencies can be the target of future studies in the field.

7 Conclusions

The overall aims of this study were to compare the EN 15804 and PEF formulas concentrating on credits in the end of life and after the end of life stage, handling two controversial variables, recycling rate by developing more transparent and less subjective tools and Eer average (energy margin) by integrating energy margin tool by CDM and find the contribution of different materials to the environmental benefits in and after the end of life of the buildings. The most credits are for wooden products using EN 15804 formulas, while aluminium is in the second place. On the other hand, aluminium is in the first place and wood is second using the PEF formula. An important figure is the amount of the wooden products going for incineration at the end of life stage, the more incineration with energy recovery, the higher environmental credits for wood according to both standards. This can lead to a wrong path toward a greener economy since the future energy production grids are renewable and the lifespan of the buildings is quite long. The consequences of the credits given by these standards should be studied in detail for each type of material, in order to make the wrong and right paths more visible for the industry. For bio-based materials in construction, wooden products, Peñaloza et. al. studied how will be the effects of increased use of bio-based materials in buildings and realized that a time-horizon of more than 100 years needed to capture properly the environmental impacts of the bio-based buildings. (Peñaloza, Erlandsson, & Falk, 2016)

The methodological difference of PEF and EN 15804 formulas was that PEF includes all credits into the LCA study and add them to the results, while EN 15804 mandates to report an extra indicator in the verified LCA report separately. This is very beneficial since the correct verified LCA will not be affected by the credits that are given based on current technologies when the end of life of the building components are between 40 to 120 years away from today. A question will arise that do we really need this indicator when we need to invest a huge amount of resources and time on calculating it? The answer is not simple. There are not many or even a few studies regarding the benefits of including such credits as Module D in LCA studies and it is the same for PEF. Bach et. al. assessed and reported many shortcomings and controversial issues in terms of comparability of the studies based on PEF framework not just in PEF CFF formula but also in the rest of the PEF system such as product category rules, environmental impact assessment method etc. (Bach, Lehmann, Görmer, & Finkbeiner, 2018) Using Module D of EN 15804 for decision making is also controversial since the consequences of a huge transformation, i.e. transformation of global construction toward bio-based material such as wood, will be different than the numbers reported in the EPDs. Consequential LCA is therefore presented by ISO to help researchers in these situations. Matthias Buyle has worked on structured consequential modelling for the construction sector in his Ph.D. thesis. (Buyle, 2018) The future studies and years of experience of using these frameworks will help researchers to understand the importance of Module D and answer the question above.
The second part of this study was to introduce new tools for calculating recycling rates and Energy margin (Eer average). The first one was addressed using recyclability assessment tools of DGNB and BRE Design for Deconstruction (DFD) tool and connect them to EN 15804 and PEF formulas using a tool developed for this study. The second one was addressed using CDM tool for Energy margin calculation. For recycling rates, a method is developed to connect DGNB and BRE DFD tools to the formulas which is presented in detail with necessary formulas and variable definitions. The tools from DGNB and BRE are not perfect for this connection, but this can be a good start to connect different similar tools or developing new ones for the purpose of reducing the subjectivity of choosing the recycling rate in LCA studies. In the future, there can be a connection between building certification systems and environmental declaration systems to connect their methods with such tools in order to help practitioners find the value of the variables easier with less flexibility and subjectivity.

The current state of the people who work around LCA of buildings, green buildings and construction is confusion. Sustainability leaders and environmentalists in the construction sector are not generally familiar with all aspects and tools, their relations, their differences, and their applied benefits. Sustainability leaders and coordinators of the construction companies should improve their knowledge of every aspect of such frameworks and get to know the available tools in order to drive their companies towards sustainable goals economically.
8 References

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Appendix

Appendix 1, EN 15804 A2:2019 formula problems + flowchart

The definition of the E variables that are representative for emissions are per unit of analysis. Unit of analysis of the study is not always mass based and is not always 1 unit mass (like 1 kg or 1 gram). It means that it is not correct to have mass of each flow multiplied by the E of that flow. The mass multipliers should be proportional. My suggestion is to add Mtotal to the formulas so they will look like formulas bellow:

\[ e_{\text{module } C} = \frac{M_{\text{MR out}}}{M_{\text{total}}} * E_{\text{MR before EoW out}} + \frac{M_{\text{ER out}}}{M_{\text{total}}} * E_{\text{ER before EoW out}} + \frac{M_{\text{INC out}}}{M_{\text{total}}} * E_{\text{INC}} + \frac{M_{\text{LF}}}{M_{\text{total}}} \]  

(11)

\[ e_{\text{module } D} = e_{\text{module D1}} + e_{\text{module D2}} + e_{\text{module D3}} + e_{\text{module D4}} \]  

(12)

\[ e_{\text{module D1}} = \sum_i \left( \frac{M_{\text{MR out}}|i} {M_{\text{total}}} - \frac{M_{\text{MR in}}|i} {M_{\text{total}}} \right) * \left( E_{\text{MR after EoW out}}|i - E_{\text{VM sub out}}|i * \frac{Q_{\text{R out}}}{Q_{\text{sub}}}|i \right) \]  

(13)

\[ e_{\text{module D2}} = \sum_i \left( \frac{M_{\text{ER out}}|i} {M_{\text{total}}} - \frac{M_{\text{ER in}}|i} {M_{\text{total}}} \right) * \left( E_{\text{ER after EoW out}}|i - E_{\text{ER average}} \right) \]  

(14)

\[ E_{\text{ER average}} = \text{LHV} * X_{\text{ER heat}} * E_{\text{SE heat}} + \text{LHV} * X_{\text{ER elec}} * E_{\text{SE elec}} \]  

(15)

\[ e_{\text{module D3}} = -\frac{M_{\text{INC out}}}{M_{\text{total}}} * \left( \text{LHV} * X_{\text{INC heat}} * E_{\text{SE heat}} + \text{LHV} * X_{\text{INC elec}} * E_{\text{SE elec}} \right) \]  

(16)

\[ e_{\text{module D4}} = -\frac{M_{\text{LF}}}{M_{\text{total}}} * \left( \text{LHV} * X_{\text{LF heat}} * E_{\text{SE heat}} + \text{LHV} * X_{\text{LF elec}} * E_{\text{SE elec}} \right) \]  

(17)

\[ M_{\text{total}}: \text{the total amount of material input.} \]

In formula 5 for \( E_{\text{ER average}} \) calculation, the definitions of emissions are written below. Since the LHV unit is (energy/mass or volume, like MJ/kg) and X is efficiency and doesn’t have a unit, if we follow the definitions, there is no way that multiplying LHV with emissions that are per unit of analysis, result in another emission per unit of analysis. My suggestion is to change “unit of analysis” with “unit of energy” in the definition so an example result will be like this:

\[ E_{\text{ER average}} \left( \frac{kg \text{ Co2}}{Kg \text{ material}} \right) = \text{LHV} \left( \frac{MJ}{Kg} \right) * X_{\text{LF heat}} * E_{\text{SE heat}} \left( \frac{kg \text{ Co2}}{MJ} \right) + \text{LHV} \left( \frac{MJ}{Kg} \right) * X_{\text{LF elec}} * E_{\text{SE elec}} \left( \frac{kg \text{ Co2}}{MJ} \right) \]

\[ E_{\text{SE heat}}: \text{specific emissions and resources consumed per unit of analysis energy that would have arisen from specific current average substituted energy source: heat} \]

\[ E_{\text{SE elec}}: \text{specific emissions and resources consumed per unit of analysis energy that would have arisen from specific current average substituted energy source: electricity} \]

\[ E_{\text{ER average}}: \text{specific emissions and resources per unit of analysis that would have arisen from specific current average substituted energy source: heat and electricity} \]

\[ \text{LHV}: \text{Lower Heating Value of the material in the product that is used for energy recovery.} \]
Since $E_{SE \text{ heat}}$ and $E_{SE \text{ elec}}$ are used in other parts of the formula, it is important to change their variable name like adding a star (*) infront of them to show that they are just there for $E_{EER \text{ average}}$ calculation.

The flow chart that contains important variables of both PEF and 15804 are presented below and the next page.
Appendix 2, Detailed results

Scenario 1, PEF default numbers, including recycling rates
kg CO2 credit/burden given by standards embodied in whole building during and after EoL

- natural imported stone
- aluminium
- insulation (mineral based)
- copper
- gypsum
- oil based, landfilled
- oil based, recoverable
- glass
- wood
- steel (other)
- steel (frame, structural elements)
- steel (studs and plates)
- steel (rebar)
- mortar, blocks and bricks, tiles
- concrete inplace (concrete)
- gravel & cement (shotcrete included)
- concrete elements (concrete)

- EN 15804 Module D (reported separately, not added to LCA results)
- EN 15804, Module C (included in LCA)
- Circular Footprint Formula (PEF, A varies by industry)
Scenario 2, Recycling rates from DGNB-based tool

kg CO2 credit/burden given by standards per lifecycle stage, embodied in whole building during and after EoL

- Avoiding virgin
- Recycled content
- Recycling EoL
- energy recovery EoL
- energy recovery (export of energy, incineration and landfill)
- Disposal
kg CO2 credit/burden given by standards embodied in whole building during and after EoL

- natural imported stone
- aluminium
- insulation (mineral based)
- copper
- gypsum
- oil based, landfilled
- oil based, recoverable
- glass
- wood
- steel (other)
- steel (frame, structural elements)
- steel (studs and plates)
- steel (rebar)
- mortar, blocks and bricks, tiles
- concrete inplace (concrete)
- gravel & cement (shotcrete included)
- concrete elements (concrete)

- **EN 15804 Module D** (reported separately, not added to LCA results)
- **EN 15804, Module C** (included in LCA)
- Circular Footprint Formula (PEF, A varies by industry)
Scenario 3, Recycling rates from BRE-based tool

kg CO2 credit/burden given by standards per lifecycle stage, embodied in whole building during and after EoL

Avoiding virgin
Recycled content
Recycling EoL
energy recovery EoL
energy recovery (export of energy, inceneration and landfill)
Disposal

KG CO2 EQUIVALENT

-400000.00  -300000.00  -200000.00  -100000.00  0.00  100000.00  200000.00  300000.00
kg CO2 credit/burden given by standards embodied in whole building during and after EoL

- natural imported stone
- aluminium
- insulation (mineral based)
- copper
- gypsum
- oil based, landfilled
- oil based, recoverable
- glass
- wood
- steel (other)
- steel (frame, structural elements)
- steel (studs and plates)
- steel (rebar)
- mortar, blocks and bricks, tiles
- concrete inplace (concrete)
- gravel & cement (shotcrete included)
- concrete elements (concrete)

EN 15804, Module D (reported separately, not added to LCA results)
EN 15804, Module C (included in LCA)
Circular Footprint Formula (PEF, A varies by industry)
Scenario 4, using the country average technology from literature.
kg CO2 credit/burden given by standards embodied in whole building during and after EoL

- natural imported stone
- aluminium
- insulation (mineral based)
- copper
- gypsum
- oil based, landfilled
- oil based, recoverable
- glass
- wood
- steel (other)
- steel (frame, structural elements)
- steel (studs and plates)
- steel (rebar)
- mortar, blocks and bricks, tiles
- concrete inplace (concrete)
- gravel & cement (shotcrete included)
- concrete elements (concrete)

EN 15804 Module D (reported separately, not added to LCA results)
EN 15804, Module C (included in LCA)
Circular Footprint Formula (PEF, A varies by industry)
## Appendix 3, DGNB criteria

### Table 18 Scoring system according to DGNB

<table>
<thead>
<tr>
<th>Component Group</th>
<th>Ease of recycling</th>
<th>recycling potential</th>
<th>Max. 45</th>
<th>reusing potential</th>
<th>Max. 45</th>
<th>score according to DGNB criteria</th>
<th>Will the components be reused?</th>
<th>Does 90% of the SBC at least in QL2?</th>
<th>Total mass (kg) or surface (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Selection of easy-to-recycle construction materials Building components (relevant reference values)</td>
<td>60% of the SBC at least in QL1</td>
<td>Upgrading to QL1: Per SBC, &gt;10% in QL2 in addition</td>
<td>60% of the SBC at least in QL2</td>
<td>60% of the SBC at least in QL1</td>
<td>60% of the SBC at least in QL2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>External walls (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-load-bearing or prefabricated (cost group 332, cost group 337)</td>
<td>0.5</td>
<td>0.5</td>
<td>2</td>
<td>0.5</td>
<td>3</td>
<td>5</td>
<td>481755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cladding units and internal linings (of external walls) (cost group 335, cost group 336)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External doors and windows (cost group 334)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td>2</td>
<td>3</td>
<td>38279</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Internal walls (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-load-bearing or prefabricated (cost group 342, cost group 346)</td>
<td>0.5</td>
<td>1.5</td>
<td>4</td>
<td>1.5</td>
<td>6</td>
<td>10</td>
<td>21964</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal linings (of internal walls) (cost group 345)</td>
<td>0.5</td>
<td>1.5</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>10</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal doors and windows (cost group 344)</td>
<td>0.5</td>
<td>1</td>
<td>3</td>
<td>1.5</td>
<td>6</td>
<td>9</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Floors and ceilings (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat roofs and roof coverings (cost group 352)</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>9</td>
<td>15</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceiling linings (cost group 353)</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>9</td>
<td>14</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Roofs (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load-bearing external walls (cost group 331)</td>
<td>0.5</td>
<td>1.5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External columns (cost group 333)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load-bearing internal walls (cost group 341)</td>
<td>0.5</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Load-bearing structures (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal columns (cost group 343)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor structures (cost group 351)</td>
<td>0.5</td>
<td>1.5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof structures (cost group 361)</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Foundations (m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallow or deep foundations (cost group 322, cost group 323)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsoil and base slabs and sealing of buildings (cost group 324, cost group 326)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floorings (cost group 325)</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 19 Quality levels according to DGNB for recycling potential

<table>
<thead>
<tr>
<th>Material recovery in building construction</th>
<th>QL 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>With currently available technology, the material of the building component/building sub component/construction product can predominantly be recovered, enabling it to be used for production of a new building component/building sub component/construction product for building construction.</td>
<td>58</td>
</tr>
</tbody>
</table>

---

The table above outlines the scoring system according to DGNB, detailing the ease of recycling, recycling potential, and scoring system for various components in building construction. Each component is assessed based on its material recovery potential, with specific criteria for non-load-bearing and prefabricated materials, cladding units, internal linings, external doors and windows, and more. The table also includes quality levels according to DGNB for recycling potential, ensuring a comprehensive evaluation of building components' recycling potential.
<table>
<thead>
<tr>
<th><strong>Material recovery</strong></th>
<th>With currently available technology, the building component/building sub-component/construction product can predominantly be used as a secondary raw material for use outside of building construction.</th>
<th><strong>QL 2</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy recovery</strong></td>
<td>With currently available technology, the building component/building sub-component/construction product is predominantly used as a substitute fuel in a production building (e.g. a cement plant or an in-house cogeneration plant) or in a waste incineration plant, enabling recovery of its energy.</td>
<td><strong>QL 1</strong></td>
</tr>
<tr>
<td><strong>Backfilling</strong></td>
<td>With currently available technology, the building component/building sub-component/construction product is predominantly used as a substitute for other backfill materials for backfilling (residual) cavities. (should be considered only if the current average technology of the country supports, for example, crushed concrete using in road construction in Sweden. Otherwise, landfill should be considered)</td>
<td><strong>QL 1</strong></td>
</tr>
<tr>
<td><strong>Disposal in landfill</strong></td>
<td>With currently available technology, the building component/building sub-component/construction product is predominantly disposed of in landfills (landfill class 1).</td>
<td><strong>QL 0</strong></td>
</tr>
</tbody>
</table>

**Quality Levels according to DGNB for reusing potential**

- For the purposes of this criterion, quality level 2 "easy-to-recover building structure" has been achieved if it is possible to remove the building components using non-destructive methods and the component layers can be separated into specific and distinct types or separation of the layers is not required because the individual layers/elements belong to the same (raw) material group.
- Quality level 1: Building structure that is not explicitly implemented with consideration to ensuring an easy-to-recover building structure as described above (quality level 2 – "easy-to-recover building structure"), but the building owner is aware of the possibility of recovery.
- For the purposes of this indicator, removal of building components using non-destructive methods means that it is possible to make the building component available for loss-free reuse or continued use (preparation for recycling path 2 in indicator 1). For this purpose, it must be possible to release the connections between the component and the building or adjacent building components without destroying remaining building components or building component layers.
- For the purposes of this indicator, ease of separation of building component layers into specific and separate types means that recovery of the materials is possible without limitation.
### Appendix 4, BRE DFD criteria

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame</td>
<td>Timber studs, lined both sides with plasterboard, 90mm miner wool insulation between the studs</td>
</tr>
<tr>
<td>Foundation</td>
<td>Concrete trench fill foundations. External brick block sub-structure, PIR insulation to underbuilding cavity, wooden sole plate (140x30mm) nailed to base layer</td>
</tr>
<tr>
<td>External walls</td>
<td>SIPs – breather membrane on OSB, fully insulated 258mm Space stud timber framed walls, OSB, 70mm rigid insulation, 38mm service zone, plasterboard</td>
</tr>
</tbody>
</table>
| Ground floor, upper floor and Ceiling | Ground floor – tongue and groove boards, airtight barrier on 200mm rigid PIR insulation on ground bearing reinforced concrete slab  
Upper floor – tongue and groove boards on Timber floor truss, mineral wool insulation between the floor truss |
| Roof | Roof cassettes – with slate, roof membrane on t sheathing board, fully insulated 300mm joists, OSB, 55mm rigid insulation, 38mm service zone, plasterboard |
| Cladding | Timber or render cladding |
| Floor finishes | Tongue and groove solid timber (22mm) flooring |
| Windows and doors | Timber framed externally aluminium cladded and triple glazed |
| Sanitary ware | No information available |
| Services | Mechanical Heat Ventilation System, Wood burner and Solar Thermal panels |
| Fixtures and Fittings | No information available |

The four scored criteria according to DFD are:

- Reuse and recycling potential of the key elements and components within
- The connections between the elements and components (a checklist approach is used for connections for the first stages of design followed by the scoring approach)
- The accessibility of elements and components
- The deconstruction processes.

Depending on the design process considerations, each of these criteria should be scored either 1, 0.5 or 0. If it is fully (1) partially (0.5) or not (0) considered. The score for each criterion is then aggregated across the elements and presented as a percentage.
### Appendix 5, assigned variables of case study for scenarios DGNB, BRE, literature review

**Table 20 variable values for scenarios DGNB, BRE, literature review**

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Material groups</th>
<th>R1</th>
<th>R2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>concrete elements (concrete)</td>
<td>0%</td>
<td>81%</td>
</tr>
<tr>
<td>scenario DGNB</td>
<td>gravel &amp; cement (shotcrete included)</td>
<td>0%</td>
<td>74%</td>
</tr>
<tr>
<td></td>
<td>concrete inplace (concrete)</td>
<td>0%</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>mortar, blocks and bricks, tiles</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>steel (rebar)</td>
<td>90%</td>
<td>83%</td>
</tr>
<tr>
<td></td>
<td>steel (studs and plates)</td>
<td>18%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>steel (frame, structural elements)</td>
<td>0%</td>
<td>82%</td>
</tr>
<tr>
<td></td>
<td>steel (other)</td>
<td>63%</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>wood</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>glass</td>
<td>0%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>oil based, recoverable</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>oil based, landfilled</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>gypsum</td>
<td>25%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>copper</td>
<td>46%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>insulation (mineral based)</td>
<td>25%</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>aluminium</td>
<td>0%</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td>natural imported stone</td>
<td>0%</td>
<td>19%</td>
</tr>
</tbody>
</table>

<p>| scenario BRE | concrete elements (concrete)             | 0%     | 47%    |
|              | gravel &amp; cement (shotcrete included)     | 0%     | 61%    |
|              | concrete inplace (concrete)              | 0%     | 59%    |
|              | mortar, blocks and bricks, tiles         | 0%     | 50%    |
|              | steel (rebar)                            | 90%    | 49%    |
|              | steel (studs and plates)                 | 18%    | 49%    |
|              | steel (frame, structural elements)       | 0%     | 50%    |
|              | steel (other)                            | 63%    | 56%    |
|              | wood                                     | 0%     | 0%     |
|              | glass                                    | 0%     | 12%    |
|              | oil based, recoverable                   | 0%     | 2%     |</p>
<table>
<thead>
<tr>
<th>Scenario Literature</th>
<th>Concrete Elements (Concrete)</th>
<th>Gravel &amp; Cement (Shotcrete Included)</th>
<th>Concrete Inplace (Concrete)</th>
<th>Mortar, Blocks and Bricks, Tiles</th>
<th>Steel (Rebar)</th>
<th>Steel (Studs and Plates)</th>
<th>Steel (Frame, Structural Elements)</th>
<th>Steel (Other)</th>
<th>Wood</th>
<th>Glass</th>
<th>Oil Based, Recoverable</th>
<th>Oil Based, Landfilled</th>
<th>Gypsum</th>
<th>Copper</th>
<th>Insulation (Mineral Based)</th>
<th>Aluminium</th>
<th>Natural Imported Stone</th>
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<tr>
<td></td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>40%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>25%</td>
<td>46%</td>
<td>25%</td>
<td>0%</td>
<td>0%</td>
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**Appendix 4 list of components**

<table>
<thead>
<tr>
<th>Stage: Production</th>
<th>virgin or recycled</th>
<th>groups</th>
<th>components</th>
<th>weight kg</th>
<th>percent age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precast other IVL (LCR)</td>
<td>virgin</td>
<td>concrete elements</td>
<td>precast</td>
<td>2 497 000</td>
<td>31%</td>
</tr>
<tr>
<td>Soterat gravel IVL (LCR)</td>
<td>virgin</td>
<td>gravel</td>
<td>Shallow or deep foundations</td>
<td>1 649 250</td>
<td>20%</td>
</tr>
<tr>
<td>Inner wall V20 (200 mm)</td>
<td>virgin</td>
<td>inner walls</td>
<td>Non-load- inner wall</td>
<td>1 090 870</td>
<td>13%</td>
</tr>
<tr>
<td>Inner wall VI35 (350 mm)</td>
<td>virgin</td>
<td>inner walls</td>
<td>Non-load- inner wall</td>
<td>629 376</td>
<td>8%</td>
</tr>
<tr>
<td>Outer wall W42 cassette 420 mm (IVL Skanska)</td>
<td>virgin</td>
<td>outer walls</td>
<td>Non-load external wall</td>
<td>570 768</td>
<td>7%</td>
</tr>
<tr>
<td>Construction Concrete C32 / 40 (IVL LCR)</td>
<td>virgin</td>
<td>concrete inplace</td>
<td>Subsoil and base slabs</td>
<td>429 948</td>
<td>5%</td>
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62
<table>
<thead>
<tr>
<th>Description</th>
<th>Material Type</th>
<th>Product Type</th>
<th>Quantity</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Concrete C35 / 45 (IVL LCR)</td>
<td>virgin</td>
<td>concrete inplace</td>
<td>130 751</td>
<td>2%</td>
</tr>
<tr>
<td>Flat glass IVL (LCR)</td>
<td>virgin</td>
<td>glass</td>
<td>100 784</td>
<td>1%</td>
</tr>
<tr>
<td>Inner wall V15 (150 mm)</td>
<td>virgin</td>
<td>inner walls</td>
<td>90 600</td>
<td>1%</td>
</tr>
<tr>
<td>Tiles, tile IVL (LCR)</td>
<td>virgin</td>
<td>tiles</td>
<td>67 103</td>
<td>1%</td>
</tr>
<tr>
<td>Parquet floors, lammelparkett IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>47 931</td>
<td>1%</td>
</tr>
<tr>
<td>Plasterboard, cardboard plasterboard unspecified IVL (LCR)</td>
<td>virgin</td>
<td>gypsum</td>
<td>47 427</td>
<td>1%</td>
</tr>
<tr>
<td>ABT 8, with cement IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>40 581</td>
<td>0.50%</td>
</tr>
<tr>
<td>Light concrete (reinforced) IVL (LCR)</td>
<td>virgin</td>
<td>concrete inplace</td>
<td>Subsoil and base slabs</td>
<td>39 837</td>
</tr>
<tr>
<td>Ceramic tiles Block (Leca), unreinforced IVL (LCR)</td>
<td>virgin</td>
<td>Block</td>
<td>39 837</td>
<td>0.49%</td>
</tr>
<tr>
<td>Steel studs (IVL LCR)</td>
<td>virgin</td>
<td>Steel (studs)</td>
<td>Non-load- inner wall</td>
<td>29 465</td>
</tr>
<tr>
<td>stairs concrete IVL (LCR)</td>
<td>virgin</td>
<td>concrete elements</td>
<td>precast</td>
<td>26 600</td>
</tr>
<tr>
<td>Structural steel, uncoated IVL (LCR)</td>
<td>virgin</td>
<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>22 000</td>
</tr>
<tr>
<td>Flat tiles, tiles IVL (LCR)</td>
<td>virgin</td>
<td>tiles</td>
<td>21 340</td>
<td>0.26%</td>
</tr>
<tr>
<td>Plywood IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>20 647</td>
<td>0.25%</td>
</tr>
<tr>
<td>Connection cable (FK, RK) IVL (LCR)</td>
<td>virgin</td>
<td>copper</td>
<td>building services</td>
<td>19 058</td>
</tr>
<tr>
<td>Sheet materials other, MDF (IVL LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>17 933</td>
</tr>
<tr>
<td>Windows, wooden, three glasses IVL (LCR)</td>
<td>virgin</td>
<td>windows</td>
<td>doors and windows</td>
<td>14 880</td>
</tr>
<tr>
<td>Plywood IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>Non-load- inner wall</td>
<td>13 801</td>
</tr>
<tr>
<td>Ytpapp, unspecified IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>roof covering</td>
<td>13 317</td>
</tr>
<tr>
<td>Mineral wool insulation IVL (LCR)</td>
<td>virgin</td>
<td>insulation</td>
<td>linings 2</td>
<td>12 181</td>
</tr>
<tr>
<td>Construction Concrete C25 / 30 (IVL LCR)</td>
<td>virgin</td>
<td>concrete inplace</td>
<td>Shallow or deep foundations</td>
<td>11 809</td>
</tr>
<tr>
<td>Material Description</td>
<td>Type</td>
<td>Material Type</td>
<td>Category</td>
<td>Quantity</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>---------------</td>
<td>---------------------</td>
<td>---------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Aluminum profile (IVL LCR)</td>
<td>virgin</td>
<td>aluminium</td>
<td>building services</td>
<td>11 250</td>
</tr>
<tr>
<td>The fiber cement boards (IVL LCR)</td>
<td>virgin</td>
<td>cement</td>
<td>linings 1</td>
<td>10 311</td>
</tr>
<tr>
<td>Flat tiles, tiles IVL (LCR)</td>
<td>virgin</td>
<td>tiles</td>
<td>floorings</td>
<td>8 896</td>
</tr>
<tr>
<td>Plywood IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>Non-load external wall</td>
<td>8 577</td>
</tr>
<tr>
<td>Steel studs (IVL LCR)</td>
<td>virgin</td>
<td>Steel (studs)</td>
<td>Non-load- inner wall</td>
<td>8 081</td>
</tr>
<tr>
<td>Structural steel, uncoated IVL (LCR)</td>
<td>virgin</td>
<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>7 147</td>
</tr>
<tr>
<td>Pine / fir, planed and sawn IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>Subsoil and base slabs</td>
<td>6 639</td>
</tr>
<tr>
<td>Pipe cast iron IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>sanitary ware</td>
<td>6 522</td>
</tr>
<tr>
<td>Particleboard IVL (LCR)</td>
<td>recycled</td>
<td>wood</td>
<td>floorings</td>
<td>6 280</td>
</tr>
<tr>
<td>The fiber cement boards (IVL LCR)</td>
<td>virgin</td>
<td>cement</td>
<td>linings 1</td>
<td>6 243</td>
</tr>
<tr>
<td>Byggbetong Skanska C20 / 25 (IVL Skanska)</td>
<td>virgin</td>
<td>concrete</td>
<td>Shallow or deep foundations</td>
<td>5 463</td>
</tr>
<tr>
<td>Roof plate, galvanized IVL (LCR)</td>
<td>virgin</td>
<td>Steel (plates)</td>
<td>roof</td>
<td>5 403</td>
</tr>
<tr>
<td>Reinforcement, scrap based IVL (LCR)</td>
<td>recycled</td>
<td>steel (rebar)</td>
<td>Shallow or deep foundations</td>
<td>5 057</td>
</tr>
<tr>
<td>Structural steel, galvanized IVL (LCR)</td>
<td>virgin</td>
<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>4 955</td>
</tr>
<tr>
<td>Washing IVL (LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>4 682</td>
</tr>
<tr>
<td>Steel doors IVL (LCR)</td>
<td>virgin</td>
<td>doors</td>
<td>doors and windows</td>
<td>4 678</td>
</tr>
<tr>
<td>Floor Filler, dry mortar IVL (LCR)</td>
<td>virgin</td>
<td>mortar</td>
<td>floorings</td>
<td>4 295</td>
</tr>
<tr>
<td>Structural steel, uncoated IVL (LCR)</td>
<td>virgin</td>
<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>4 077</td>
</tr>
<tr>
<td>Structural steel, uncoated IVL (LCR)</td>
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<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>4 068</td>
</tr>
<tr>
<td>Plywood IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>roof</td>
<td>3 964</td>
</tr>
<tr>
<td>Refrigerator / Freezer cool and IVL (LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>3 951</td>
</tr>
<tr>
<td>Unreinforced concrete blocks, paving stones, tiles, etc. IVL (LCR)</td>
<td>virgin</td>
<td>Block</td>
<td>floorings</td>
<td>3 812</td>
</tr>
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<td>Dishwasher IVL (LCR)</td>
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<td>furniture</td>
<td>other</td>
<td>3 512</td>
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<tr>
<td>Pine / fir, planed and sawn IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>Subsoil and base slabs</td>
<td>3 414</td>
</tr>
<tr>
<td>Mineral wool insulation IVL (LCR)</td>
<td>virgin</td>
<td>insulation</td>
<td>linings 1</td>
<td>3 047</td>
</tr>
<tr>
<td>Particleboard IVL (LCR)</td>
<td>recycled</td>
<td>wood</td>
<td>floorings</td>
<td>3 026</td>
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<td>Material</td>
<td>Type</td>
<td>Application</td>
<td>Quantity</td>
<td>Percentage</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>-------------</td>
<td>------------------------------</td>
<td>----------</td>
<td>------------</td>
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<tr>
<td>Pipe uncoated copper IVL (LCR)</td>
<td>virgin</td>
<td>copper</td>
<td>2,963</td>
<td>0.04%</td>
</tr>
<tr>
<td>Pipe plated copper IVL (LCR)</td>
<td>virgin</td>
<td>copper</td>
<td>2,760</td>
<td>0.03%</td>
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<tr>
<td>Pipe cast iron IVL (LCR)</td>
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<td>steel (other)</td>
<td>2,653</td>
<td>0.03%</td>
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<tr>
<td>Radiator, water (IVL LCR)</td>
<td>device</td>
<td>steel (other)</td>
<td>2,592</td>
<td>0.03%</td>
</tr>
<tr>
<td>Mineral wool insulation IVL (LCR)</td>
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<td>insulation</td>
<td>2,423</td>
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<tr>
<td>Galvanized steel and wrought IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>2,148</td>
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<tr>
<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>2,077</td>
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</tr>
<tr>
<td>The foam, expanded polystyrene (EPS) IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>1,878</td>
<td>0.02%</td>
</tr>
<tr>
<td>Skåpinrede in the kitchen</td>
<td>device</td>
<td>furniture</td>
<td>1,828</td>
<td>0.02%</td>
</tr>
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<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
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<td>steel (other)</td>
<td>1,747</td>
<td>0.02%</td>
</tr>
<tr>
<td>Roof plate, galvanized IVL (LCR)</td>
<td>virgin</td>
<td>Steel (plates)</td>
<td>1,588</td>
<td>0.02%</td>
</tr>
<tr>
<td>Window seat, imported natural stone IVL (LCR)</td>
<td>virgin</td>
<td>stone</td>
<td>1,466</td>
<td>0.02%</td>
</tr>
<tr>
<td>Stainless steel tubes (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>1,462</td>
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<tr>
<td>Galvanized steel and wrought IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>1,358</td>
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<td>Oil based films (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>1,290</td>
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<td>insulation</td>
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<td>Pipe uncoated copper IVL (LCR)</td>
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<td>copper</td>
<td>1,205</td>
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<tr>
<td>Windows, wooden, three glasses IVL (LCR)</td>
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<td>windows</td>
<td>1,166</td>
<td>0.01%</td>
</tr>
<tr>
<td>Connection cable (FK, RK) IVL (LCR)</td>
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<td>copper</td>
<td>1,159</td>
<td>0.01%</td>
</tr>
<tr>
<td>Pine / fir, planed and sawn IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>1,126</td>
<td>0.01%</td>
</tr>
<tr>
<td>Pipe plated copper IVL (LCR)</td>
<td>virgin</td>
<td>copper</td>
<td>1,121</td>
<td>0.01%</td>
</tr>
<tr>
<td>Diesel combustion, production IVL (LCR)</td>
<td>what is this? :D</td>
<td>what is this? :D</td>
<td>1,100</td>
<td>0.01%</td>
</tr>
<tr>
<td>Plasterboard, cardboard</td>
<td>virgin</td>
<td>gypsum</td>
<td>1,097</td>
<td>0.01%</td>
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<tr>
<td>Item</td>
<td>Material</td>
<td>Application</td>
<td>Quantity</td>
<td>Recovery</td>
</tr>
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<td>----------------------------------------------------------------------</td>
<td>-------------------</td>
<td>----------------------</td>
<td>----------</td>
<td>----------</td>
</tr>
<tr>
<td>plasterboard</td>
<td>unspecified IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>roof</td>
</tr>
<tr>
<td>Galvanized nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>sanitary ware</td>
<td>1082</td>
</tr>
<tr>
<td>Pipe cast iron IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 2</td>
<td>1078</td>
</tr>
<tr>
<td>Joinery Color indoor alkyd 70% OR IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>linings 2</td>
<td>977</td>
</tr>
<tr>
<td>Steel studs (IVL LCR)</td>
<td>virgin</td>
<td>Steel (studs)</td>
<td>Non-load- inner wall</td>
<td>1059</td>
</tr>
<tr>
<td>Radiator, water (IVL LCR)</td>
<td>device</td>
<td>steel (other)</td>
<td>building services</td>
<td>1054</td>
</tr>
<tr>
<td>Coated wooden strips (IVL LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>linings 2</td>
<td>1004</td>
</tr>
<tr>
<td>roof protect, unspecified IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>roof</td>
<td>997</td>
</tr>
<tr>
<td>oil based films (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>linings 2</td>
<td>951</td>
</tr>
<tr>
<td>roof ladder, other protections IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 2</td>
<td>915</td>
</tr>
<tr>
<td>Galvanized steel and wrought IVL (LCR)</td>
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<td>steel (other)</td>
<td>other</td>
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<td>floorings</td>
<td>651</td>
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<td>Stainless steel tubes (IVL LCR)</td>
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<td>steel (rebar)</td>
<td>steel column, beam, wall</td>
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<td>Worktop, hötryckslaminat (type HGP) IVL (LCR)</td>
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<td>furniture</td>
<td>other</td>
<td>523</td>
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<td>steel (other)</td>
<td>floorings</td>
<td>511</td>
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<td>Sinks, sinks, rash jaws of stainless steel (IVL LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>485</td>
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<td>Floor Filler, dry mortar IVL (LCR)</td>
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<td>mortar</td>
<td>floorings</td>
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<td>Masonry and plaster, fördiblandat dry mortar IVL (LCR)</td>
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<td>mortar</td>
<td>Non-load external wall</td>
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<td>Wooden laths, untreated IVL (LCR)</td>
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<td>wood</td>
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<td>Sheet metal parts galvanized IVL (LCR)</td>
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<td>steel (plates)</td>
<td>roof</td>
<td>445</td>
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<td>steel (other)</td>
<td>floorings</td>
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<td>wood</td>
<td>floorings</td>
<td>442</td>
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<td>Galvanized nails, screws and fittings (IVL LCR)</td>
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<td>steel (other)</td>
<td>roof</td>
<td>436</td>
</tr>
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<td>Sound absorber, disc noise, acoustic, -vägg, mineral wool type IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>floorings</td>
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<td>gypsum</td>
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<td>oil based, recovery</td>
<td>roof</td>
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<td>Steel (plates)</td>
<td>roof</td>
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<td>Steel (plates)</td>
<td>roof</td>
<td>309</td>
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<td>The foam, expanded polystyrene (EPS) IVL (LCR)</td>
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<td>oil based, landfilled</td>
<td>linings 2</td>
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<td>steel (other)</td>
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<td>Stone wool IVL (RR)</td>
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<td>insulation</td>
<td>linings 1</td>
<td>274</td>
</tr>
<tr>
<td>Pine / fir, planed and sawn IVL (LCR)</td>
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<td>wood</td>
<td>Subsoil and base slabs</td>
<td>269</td>
</tr>
<tr>
<td>The foam, expanded polystyrene (EPS) IVL (LCR)</td>
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<td>oil based, landfilled</td>
<td>Subsoil and base slabs</td>
<td>263</td>
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<td>Stir and rörstolpar mm galvanized steel IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>sanitary ware</td>
<td>252</td>
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<td>Sanitaryware IVL (LCR)</td>
<td>device</td>
<td>steel (other)</td>
<td>sanitary ware</td>
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<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
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<td>steel (other)</td>
<td>linings 1</td>
<td>238</td>
</tr>
<tr>
<td>oil based nylon / polyamide (PA) (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>doors and windows</td>
<td>219</td>
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<td>rebars, chrome plated brass IVL (LCR)</td>
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<td>steel (rebar)</td>
<td>steel column, beam, wall</td>
<td>217</td>
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<td>oil based otherwise unspecified, polyolefin (PP / PE) (IVL LCR)</td>
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<td>oil based, recovery</td>
<td>linings 1</td>
<td>217</td>
</tr>
<tr>
<td>Geotextile (nonwoven fabric) (IVL LCR)</td>
<td>virgin</td>
<td>oil based, landfilled</td>
<td>Subsoil and base slabs</td>
<td>200</td>
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<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>roof</td>
<td>194</td>
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<tr>
<td>Mineral wool insulation IVL (LCR)</td>
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<td>insulation</td>
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<td>188</td>
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<tr>
<td>Aluminum profile (IVL LCR)</td>
<td>virgin</td>
<td>aluminium</td>
<td>building services</td>
<td>186</td>
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<td>Vinyl</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>floorings</td>
<td>159</td>
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<tr>
<td>Galvanized steel and wrought IVL (LCR)</td>
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<td>steel (other)</td>
<td>other</td>
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<td>Sealant, silicon IVL (LCR)</td>
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<td>oil based, landfilled</td>
<td>sanitary ware</td>
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<td>Quantity</td>
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<td>cement</td>
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<td>Sheet materials other, MDF (IVL LCR)</td>
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<td>furniture</td>
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<td>Structural steel, uncoated IVL (LCR)</td>
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<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
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<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
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<td>steel (other)</td>
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<td>steel (other)</td>
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<td>steel (other)</td>
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<tr>
<td>Form plywood panels (IVL LCR)</td>
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<td>wood</td>
<td>other</td>
<td>111</td>
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<tr>
<td>Cabinet, drawer and furniture fittings (IVL LCR)</td>
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<td>furniture</td>
<td>other</td>
<td>109</td>
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<td>Plywood IVL (LCR)</td>
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<td>wood</td>
<td>roof</td>
<td>104</td>
</tr>
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<td>Plywood IVL (LCR)</td>
<td>virgin</td>
<td>wood</td>
<td>roof</td>
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<td>steel (other)</td>
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<td>Steel studs (IVL LCR)</td>
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<td>Steel (studs)</td>
<td>Non-load- inner wall</td>
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<td>oil based, recovery</td>
<td>doors and windows</td>
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<td>Particleboard IVL (LCR)</td>
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<td>steel (other)</td>
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<td>sanitary ware</td>
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<td>oil based, recovery</td>
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<td>steel (other)</td>
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<td>Cooker oven (IVL LCR)</td>
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<td>steel (other)</td>
<td>floorings</td>
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</tr>
<tr>
<td>Flat glass IVL (LCR)</td>
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<td>glass</td>
<td>other</td>
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<td>Dränledningar, polyvinyl chloride PVC IVL (LCR)</td>
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<td>oil based, recovery</td>
<td>sanitary ware</td>
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<td>Joinery Color indoor alkyd 70% OR IVL (LCR)</td>
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<td>oil based, recovery</td>
<td>linings 2</td>
<td>49</td>
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<td>Aluminum profile (IVL LCR)</td>
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<td>aluminium</td>
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<td>Geotextile (nonwoven fabric) (IVL LCR)</td>
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<td>oil based, landfilled</td>
<td>Subsoil and base slabs</td>
<td>37</td>
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<td>oil based films (IVL LCR)</td>
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<td>oil based, recovery</td>
<td>floorings</td>
<td>37</td>
</tr>
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<td>Roof plate, galvanized IVL (LCR)</td>
<td>virgin</td>
<td>Steel (plates)</td>
<td>roof</td>
<td>34</td>
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<td>Sealant, silicon IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>sanitary ware</td>
<td>31</td>
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<td>oil based, landfilled</td>
<td>sanitary ware</td>
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<td>Details Tin painted IVL (LCR)</td>
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<td>Steel (plates)</td>
<td>roof</td>
<td>29</td>
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<td>Flat glass IVL (LCR)</td>
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<td>glass</td>
<td>other</td>
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<td>Sealant, silicon IVL (LCR)</td>
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<td>oil based, landfilled</td>
<td>sanitary ware</td>
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<td>Pipe uncoated copper IVL (LCR)</td>
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<td>copper</td>
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<td>26</td>
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<tr>
<td>Masonry and plaster, fördigblandat dry mortar IVL (LCR)</td>
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<td>mortar</td>
<td>Non-load external wall</td>
<td>24</td>
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<td>oil based polycarbonate (plexiglass), otherwise</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>roof</td>
<td>23</td>
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<td>Dränledningar, polyvinyl chloride PVC IVL (LCR)</td>
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<td>oil based, recovery</td>
<td>sanitary ware</td>
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<td>21</td>
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<td>Mineral wool insulation IVL (LCR)</td>
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<td>insulation</td>
<td>linings 1</td>
<td>21</td>
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<tr>
<td>Pine / fir, planed and sawn IVL (LCR)</td>
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<td>wood</td>
<td>Subsoil and base slabs</td>
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<td>oil based, recovery</td>
<td>linings 2</td>
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<td>aluminium</td>
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<td>steel (other)</td>
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<td>aluminium</td>
<td>building services</td>
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<td>steel (frame)</td>
<td>steel column, beam, wall</td>
<td>14</td>
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<tr>
<td>The foam, expanded polystyrene (EPS) IVL (LCR)</td>
<td>virgin</td>
<td>oil based, landfilled</td>
<td>linings 2</td>
<td>13</td>
</tr>
<tr>
<td>Details Tin painted IVL (LCR)</td>
<td>virgin</td>
<td>steel (plates)</td>
<td>roof</td>
<td>12</td>
</tr>
<tr>
<td>Galvanized steel and wrought IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>other</td>
<td>8</td>
</tr>
<tr>
<td>Particleboard IVL (LCR)</td>
<td>recycled</td>
<td>wood</td>
<td>floorings</td>
<td>7</td>
</tr>
<tr>
<td>Galvanized nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>roof</td>
<td>6</td>
</tr>
<tr>
<td>The foam, expanded polystyrene (EPS) IVL (LCR)</td>
<td>virgin</td>
<td>oil based, landfilled</td>
<td>linings 2</td>
<td>5</td>
</tr>
<tr>
<td>Galvanized nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 2</td>
<td>5</td>
</tr>
<tr>
<td>oil based otherwise unspecified, polyolefin (PP / PE) (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>linings 1</td>
<td>4</td>
</tr>
<tr>
<td>Details Tin painted IVL (LCR)</td>
<td>virgin</td>
<td>steel (plates)</td>
<td>roof</td>
<td>4</td>
</tr>
<tr>
<td>Sinks, sinks, rash jaws of stainless steel (IVL LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>3</td>
</tr>
<tr>
<td>Particleboard IVL (LCR)</td>
<td>recycled</td>
<td>wood</td>
<td>floorings</td>
<td>3</td>
</tr>
<tr>
<td>Pipe insulation, NBR-cell rubber (B) (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>sanitary ware</td>
<td>3</td>
</tr>
<tr>
<td>Joinery Color indoor alkyd 70% OR IVL (LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>linings 2</td>
<td>3</td>
</tr>
<tr>
<td>Vinyl</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>floorings</td>
<td>3</td>
</tr>
<tr>
<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 2</td>
<td>2</td>
</tr>
<tr>
<td>Description</td>
<td>Virgin</td>
<td>Steel (Other)</td>
<td>Linings</td>
<td>Quantity</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>--------</td>
<td>----------------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 1</td>
<td>2</td>
</tr>
<tr>
<td>Rökgaslucka steel IVL (LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>roof</td>
<td>2</td>
</tr>
<tr>
<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 1</td>
<td>2</td>
</tr>
<tr>
<td>Cabinet, drawer and furniture fittings (IVL LCR)</td>
<td>device</td>
<td>furniture</td>
<td>other</td>
<td>2</td>
</tr>
<tr>
<td>Zinc-plated nails, screws and fittings (IVL LCR)</td>
<td>virgin</td>
<td>steel (other)</td>
<td>linings 1</td>
<td>1</td>
</tr>
<tr>
<td>Pipe insulation, NBR-cell rubber (B) (IVL LCR)</td>
<td>virgin</td>
<td>oil based, recovery</td>
<td>sanitary ware</td>
<td>1</td>
</tr>
<tr>
<td>Structural steel, galvanized (IVL LCR)</td>
<td>virgin</td>
<td>Steel (frame)</td>
<td>steel column, beam, wall</td>
<td>1</td>
</tr>
</tbody>
</table>