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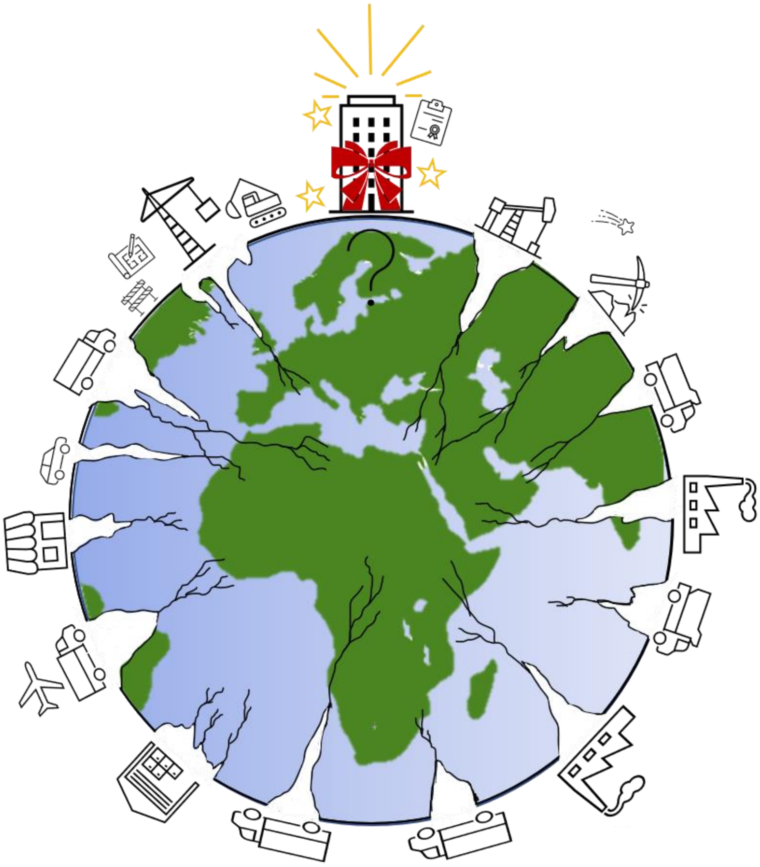

Deep Dive into Sustainability Assessment Methods

Cradle-to-Grave: Detriment or Benefit?

Master's thesis in Design and Construction Project Management

JOSEFINE FLODIN

DEPARTMENT OF CONSTRUCTION MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se

MASTER’S THESIS ACEX30

A deep dive into Sustainability Assessment Methods

From cradle-to-grave – benefit or detriment?

Master’s Thesis in the Master’s Programme Design and Construction Project Management

JOSEFINE FLODIN

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Chalmers tekniska högskola, 2021

Department of Architecture and Civil Engineering
Division of Construction Management
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
"The true cost of Sustainability Assessment Methods?" – By Author.
Department of Architecture and Civil Engineering
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ABSTRACT

The Construction Industry has been portrayed as a culprit in the global pursuit of sustainable development due to the vast resources that the industry exploits and the chemicals and pollutants it emits. It is commonly estimated that the construction industry utilizes about 30-40% of the global natural resources. An important mitigator in the quest for a more sustainable construction industry is Sustainability Assessment Methods (SAMs) or Green Building Rating Systems.

SAMs were first introduced in the early 2000s and has since gained momentum worldwide. It is now predicted to become a mainstream practice for large construction projects. Different studies show that capital costs may increase short-term, compared to a 'ordinary' project. However, certifying can lead to 6-30% in long-term capital savings. On the other hand, actors in the industry sometimes perceive certain criteria or sustainability indicators (SIs) belonging to SAMs to be ill-considered. Do these SIs still contribute toward sustainability, are they beneficial or detrimental to the project?

This Master Thesis investigates three SAMs, BREEAM, LEED and Miljöbyggnad along with the ecolabel Nordic Swan and service SundaHus. What are their sustainability indicators grounded on? Are they aligned with the United Nations Sustainable Development Goals (SDGs) and does a certified building equal a sustainable one?

Two case studies are included in the Thesis. These investigate whether or not energy saving measures from two different kinds of heat exchangers are more sustainable then procuring only green power, such as BraMiljöval, in a specific real-life project. The case studies evaluate the possible energy savings and what Global Warming Potential (GWP) they have and compare which solution has the lowest GWP.

The conclusion is that certified buildings do not equal sustainable buildings, but it is likely that the CO_2 footprint of a certified building will be less than that of a non-certified. Since SAMs are not adapted per project, in certain scenarios some SIs become a detriment rather than a benefit, but in a larger sense are still beneficial. Additionally, SAMs do contribute toward the UNs SDGs and Sweden's Environmental Quality Goals.

Key words: Sustainability, Sustainability Assessment Methods, Green Building Rating Systems, BREEAM, LEED, Miljöbyggnad, UNs sustainability goals…

En djupdykning i miljöcertifieringssystem:

Från vagga till grav - nytta eller nackdel?

Examensarbete inom mastersprogrammet Design and Construction Project Management

JOSEFINE FLODIN

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Construction Management
Chalmers tekniska högskola

SAMMANFATTNING

Byggindustrin har på grund av sin resursintensitet och utsläppsbenägenhet illustrerats som en bov i den världsomspännande jakten på hållbar utveckling.
Generellt uppskattas det att byggindustrin använder cirka 30–40% av globala naturresurser.

En viktig del mot en mer hållbar byggindustri är Miljöcertifieringssystem. Miljöcertifieringssystem introducerade på marknaden tidigt 2000-tal och har sedan dess vuxit i omfattning världen runt. Nu förebådas att Miljöcertifieringssystem kommer att bli standard i stora byggprojekt. Studier visar på att kortsiktigt kan kapitala kostnader öka i jämförelse med ’vanliga’ projekt men att certifiera kan leda till kapitalbesparingar på 6–30% i det långa loppet.

Å andra sidan upplever branschaktörer ibland att vissa kriterier för att nå certifiering är ogenomtänkta. Leder dessa kriterier fortfarande till bättre hållbarhet? Är de till nytta eller nackdel?

Detta exjobb utreder tre Miljöcertifieringssystem; BREEAM, LEED och Miljöbyggnad, samt miljömärkningen Svanen och tjänsten SundaHus.
Vad baserar kriterierna på? Är dem i linje med Förenade Nationernas hållbarhets mål? Och, är en certifierad byggnad alltid en hållbar byggnad?

Två fallstudier är inkluderade i detta exjobb. Dessa utvärderar ifall energibesparingsmetoder så som installation av två olika sorters värmeväxlare är mer hållbara lösningar än att endast köpa grön el märkt med BraMiljöval?
Fallstudierna utvärderar hur mycket energi som kan sparas och vilket GWP de uppnår. De olika alternativen jämförs för att bestämma vilken lösning som har lägst påverkan på miljön.

Slutsatsen blir att certifierade byggnader inte måste vara hållbara, men det är troligt att deras koldioxid avtryck blir mindre än för en icke-certifierad byggnad. Eftersom Miljöcertifieringssystem inte är anpassade per projekt händer det att somliga kriterier i vissa fall blir närmare en nackdel än en fördel men helhetsnyttan kvarstår. Vidare bidrar Miljöcertifieringssystem till både FN:s och Sveriges hållbarhetsmål.

Nyckelord: Hållbarhet, Miljöcertifieringssystem, Gröna byggnader, BREEAM, LEED, Miljöbyggnad, FN:s hållbarhetsmål…

Contents

Preface

This Master Thesis marks the end of my studies and journey through the 5 years I spent working on a civil engineering degree at Chalmers University of Technology.

Naturally, these 5 years, likewise as the last 5 months I have spent on this thesis have had its highs and lows. I could not have done it without the help and support from my friends and family, specifically my partner, Edvin Bengtsson, who never fails to amaze me with his desire and ability to help. During the master thesis the guidance and support I received from my supervisors, Mathias Gustafsson from Chalmers and Suzana Cordic from Sweco has been key. Last but not least, the great enthusiasm and support from my colleagues at Sweco have been indispensable.

I thank you all.

In the spirit of sustainability, this master thesis has contributed to the capture of CO_2 emissions in the atmosphere through the plantation of about 20 trees, which can capture a small part of our CO_2 emissions for many years to come. This has been done through the usage of the search engine Ecosia. Ecosia plants trees in accordance with the number of revenue generating searches. The revenue then goes towards planting trees, which not only captures carbon dioxide in the atmosphere but improves the quality of life for people in developing areas dependent on the land.

Gothenburg, 2021

Josefine Flodin

Notations

Abbreviations

BBR – Boverkets Byggregler

BCR – Benefit-cost ratio

BRE – Building Research Establishment

CSBEPI – Current Standards Building Energy Performance Index

CSR – Corporate Social Responsibility

EB – External benefits

EC – Energy consumption

EI – Environmental impact

EPDs – Environmental Product Declarations

EQO – Environmental Quality Objectives

EU – European union

GHG – Green House Gases

GWP – Global Warming Potential

LCA – Life-cycle Analysis

LCC – Life-cycle Costing

PBEPI – Predicted Building Energy Performance Index

PCR – Product Category Rules

PP – Polypropene

ROI – Return on Investment

SA – Sustainability Assessment

SAMs – Sustainability Assessment methods

SCB – Swedish Central Bureau of Statistics

SDGs – Sustainable development goals

SGBC – Sweden Green Building Council

SIs – Sustainability Indicators

UN – United Nations

USGBC – U.S. Green Building Council

Roman upper case letters

A_{temp} – Calculated building area

CO_2 – Carbon dioxide emissions per material

E_{ch} – Energy consumption for heating

E_{cool} – Energy for cooling

E_e – Energy for electricity

E_{heat} – Energy for heating

E_{hw} – Energy for hot water

EP_{pet} – Primary Energy Index

F_{geo} – Geographical factor

Q_m – Minimum external airflow rate

SX_i – Sustainability Index for any alternative

T_c – Inbound cold-water temperature

T_h – Temperature hot water

T_t – Temperature from the showerhead

T_{v2} – Temperature after pre-heating

V_c – Cold water flow

V_h – Hot water flow

V_w – Wastewater flow

W – Weight

$W_{i\,or\,j}$ – Weight of criterion

Roman lower case letters

c_{pw} – Water’s specific heat capacity

e_{ji} – Value of alternative i for criterion j.

m – Mass

q_{medel} – Average external airflow rate

Greek upper case letters

ΔT – Temperature difference

etc

1 Introduction

The following headings introduces the topic of Sustainability Assessment Methods (SAMs) in the construction industry, as well as the aim of the thesis, delimitations, and method.

1.1 Background

The Construction Industry has been portrayed as a culprit in the global pursuit of sustainable development due to the vast resources that the industry exploits and the chemicals and pollutants it emits. It is commonly estimated that the construction industry utilizes about 30-40% of global natural resources (Malmberg, 2015; Tien Doan, et al., 2017). Table 1 shows an estimation of the industry's consumption of different resources.

Table 1: The Construction Industry's utilization of Global Natural Resources (Andersson & Elofsson, 2016; *Malmberg, 2015*; Tien Doan, et al., 2017)

Global Natural Resources	***Percentage [%]***
Global Freshwater	16,7%
Raw Materials	25%
- Wood	40%
- Stone, Sand & Gravel	40%
*Solid Waste**	40%
*Energy**	40%
Green House Gases	48%
Total of Global Natural Resources	40-50%

** Construction industry's waste is 40% of global solid waste in developed countries.*
** 10% of the global energy supply is used only through the manufacturing of building materials.*

The construction industry in Europe accounts for about 9% of the continents GDP and maintains approximately 18 million jobs (European Union, 2020). In Sweden alone, the construction industry utilizes about 40% of the total energy use of the entire country (Andersson & Elofsson, 2016).
Except for the utilization of natural resources, the buildings erected by the industry consumes about 32% of the global energy and emits about 19% of global greenhouse gases (GHG) related to energy (Tien Doan, et al., 2017). In Sweden, the real estate sector is responsible for 38% of the country's total use of energy. A further 90% of those 38%, is utilized through the energy use of housing and commercial properties. Heating, water, and lighting are the biggest areas of consumption* (Malmberg, 2015). In Europe, 75% of the building stock was built over 50 years ago. Of those, 1% is renovated each year, however, the remaining unrenovated buildings continue to be energy inefficient. Getting these buildings up to standards could lead to significant energy savings within the European Union (EU). The EU believes that a reduction of the EU's total energy use can be reduced by 5-6% and a 5% decrease of CO_2 emissions is possible (European Union, 2020).

More encouragingly, the *Intergovernmental panel for climate change* (IPCC) (2007) consider the construction and real estate industry to have the highest energy effectivization and pollution reduction potential due to the flexibility of the industry's demands. Further, IPCC claims that, if the sectors adopt sustainability and subsequently, sustainable practices, a possible total reduction of nearly 6 Gt CO_2-eq / year globally is reachable within the next 20 years. To put that into perspective, Sweden emitted ~41 Mt of CO_2 in 2018 which was about 0.11% of the global emissions (Our World in Data, 2019), the Swedish construction industry emitted ~11 Mt CO_2-eq in 2015 (Boverket, 2019). Whilst the world leader, China, emitted about 27.5% of the global emissions, equivalent to 10.06 Gt of CO_2 emissions, according to Our World In Data (2019). A clear case of the importance of making the industry more environmentally sound (IPCC, 2007; Butera, 2010).

Besides the energy use and CO_2 emissions, the construction industry also releases a lot of chemicals into the environment. This is a problem due to the nature of many of these chemicals, which are present in construction materials and processes. Some of these chemicals are so-called POP-substances, *Persistent and Organic Pollutants,* and some are so-called CMR-substances, *Carcinogenic, mutagenic and reprotoxic.* POPs are, as the name implies, persistent i.e., long-lived, bioaccumulating and toxic whilst CMRs are cancerous, can cause mutations and harm the reproductive systems. These toxins affect both humans, animals, and nature. Due to above and other reasons, it is vital to remove as much of these substances as possible, not only from the construction industry but from all sectors (Rosvall, 2014).

Additionally, people spend about 90% of their time inside of their homes, offices and during spare-time activities, i.e. inside of buidlings, therefore the indoor environment is curcial for well-being (Božiĉek, et al., 2020).

Inorder to counter the high environmental impact of the construction and real estate sectors the first Sustainability Assessment Method (SAM) called BREEAM was founded in the United Kingdom (UK) by The *Building Research Establishment* (BRE) in 1990. The SAM was founded to evaluate and assess buildings from a sustainability perspective through certifying buildings that achieve different goals i.e. sustainability indicators (SI). Several associations and authorities joined the BRE initiative and established their own SAM's, e.g., LEED by the U.S Green Building Council (USGBC) in 2000 (Andersson & Elofsson, 2016; Tien Doan, et al., 2017) and Miljöbyggnad by the Sweden Green Building Council (SGBC) in 2005 (Andersson & Elofsson, 2016). Approximately, 600 SAMs exist globally but BREEAM and LEED are the most known and used worldwide (Tien Doan, et al., 2017).

Studies show that SAMs can reach a 6-30% decrease in operating costs for certified buildings (Tien Doan, et al., 2017). It can also improve employee performance due to the better indoor- and work environment. Studies on performance related to indoor environmental quality found that the better the daylight quality the higher the performance of the residents. The performance increases varied between 7-20% dependent on prior conditions (Leon, et al., 2003). Certifying a building is usually not a costly business compared to the construction cost (Tien Doan, et al., 2017) even though it is often misconceived as incurring a higher overall project cost (Leon, et al., 2003).

Due to the above-mentioned factors, more companies are increasingly realising the benefits of certifying their new developments and current stock. The progression of the industry would suggest that it is likely that certifying buildings will become mainstream. To make a case of that there are both economic and environmental as well as social benefits to sustainability assessment and certified buildings can become a powerful incentive to property owners and contractors, leading to healthier, more energy-efficient and sustainable buildings and built environment.

However, studies have been conducted, the majority of which have focused on countries other than Sweden. Some studies have investigated the benefits of certifying buildings, but it is still unclear which factors add value and to what extent (Andersson & Elofsson, 2016).

Furthermore, a manager at one of Sweden’s largest construction consulting firms describes that companies working towards certification can experience some criteria as unnecessary and extreme. This, due to the high demands put on e.g., water consumption and run-off measuring from all wet surfaces needless of the size of their contribution. This can cause a secondary piping system needed to be installed for one or two sets of data collection, hence why the companies are questioning its sustainability. This is can lead to a blind chase of points in the SAM and lack of a comprehensive view of the entire project. In these cases, technical solutions can become too advanced and too hard to operate during the lifetime of the building (Cordic, 2020).

Are the SAMs fool proof and an indubitable way to a more sustainable building from raw materials to demolition? Are SAMs in-line with the UNs sustainability goals?

1.2 Aim

This thesis aims to delve deeper into SAMs (BREEAM, LEED & Miljöbyggnad) and the value-adding factors associated with SAMs, additionally, the measures taken by companies to adhere to the certification criteria will also be investigated.

The aim is to clarify the actual cause and effect on the environmental aspects when pursuing the certifications offered by the SAMs as well as investigating on which basis the criteria are decided upon and how far back in the supply chain, they consider the effects of necessary measures. Furthermore, a case study is to be performed in order to see the examples of measures taken to achieve the certifications as well as to investigate the effects on the final product. This is done in order to answer the research questions, being:

- RQ1: Do the undertaken measures to certify a building, perceived as extreme, frustrating, or useless, result in a positive, or rather, lesser impact on the environment or vice versa?
- RQ2: What factors are the criteria/sustainability indicators of sustainability assessment methods grounded on?
- RQ3: Do the sustainability criteria/sustainability indicators aid toward the UN's sustainability goals, are they connected?

1.3 Delimitations

Delimitations are essential in order to manage the comprehensiveness and workload of this thesis. The subject of sustainability has endless information and aspects to look upon, however considering the scope and time limit of the project delimitations are needed.

This thesis has been limited to the investigation of three SAMs, BREEAM, LEED and Miljöbyggnad as well as one ecolabel and one other method of ensuring material sustainability, SundaHus and Svanen. The focus will be kept to the Swedish context. Further, the thesis will be limited to the expertise areas, certifications, and the UN's sustainable development goals (SDG) that are relevant to Swedish construction consultancy firms, with extra stress on the installation side of construction.

1.4 Method

A qualitative approach has been chosen for this thesis as it is seen as the most appropriate and approachable approach. This thesis will be divided into four main parts, Introduction, Literature review, case study and a concluding section.

The literature review stands as the foundation of this thesis and aims at providing basic knowledge of sustainability and to dismantle the current sustainability assessment methods, compare them and investigate what their criteria are based on and how far back in the supply chain, considering environmental and social sustainability, they are able to reach. The literature used is based on a literature search through functions such as *Scopus* and *Google scholar.* An example of a literature search: TITLE-ABS-KEY (“Construction" AND " Sustainability" AND "sustainability assessment" OR "BREEAM" OR "LEED"), sorted on newest. Since the situation regarding sustainability is rapidly changing and expanding using mostly recent literature have been identified as critical to accurately analyse the present and future. When a relevant article was found, more articles that were relevant could often be found through the citations of the first articles. Searching by ‘most cited’ was also commonly used throughout working with the thesis. Scopus and Google scholar are well-known and well-covering sources for literature research (Guz & Rushchitsky, 2009). The information provided by the SAMs founding associations etc. has also stood as a foundation for the theory comprised in this thesis.

The majority of literature used have been written in English with a few articles/reports in Swedish along with some online sources, being in either English or Swedish. The fields of study represented within the literature review are mostly; *Sustainable development, Environmental Management, Building and Environment* and *Clean Production.* The articles used in the literature search spanned from the Brundtland report in 1987 to very recent literature (2020). With the majority of sources dating from 2005 -2020. Following the literature review a case study of two projects from a large Swedish construction consultancy firm was undertaken to investigate to which extent the discomfort surrounding some assessment criteria was realised and to what effects the measures taken by the company in order to certify the building had on the final product. This has been investigated through two case studies provided by the consultancy. These case studies explore the environmental impact of energy-saving measures in order to adhere to SAMs and reduce energy consumption. The case studies are based on an actual project currently in the design phase. The foundation of the case studies are various programme-, project planning- and other supporting documents from the design consultancy along with various manufacturers' EPDs. Based on these documents, estimations and following calculations have been undertaken in order to predict and compare the Global Warming Potential (GWP) for each investigated alternative. The case studies result in an estimation of each alternatives GWP and a prediction of which solution is the most beneficial out of the alternatives presented, from an environmental perspective.

2 Theory

The theory section comprises and reviews the literature found during the literature search and provides a foundation for coming discussions and conclusions.

2.1 Sustainable Development

Humankind has, without a shadow of a doubt, the biggest impact on this planet out of any species ever to have existed (Blewitt, 2008). The advancement of our species has always been viewed upon with great pride, however, since the establishment of agriculture, the intrusion made by humans have left the plane not able to replenish itself in the rate that it is being exploited (Gröndahl & Svanström, 2011). The knowledge of the impact that our actions have on the planet have greatly increased over the last century. The mindset has gone from a feeling of accomplishment, advancement and superiority from the black smoke escaping the mid -1800th chimneys, naturally the effect of the lack of knowledge, to being more and more aware of the impact any small action of ours have on the world around us and trying to minimize it (Rydh, et al., 2010).

Moreover, it was not until the 1970s that the term Sustainable development was coined by the UN, but the term suffered confusion surrounding its definition but commonly the Brundtland commissions 1987s definition is seen as the main one (Andersson & Elofsson, 2016; Tien Doan, o.a., 2017).

“Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.” - (World Commission on Environment and Development, 1987).

Sustainable development needs to be achieved through knowledge and education leading to people changing their lifestyles by their own accord and viewing society as being a part of, and entirely dependent on nature – a holistic and ecocentric approach (Blewitt, 2008; World Commission on Environment and Development, 1987), as well as a balance between environment, social and economic sustainable development (Andersson & Elofsson, 2016), which will be discussed further in coming sections.

Some argue that humans cannot live a modern life, entirely sustainable and without the utilization of non-renewable resources, this notion often leads to the discussion of substituting resources. Is it viable to utilize one resource which may not be renewable and pay with the replenishment of one that is? Either, one decides on yes or no, in the question above categorising one into either weak sustainable development or strong sustainable development (Andersson & Elofsson, 2016).

The concept of Weak sustainability is based on the belief or rather the decision that all capital, natural, social and economic is interchangeable and valued equally, therefore, renewable resources can be exchanged for the usage of non-renewables as long as the total capital remains (Andersson & Elofsson, 2016; Blewitt 2008; Dedeurwaerdere, Pelenc, & Ballet, 2015; …), see Figure 1. This would, according to Neumayer (2003, p1) mean that *"It does not matter whether the current generation uses up non-renewable resources or dump* CO_2 *in the atmosphere as long as enough machineries, roads and ports are built in compensation".* Non-renewable resources and CO_2 being natural capital, exchanged for economic/ social capital in the form of infrastructure etc. This also entails that they have the same value e.g., the pollution of the atmosphere being worth or substitutable X ports or X miles of road (Dedeurwaerdere, et al., 2015). This view has been heavily criticised by several sources (Daly, 1996; Martínez-Alier, 1995; Neumayer, 2003) due to that, much natural capital is vital to the existence of life on earth and therefore cannot be compared to anything with monetary value (Tatcher, 2015).

The concept of Strong sustainability is the opposite of weak sustainability, in where natural capital cannot be equalised to anything tangible or exchangeable, (Andersson & Elofsson, 2016; Dedeurwaerdere, Pelenc, & Ballet, 2015) natural capital becomes something above that, almost like a higher power. Natural capital differs from social and economic capital as these are manufactured (not all social capital) and can be both reproduced and, for the most part, destroyed. Whilst natural capital, firstly, is the foundation of the economic and social capitals it is also a system, service (ecosystem services') and ever-evolving. Giddings (2002) suggests a weighted and hierarchal system between the different capitals, as can be visualised in Figure 2. It envisions nature, or the biosphere as the ultimate resource and that humankind cannot develop anything outside of it – an ecocentric view (Morandín-Ahuerma, et al., 2019). The effects of the usage or destruction of some natural capital cannot be securely foreseen, therefore these are critical natural capital and sustain human well-being and can, according to strong sustainability, not be compensated for in any way since our knowledge of the ecosystem and ecosystems services are yet too small (Dedeurwaerdere, et al., 2015).

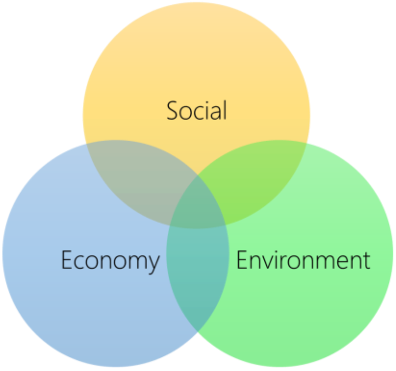


Figure 1 - Visualisation of Weak Sustainability. Source: Brundtland, 1987.

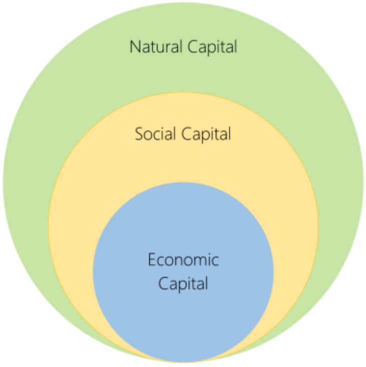


Figure 2 - Visualisation of Strong Sustainability. Source: Adapted from Giddings, 2002.

The strong sustainability view has been criticised due to that it entails knowing the needs of future generations and neglecting current human needs, rendering it impracticable (Tatcher, 2015).

The destruction of the planet at a rate which it cannot replenish itself fast enough is not a new phenomenon and sustainable development is a wide term but not an impossible one, according to Blewitt (2008). However, differing opinions exist as Redcliff (2007) states *"sustainable development is an oxymoron as human development inevitably means environmental degradation."* (Thatcher, 2015, p. 4).

For organisations, the nature of sustainability is problematic as well. The corporate perspective on sustainability is ill-defined, yet important, it is dynamic and has ambiguous objectives since every issue is a symptom of another problem. It is also forever-going, i.e., it has no end or finish line. Therefore, it can be described as a wicked problem, see Figure 3.

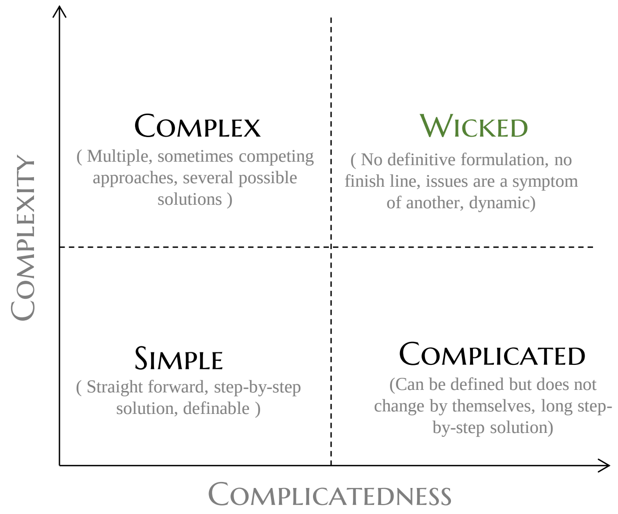


Figure 3 - Types of problems: Source by author.

A wicked problem is a categorised type of problem which embody the above-mentioned characteristics. One way to answer to the wicked problem of sustainability is for companies to engage in the three pillars of sustainability or triple bottom line (TBL) (Brønn & Simic Brønn, 2019).

The problem of climate change cannot be managed and reversed, neither with small, isolated actions nor with the same ways of thinking or logics that created the problem in the first place. Morandín-Ahuerma, Contreras-Hernández, Ayala-Ortiz, and Pérez-Maqueo (2019) identify that sustainability must be achieved through the understanding of the complex coupled systems between environment, society and economy. Improvement will only succeed through profound collaborative actions towards change and when the economy serves society which in turn base its decisions on ethics rather than profit. It is not a straight road but rather a space with invisble demarcation leading to a funnel, into which all pratcices must fall. Figure 4 portrays the way forward and the challenge that society and organisations face regarding sustainable practices.

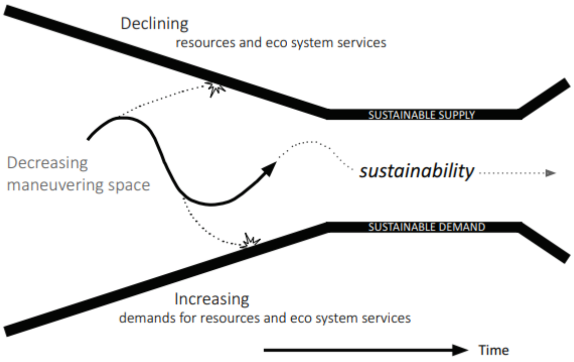


Figure 4 – "The natural step", manoeuvring practices within the realm of sustainability. Source: Lee-Källman and Lundqvist (2013) figure 1, p.10, adapted from Bertner (2008).

2.2 Three Pillars of Sustainability

As briefly mentioned in the previous section, to reach sustainable development, a balance between social, economic, and environmental development aspects must be achieved – the so-called triple bottom line (TBL), see Figure 5 & 6.

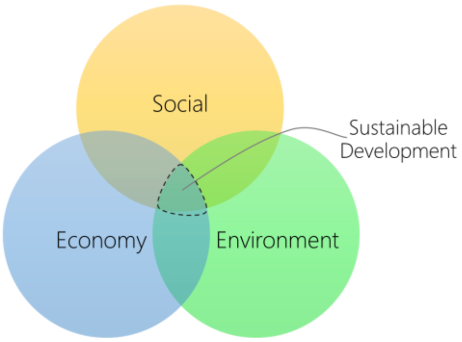


Figure 5 - The balance of Sustainable Development. Source: adapted from Andersson & Elofsson, 2016, based of Brundtland, 1987.

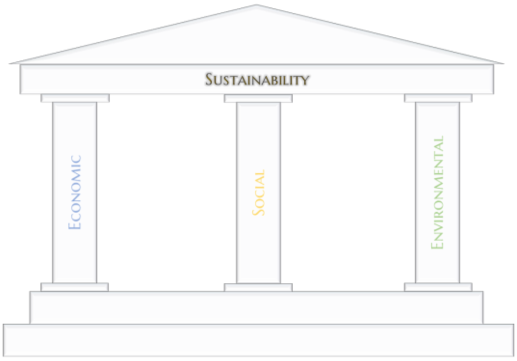


Figure 6 - The Three Pillars of Sustainability. Source: adapted from United Nations World Summit, 2005.

John Elkington lay claim to the term in 1994 as a response to less broad terms that did not include social impacts and had a narrower view on economic impacts as well (Elkington, 2013). Brønn & Simic Brønn, (2019) describes the current situation as a system of springs connected between the social, economic and environmental dimensions. If all springs are tightened equally there is equilibrium between them, but the stiffer springs, which has historically been the economic one, pulls the attention more towards that making the other springs stretch. This can be put in the perspective of manergial attention, where the goal of stakeholder return on investment (ROI) pulls the spring even tighter and out of balance, the snapback can become devastating. Therefore, when the social and environmental aspects are neglected, the company needs to increase their Corporate social responsibility (CSR) and add non-human aspects as stakeholders (Brønn &

Simic Brønn, 2019), such as the environment.

2.2.1 Sustainable Economic Development

Sustainable economic development can either be seen through a holistic approach or a more neo-classical approach. The more holistic approach being economic development that does not hinder or have negative effects on the sustainable development of neither social nor environmental factors, meaning that economic growth or the increase of capital cannot pray upon social or natural capital. On the contrary, the neo-classical approach leans toward that economic growth can be seen as sustainable as long as capital increases no matter the consequences on social or environmental factors (KTH, 2020). Economic capital can be e.g., revenue, growth (Brønn & Simic Brønn, 2019) buildings, infrastructure, technologies (Thatcher, 2015) etc.

The leading criticism concerning sustainable economic development is in the oxymoron between the demand for continuous growth and development and the fact that the planet has strict limitations and is not evergreen (Morandín-Ahuerma, et al., 2019; Pintér, et al., 2018).

2.2.2 Sustainable Environmental Development

Sustainable environmental development is perhaps the easiest or most unanimously agreed upon definition out of the three (economic, social, and environmental), but achieving it is easier said than done.
Sustainable environmental development is achieved when any human activity, production, or service, does not remove resources or destroy ecosystems in a more rapid pace then nature naturally replenishes them. Additionally, the quality of soil, water, and air etc cannot be compromised (KTH, 2020). Capital can according to Thatcher (2015) be biodiversity, raw materials, as well as eco-system services of another nature. The concept of the nine planetary boundaries have been purposed by a team of environmental scientists around the world, ranging from Stockholm Resilience Centre to the Australian National University. The planetary boundaries have been quantified in order to give a measure of how much toil this planet and its ecosystems can take before damage may become irreversible (Stockholm Resilience Centre, 2018).

The *Swedish environmental quality objectives* have been defined according to the planetary boundaries and portray the environment that Sweden wants to reach. These can be used to see what environmental problems the Swedish government believe is relevant and concurrent at the time (KTH, 2020).

2.3 The United Nations Sustainable Development Goals

The UNs SDGs have been decades in the making. From the *Earth Summit* in Rio, 1992 and *Agenda 21* to Johannesburg declaration on sustainability at the *World summit on sustainable development* in 2002, all the way to the adoption of the *2030 Agenda for sustainable development* at the *Sustainable development summit* in 2015, where the 17 SDGs were finally presented and accepted by all the UN member states. The UNs 17 SDGs are a call for urgent, radical, and concrete action by all nations and a guide to sustainable development (United Nations: Department of Economic and Social Affairs, u.d.).

The SDGs were made to broaden the scope of the previous *Millennium Development goals*, to also include environmental aspects, so that all aspects of the TBL were incorporated (Biermann, et al., 2017; Weitz, et al., 2015). The goals aim to ensure lasting protection of the planet and its natural resources, as well as for the governments of the world to lead in a sustainable and just way, eradicate poverty and starvation, fight inequality and guarantee human rights for all. The goals also aim to promote peace and build resilient societies that are inclusive (Regeringskansliet, 2018).

The focus of the goals is on redressing certain identified issues that stand in the way of a globally sustainable future in both social, economic, and environmental aspect (Weitz, et al., 2015). All 17 SDGs are based on the TBL and consequently, the 17 SDGs fall under either the economic, societal, or environmental category (Regeringskansliet, 2018; Weitz, et al., 2015), a hierarchical pyramid figure visualising the SDGs under each TBL category can be seen in Figure 7.

Figure 7 - The Sustainable development goal pyramid. Source: adapted from Azote Images for Stockholm Resilience Centre.

Some examples of the SDGs are “Achieve gender equality”, “Ensure sustainable consumption and production patterns” and “Promote sustainable use of terrestrial ecosystems” (Weitz, et al., 2015).

The 17 SDGs are accompanied by 169 targets and a set of indicators for each target (United Nations: Department of Economic and Social Affairs, u.d.). The targets can describe a preferred end-state or certain actions to be undertaken, they can deal with regional – or national-level, multidimensional or a single issue, often a few targets address ways of implementation to reach the goals (Weitz, et al., 2015). Albeit the number of targets to each goal they are still perceived as vague (most are qualitative rendering them subject for interpretation) and there’s a further need for concretization (Biermann, et al., 2017; Weitz, et al., 2015).
The 17 SDGs are certainly ambitious, and the largest effort made at pushing a goal-setting into the centre of global policy and global governance so far. The goals are not legally binding, rather they are an incentive and urging to advance public policy, regulations, and legislation toward reaching the goals and creating a more sustainable society and healthier planet (Biermann, et al., 2017).

Private organisations will want to follow the SDGs as well, as they can be seen as a crystal ball for the organisations, what the goals entail will likely be what will be on demand for the coming decade leading up to 2030. Additionally, if the goals are followed within the practices of the organisation their preparedness for the future and future changes in regulation and legislation will increase. This can be used as a sort of long-term policy framework which the organisation can run their operations within, and which can be used to assess investments, innovation, business opportunities and support in decision-making for further developments (Pedersen, 2018).

Not the least will the yield and ROI be high for organisations who can take advantage of this rare opportunity to look into the crystal ball, but for the innovationists who can conjure a solution to the SDGs. *The Business & Sustainable Development Commission* predict that their worth can be upwards of € 10 trillion / year in market opportunities and could generate up to 380 million new work prospects by 2030. For the construction industry delivering affordable housing, energy-efficient buildings, building with timber etc. are identified as some of the biggest market opportunities related to the SDGs (Business & Sustainable Development Commission, 2017).

Furthermore, the UNs member states signing of the SDGs agreement have been an incentive to develop environmental, social, and economic sustainable development targets on a national level. Already in July 2016, only 10 months after the *Sustainable development summit* where *2030 Agenda* and the 17 SDGs was agreed upon, the first nations presented their national plans for reaching the SDGs, and remaining nations followed to present their plans up until 2020 (Biermann, et al., 2017).

2.3.1 Sweden’s Sustainable Development goals

Sweden is considered as a country at the forefront of environmental policy and an ecologically modern country. It was one of the first countries to establish an environmental protection agency and to develop comprehensive environmental legislation (Lidskog & Elander, 2012). Sweden has signed on to the Agenda 2030 and the Swedish government published its sustainable development plan in 2018. In the plan report, the government states that the goal is for Sweden to be a world leader and role model for all three pillars of sustainability (this has been a governmentally stated goal since 1996 (Lidskog & Elander, 2012)) and in order to reach these goals no part of society can be left out (Regeringskansliet, 2018). They also state that the most critical environmental issues will have to be solved within the span of one generation (Lidskog & Elander, 2012).

A working paper written by Weitz et al. (2015) screened all 17 SDGs and their targets in order to determine which ones were relevant to the Swedish context. They found that no targets could be completely excluded and that all were applicable at some level however, 76% were clearly relevant and 26% could be viewed as already achieved. Further, the study by Weitz et al. (2015) finds that the following goals are critical for Sweden:

- Goal 4:” Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all”.
    - Target 4.4
- Goal 8: “Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all”.
    - Target 8.5 and 8.6
- Goal 10: “Reduce inequality within and among countries”.
    - Target 10.1, 10.2 and 10.7
- Goal 12: “Ensure sustainable consumption and production patterns”.
    - Target 12.2, 12.3, 12.4 and 12.5
- Goal 13: “Take urgent action to combat climate change and its impacts”.
    - Target 13.1 and 13.2
- Goal 14: “Conserve and sustainably use the oceans, seas and marine resources for sustainable development”.
    - Target 14.1, 14.2 and 14.4

The plan for 2018-2020 was focused on governmental measures with 4 key factors, being: Governance and follow-ups, local and regional implementation, partnership and collaboration, and international leadership (Regeringskansliet, 2018).

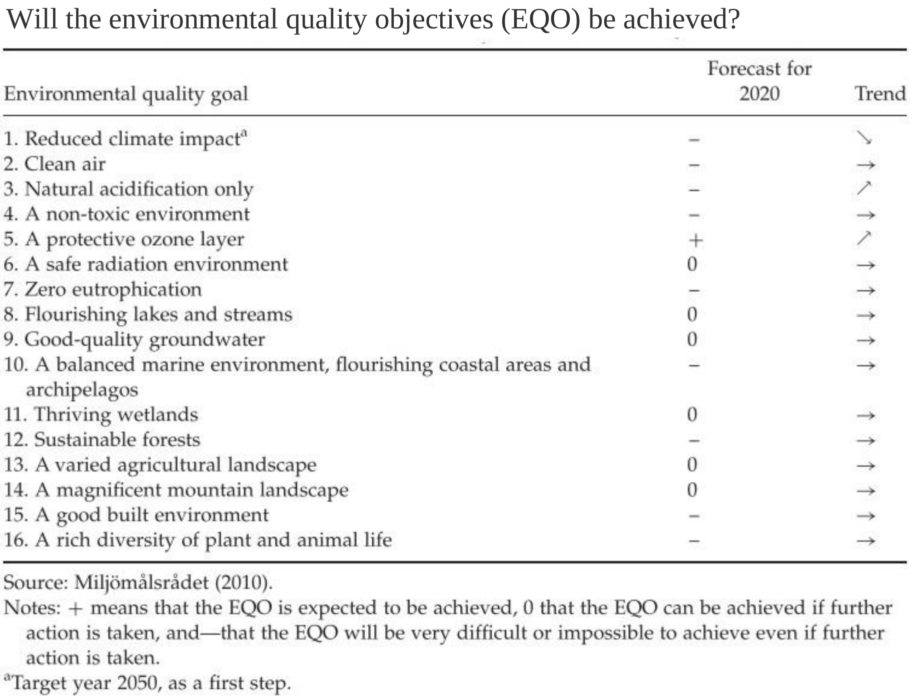
Additionally, Sweden set ambitious environmental quality goals (EQO) already in 2002, 15 of which were aimed at being achieved by 2020 and the last one, no net emissions of GHG into the atmosphere, before 2050 (Lidskog & Elander, 2012). Further, since 2015, the UNs 17 SDGs are to be considered in Sweden’s policymaking and sustainability work.

Previous forecasts can be analysed but results and evaluations concerning the goals leading up to year 2020, have not yet been published.

In 2019 the Swedish central bureau of statistics (SCB) released an outlook on Sweden’s progress towards the SDGs. They clearly state that the goal of zero GHG will not be achieved by 2050 if the predicted rate of reduction is continued and not heavily increased. Some targets regarding goal 14- “Conserve and sustainably use the oceans, seas and marine resources for sustainable development”, like “shore- and ocean environments protection” is overachieved by 3.8% (minimum 10% protected area) but the whole goal 14 will not be achieved within the set timeframe (2020) (Statistiska centralbyrån, 2019).

Beyond the previously mentioned examples, Sweden’s progress is for the most part slowly improving, or the change is negligible. However, some aspects are increasing such as violence and unregulated environmental toxins (iBid). The trends regarding the progress of achieving the EQO can be seen in Table 2.

Table 2 - Trends regarding the progress of EQO. Source: Lidskog & Elander (2015, T.1, p 419)



Will the environmental quality objectives (EQO) be achieved?

Environmental quality goal	Forecast for 2020	Trend
1. Reduced climate impact[a]	–	↘
2. Clean air	–	→
3. Natural acidification only	–	↗
4. A non-toxic environment	–	→
5. A protective ozone layer	+	↗
6. A safe radiation environment	0	→
7. Zero eutrophication	–	→
8. Flourishing lakes and streams	0	→
9. Good-quality groundwater	0	→
10. A balanced marine environment, flourishing coastal areas and archipelagos	–	→
11. Thriving wetlands	0	→
12. Sustainable forests	–	→
13. A varied agricultural landscape	0	→
14. A magnificent mountain landscape	0	→
15. A good built environment	–	→
16. A rich diversity of plant and animal life	–	→

Source: Miljömålsrådet (2010).

Notes: + means that the EQO is expected to be achieved, 0 that the EQO can be achieved if further action is taken, and—that the EQO will be very difficult or impossible to achieve even if further action is taken.

[a] Target year 2050, as a first step.

In conclusion, Sweden may be at the forefront of environmental and sustainability policymaking but stands at the foot of the mountain just as the rest of the world. Sweden is one of the more ambitious countries and one of the few that has succeeded in reducing their GHG emissions (by about 9% since 1990) so far, but the rate of improvement is much too slow to reach their set goals. There is far more to be done and the gap between what is being said and what is being done is only increasing both in Sweden and other nations. The notion of *the Swedish way* and Sweden being a role model for sustainable development may be somewhat of an obsolete illusion (Lidskog & Elander, 2012).

Regarding the built environment, both UNs SDGs and Sweden’s EQO have a goal concerning sustainable cities and communities (goal 11). Urbanization has led to that over 5 billion people, 60% of the world’s population is projected to live in cities by 2030, therefore cities are a hub for pollution, waste, and other environmental detriments. About 70% of global

carbon emissions, 60-80% of energy use and over 60% of resource use derive from urban areas, according to the UN, even though the land area occupied by cities is a mere 3% (The United Nations, 2020).
Sweden is rather fortunate in this aspect as proper and safe dwelling and living standards are not big issues (targets 11.1, 11.2 and 11.7), nevertheless, the cities and their buildings need to contribute to a lesser impact on the environment and reduce their impacts (target 11.6). This needs to be done through all aspects of living, air quality, waste management, energy use, resources use, etc. (Statistiska centralbyrån, 2019). Boverket (2019) suggests that new buildings shall be designed with health and sustainability in mind, there are several stately subsidies granted for the implementation of various sustainable technologies, e.g., Solar panels, energy efficiency and innovation towards sustainability (Boverket, 2019). The European Union's (EU) *Energy performance of buildings directive* acknowledges the construction sector as vital to achieving the energy and environmental goals and purposes that 2021, all new developments must be nearly zero-energy buildings (European Union, 2020).

Concludingly, the world stands at the foot of the mountain regarding converting our practices into sustainable ones and achieving the UNs SDGs. The construction industry has a large part in this quest and needs to take concrete and radical measures to lessen its environmental impact and green the industry.

2.4 Sustainability Assessment Methods

In order to address and promote the need and potential benefits of greening the construction and real estate industry, as mentioned in the background, methods of assessment of sustainability are of great significance (Berardi, 2012).

SA has several definitions, one of the simpler ones comes from Bond et al. (2012) and defines it simply as “any process that directs decision-making towards sustainability”. In the case of the construction industry, SAs branched out and was developed into e.g., certification systems for buildings and construction (Ding, 2008) as well as e.g., Impact Assessment, Life cycle analysis (LCA) and Life cycle costing (LCC) (Waas, et al., 2014).

SAMs or Green Rating Systems, as they also can be referred to as, can be described as a method or process identifying, predicting, and assessing prospective (environmental) impacts of different alternatives and initiatives (Berardi, 2012). SAMs have been developed to encourage and incentivise developers to address the environmental impact of constructing and operating buildings (the performance of the building) as well as improving the indoor environment and through that the well-being of the people that reside within them (Tien Doan, et al., 2017; Waer & Sibley, 2005). The aim is to minimize harmful consequences of construction, in an environmental and personal health context, through the use of SIs regulating the use of chemicals and toxic materials, waste management and energy consumption etc. (Sweden Green Building Council, 2018b; Sweden Green Building Council, 2018c). Additionally, the aim is to optimize or when applicable, minimize the use of natural resources from cradle to grave (Tien Doan, et al., 2017).

Using SAMs are most commonly done by adhering to an array of criteria or SIs, the achieved amount of which is summed up and assessed to a level of certification, e.g., Silver/ Gold or good/ outstanding. SAMs can be categorised into two main categories: Assessment tools and rating tools. Assessment tools provide quantitative performance indicators for different design options, whilst rating tools determines the buildings performance by a scale – rating (Ding, 2008).

In 1990 the first SAM called BREEAM was founded in the UK by BRE. The SAM was founded to evaluate and assess buildings from a sustainability perspective through certifications which incorporate various goals i.e. SI to minimize environmental impact and improve energy efficiency, material use and indoor environment. Several associations and authorities joined BRE's initiative and established their own SAMs, e.g., LEED by the USGBC in 1998 (Andersson & Elofsson, 2016; Tien Doan, o.a., 2017) and Miljöbyggnad by the Sweden Green Building Council (SGBC) in 2005 (Andersson & Elofsson, 2016). Approximately, 600 SAMs exist globally but BREEAM and LEED are the most known and used worldwide (Tien Doan, et al., 2017).

Lately, there has been both a need and further also a willingness to decrease environmental impacts contributing to climate change (Andersson & Elofsson, 2016). As early studies show certifying new developments can lead to cost-savings through operational costs as well as higher performance among staff (Andersson & Elofsson, 2016; Leon, et al., 2003; Tien Doan, et al., 2017). However, results are varied, and few have been aimed towards the Swedish context (Andersson & Elofsson, 2016).
Proving that there are economic, environmental as well as social benefits to using SAs could become a powerful incentive to property owners and contractors to certify buildings, leading to healthier, more energy-efficient and sustainable buildings and built environment (Andersson & Elofsson, 2016).

Partly due to the above-mentioned factors, companies are increasingly realising the benefits of certifying their new developments and current stock (Andersson & Elofsson, 2016; Malmberg, 2015). SAMs and SIs can be used as tools for aiding in decision-making and promoting sustainability within the entity (Waas, et al., 2014), as well as improving the reputation and CSR externally (Malmberg, 2015).
Since most SAMs are based on multiple criteria, a sustainability index (SX) can be calculated in order to aid in assessment, project appraisal and ultimately, decision-making, often comparing different solutions or projects (Ding, 2008).

The main criteria chosen (individual criteria or grouped) can be weighted as to resemble what is most important to the project or entity, or what has the biggest impact. Every criterion is measured and combined, giving an *index score* (iBid). The SX is then calculated through equation (1) and (2).

$$SX_i = \sum_{j=1}^{J} e_{ji} W_j \ \ (i = 1, \dots, I) \quad (1)$$

$$e_{ji} = \mathrm{f}\{BCR, EC, EB, EI\} \quad (2)$$

SX_i – Sustainability index for an alternative.
W_j – Weight of criterion.
j & e_{ji} – Value of alternative *i* for criterion *j*.
BCR – benefit-cost ratio; EC – energy consumption.
EB – external benefits; EI - environmental impact.

The higher the score the better and more sustainable is the result. The method is used to aid in the decision-making process and to account for multiple criteria and include the TBL. Moreover, the method uses both objective measures (monetary values, energy consumption, etc.) and subjective measures (weighting, external benefits, impacts, etc.) (iBid). BREEAM, LEED and Miljöbyggnad (Malmberg, 2015) use similar ways of credit-weighting to aggregate the credits to a final grade, however, monetary costs are often not assigned for (Ding, 2018).

Life cycle costing (LCC) is another method of determining the ROI of different solutions and options in, or even between projects. It is a method for assessing whether a solution or investment is viable long-term through the life cycle of a building, rather than having a short-term focus on lowering initial acquisition costs - or price per unit costs, which may not result in a lower total cost (Gluch, et al., 2018; Leon, et al., 2003).

From the start (1970s) LCC was a monetary decision-making tool but since the 2000 *green LCC*, LCC from a sustainability perspective has emerged as the mainstream LCC (Gluch, et al., 2018). However, it provides some comfort as it is a way of converting the complex values of sustainability into components of more recognizable nature (Gluch & Gustafsson, 2015).

LCC calculation methods are standardised through ISO 15686-5. LCC have received criticism for not considering the environmental aspects but only the monetary, which creates trouble as sustainable products may fetch a higher price. However, this has been addressed per say due to that sustainable products often reduce the life cycle cost as e.g., energy consumption decreases. Moreover, LCC has specific benefits for SAMs as they often invoke credits, e.g., in BREEAM, which is helpful as the SAMs raises their requirements with time and new revisions (OneClick LCA, 2018).

LCA often also fetch credits in SAMs. The difference between LCA and LCC is sizable, however, they are not completely dissimilar. LCA considered the whole life cycle very thoroughly and only focus on environmental aspects of the sourcing, production, distribution, use and end of a product, process or service, whilst LCC, most often, is used for investment analysis and not as thoroughly. There is also a Social life cycle assessment (SLCA), connecting all three methods to the TBL.

As many companies use LCC and LCA, due to the increase in sustainability focused practices as well as their benefits of identifying key factors and adaptability (Gluch & Gustafsson, 2015), signs would suggest that it is likely that certifying buildings will become mainstream (Andersson & Elofsson, 2016). Partly due to that SAMs incorporate LCC and LCA practises and provide guidance and value for them, issues which have been previously identified as hindrances for their implementation (Gluch & Gustafsson, 2015).

Design and on-site management are not enough to address the problem of sustainability or constructions impact on the environment, further, guidance and concrete measures need to be developed.
Further, it can be stressed that it may be easier to design a sustainable building rather than making a design sustainable, meaning that that the earlier sustainability becomes a part of the design the better. It can be quite tricky and less effective to change an existing design into being sustainable (Ding, 2008). Early implementation is key.

Studies, the majority of which have focused on countries other than Sweden, have been conducted investigating the benefits of certifying buildings, but it is still unclear which factors add value and to which extent (Andersson & Elofsson, 2016). Some literature suggests that since SAMs only provide a relative assessment of a building’s performance, not an absolute one, there is no telling whether or not a highly certified building is contributing to global sustainability and that the sustainability of the building cannot be measured since absolute measures are needed (Ding, 2008). However, one way forward is through the use of digital platforms such as ARC, which measures and tracks a buildings performance in different categories touched upon by many SAMs such as energy- and water usage, even occupant satisfaction. A valuable tool for accessing a holistic overview, based on actual data, of the built environment (Harder, 2019). Some SAMs already refer to the use of certain Environmental Product Declarations (EPDs) or even LCA tools in their manuals (Sweden Green Building Council, 2018a; U.S. Green Building Council, 2020).

Moreover, research by Lilliehorn (2012) showed that the construction project could benefit through early implementation of SAMs as it would create a more organised project with clear common goals.

Other studies, conducted outside of Sweden, show that the use of SAMs decrease operating costs in certified buildings by 6-30%, dependent on SAM used, project prerequisites and level of certification (Tien Doan, et al., 2017).

Trends lean toward the initiation of SAM as common practice in the construction and real estate industries, rather than just a current fashion (Andersson & Elofsson, 2016; Berardi, 2012).

In summary, SAMs are an attempt to objectively measure the sustainability of a construction project. To quantify qualitative data and determine which indicators are the best at doing so, is not an easy feat (Waer & Sibley, 2005) due to the obscurity and multi-dimensional nature of sustainability, some scholars have gone so far as to call it “measuring the immeasurable” (Waas, et al., 2014, p. 5513).

2.4.1.1 Sustainability Indicators

The term SI was introduced through the UN’s *Agenda 21* at the *Rio Earth Summit* as an initiative to turn the talk about sustainability into action (Bell & Morse, 2018). The purpose of SIs is to be the measurements of which a building’s performance is evaluated, in a sustainability perspective. Naturally, to assess a rate of sustainability, an intangible measurement, requires a reference or base level of some sort, to measure against. SIs provide this and exists in a variety of forms touching on all factors of the TBL. The purpose of SI is to pinpoint issues or conditions that reflect the level of sustainability in a project (Waer & Sibley, 2005).

For SIs to be valid and effective Waer & Sibley (2005) identify the following criteria that need to be fulfilled:

- **Relevance** – *SI Need to address only relevant things, have an effect and are important to know about.*
- **Easy to Understand** – *SI needs to be* u*nderstandable for most people, one should not need to be an expert.*
- **Reliability** – *SI need to only provide reliable information.*
- **Accessibility** – *SI should be based on accessible data that is easily available so it can be acted upon.*

These characteristics are visualised in Figure 8, below.

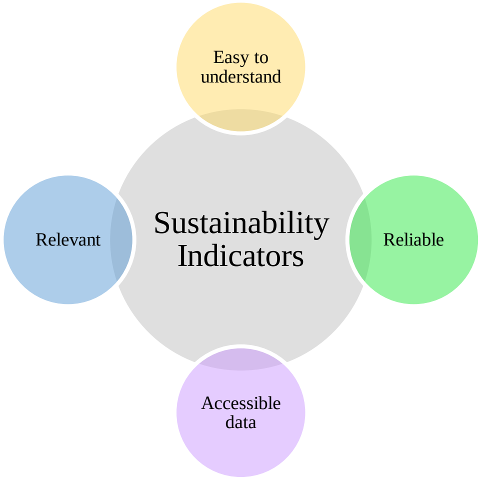


Figure 8 - Characteristics of SI. Source: Adapted from Waer & Sibley, 2005, p 532, fig. 2.

Needless to say, achieving the above-mentioned characteristic is easier said than done since e.g., ensuring reliability through validating data and procedures is difficult, additionally much data relevant to the sustainability context is not easily accessible or in a usable form and some indicators are simply subjective or non-quantifiable. Waer & Sibley (2005) further investigate what makes effective indicators through the adaptation of Bell and Morse (2003) categorization of SIs into a framework of three groupings:

- State – *SI describes the state of variable, e.g., human population, the concentration of a pollutant in water etc.*
- Process – *SI that measures a process that will sequentially influence a state, e.g., the rate at which pollutants are administered into the surroundings, etc.*
- Response – *SI that is used to evaluate a required process in terms of responding to governments, e.g., to achieve enough values of state and process indicators, etc.*

Bell & Morse published an article in 2018 by the name of "*Sustainability Indicators Past and Present: What Next?* ", as a response to what changes have transpired since their previously mentioned article in 2003. In this article, they conclude that one should be aware of the limitations of indicators due to, both the means of calculation as well as that cognitive heuristics create assumptions and biases that are not necessarily correct. Overall, they have a grim outlook on the effectiveness and accuracy of SIs, but they also acknowledge that further research and testing must commence (Bell & Morse, 2018).

Concludingly, the hardship lays in identifying not only what issues need to be addressed to control current problems (Pintér, et al., 2018) and how to fit complex coupled issues into one or a few simple measurements (Bell & Morse, 2003). The true dilemma rather lays in identifying what issues need to be addressed in order to avoid future problems or even crisis' (Pintér, et al., 2018).

Adjusting the indicators and ways that society use to measure development and progress is crucial to deal with the underlying causes of unsustainable development. Turning measurements towards benefiting the sustainable outcome rather than any other, economic, or otherwise, is a must if any SA is to be effective and successful (iBid).

2.4.1 BREEAM

BREEAM was established in 1990 by the British association BRE and is commonly known as the first SAM. BREEAM is also the most used SAM internationally (BREEAM, 2020; Tien Doan, et al., 2017) with just short of 600 000 buildings certified worldwide (BREEAM, 2020). The purpose of BREEAM is to educate and entice stakeholders about sustainability, to reduce life-cycle environmental impacts of buildings and to create recognition and value-adding to buildings with low environmental impact (Sweden Green Building Council, 2018a).

SGBC has adapted BREEAM according to Swedish standard's and re-launched it in 2013, in Sweden, under the acronym BREEAM-SE (Malmberg, 2015). For the purpose of this thesis, the name BREEAM will refer to BREEAM-SE as well.

Both new developments, major renovations or additions can be certified through BREEAM. Existing buildings cannot be certified unless through major renovation or addition where either the buildings thermal shell or structure is altered or new installation systems are installed (Malmberg, 2015). Private residences, apartment buildings, public buildings (offices, industrial, retail, education, medical centres etc.) can all be certified through BREEAM. BREEAM has several branched rating systems for other types of construction, such as BREEAM In-Use, for buildings during operation and BREEAM Infrastructure Pilot, for infrastructure projects (Sweden Green Building Council, 2018a). The Swedish adaption of BREEAM, however, only supports offices, industry, and retail (Rosvall, 2014).

The certification process for BREEAM consists of 7 steps; (1) Source a licensed BREEAM-Assessor, (2) Pre-Assessment, (3) Registration of the project to SGBC (only an assessor can register), (4) Preliminary certification, (5) Application (assessor writes a report), (6) Evaluation, (7) Certification (Sweden Green Building Council, 2020d). During the evaluation both tendering, design, execution, and operations are considered (Andersson & Elofsson, 2016).

BREEAM has 57 SIs (Sweden Green Building Council, 2018a) covering 10 main categories; energy, health & wellbeing, innovation, land use, materials, management, pollution, transport, waste and water (BREEAM, u.d.) which are weighted based on experts evaluation of the comparative impact of environmental concerns (Sweden Green Building Council, 2018a).

Depending on the function of the building in process of certification; office, commercial or industry etc. a different set of points will need to be achieved in order to attain a final grade (Malmberg, 2015). BREEAM uses the grades; Pass, good, very good, excellent, and outstanding (Andersson & Elofsson, 2016). With each grade comprising of a few minimum criteria that must be achieved, other criteria to be assessed can be chosen freely by the developer (Malmberg, 2015). Each function, and consequently grade, are associated with a certain set of SIs which must be fulfilled. What impacts the SIs are predicted to have on the environment should be described in the BREEAM manual. The building will be assessed against every relevant SI and scored. The sub-category scores are summed up and converted into a percentage of the total possible scores, thereafter the weightings per category are taken into account (Malmberg, 2015). Energy is the heaviest weighted category (Tien Doan, et al., 2017) with a weight of 18%, followed by health & indoor environment quality (17%), materials (17%) and management (11%) etc. (Sweden Green Building Council, 2018a).
The last step would be to sum the new weighted percentages, which will indicate which level of certification has been reached (Malmberg, 2015). The grades are as follows:

Grade:	Level:
Pass	≥ 30%
Good	≥ 45%
Very Good	≥ 55%
Outstanding	≥ 85%
Excellent	≥ 70%

All minimum requirements must be fulfilled in order to be able to become certified (Sweden Green Building Council, 2018a).

2.4.2 LEED

LEED was established in 1998 by the U.S. Green Building Council (USGBC) and was heavily influenced by BREEAM. LEED is the SAM that is the most widespread, globally (Tien Doan, et al., 2017). The acronym LEED stands for *Leadership in Energy and Environmental Design* and their stated purpose is to improve the construction of buildings which do not harm the environment, and which enhances society through the promotion of green buildings (Andersson & Elofsson, 2016). LEED is a rating tool rather than an assessment tool, as defined by Ding (2008) and the buildings performance is therefore measured compared to a reference building.

Private residences (semi-detached and detached homes), apartment buildings and public buildings such as offices, schools, medical centres, can be certified through LEED. These can be both existing buildings, major renovations and new developments (Sweden Green Building Council, 2020c). Similar to BREEAM, LEED has branched out into building type specific manuals, e.g., LEED for schools, LEED for neighbourhood development, LEED for Healthcare etc. (Rosvall, 2014). LEED assesses mainly environmental aspects, such as; water efficiency, energy, material use, sustainable sites and indoor environment quality as well as atmosphere and resources (Tien Doan, et al., 2017). Out of all the categories, energy aspects have the most focus (Malmberg, 2015; Tien Doan, et al., 2017). The grading goes from certified, silver, gold to platinum.

LEED can only be managed through the USGBC (except for Canada, India and Cuba, who have locally adapted the method) and therefore SGBC recommend that each project sources a certified LEED green associate, however, this is not required (Sweden Green Buidling Council, 2018d). The certification process for LEED includes 4 steps; (1) registration of the project, (2) Application submitted, (3) Review and (4) Certification (Malmberg, 2015).

Points simply add up and are not pre-weighted as for BREEAM (Tien Doan, et al., 2017) and Miljöbyggnad. However, different topics such as energy, water etc. contain a different number of points creating somewhat of a focus, nonetheless. The maximum number of points is 110 (Sweden Green Buidling Council, 2018d), and the grades are as follows:

Grade:	Score:
Certified	40-49p
Silver	50-59p
Gold	60-69p
Platinum	≥ 80p

There are also some SIs within the topics that are required regardless of said grade and these amount to no points. Beyond the mandatory SIs, the SIs with their correlated points can be chosen freely (Malmberg, 2015).
The SIs of LEED are less tangible than the ones of BREEAM, as they are not absolute, but rather are based on a scale of improvement [%], regarding the computer simulated reference building.

2.4.3 MiljöByggnad

Miljöbyggnad was established in 2005 by the Sweden Green Building Council (Boverket, 2009) as a Swedish adaptation to existing SAMs and to adhere and aid the achievement of the 16 Swedish sustainability goals (Malmberg, 2015). The method was developed through a consortium between the SGBC, the real estate sector, banks, institutions, insurance firms and authorities (Boverket, 2009; Malmberg, 2015). Miljöbyggnad is therefore specifically modified to the Swedish context including legislation, regulation, and recommendations e.g., requirements from Boverkets Byggregler (BBR) (Andersson & Elofsson, 2016; Malmberg, 2015). Materials, energy use and indoor environment are the topics evaluated when certifying a building through Miljöbyggnad and private residences (semi-detached and detached homes), apartment buildings, public buildings e.g., offices, schools, medical centres, hotels, arenas etc. can be certified.
Both new developments and existing buildings, as well as renovations and extensions, can be certified trough Miljöbyggnad (Sweden Green Building Council, 2020b). Two manuals exist, *Miljöbyggnad* and *Miljöbyggnad*

iDrift, the latter being of a similar concept to BREEAMs In-Use (Sweden Green Buidling Council, 2020f). Certification requires e.g., descriptions, blueprints, measurement protocol and energy agreements to be presented (Malmberg, 2015) in order to be evaluated according to its 16 SIs (Sweden Green Building Council, 2020b). Only aspects directly associated with the building are considered (Malmberg, 2015).

The certification process for Miljöbyggnad includes 5 main steps; (1) Registration of the project/ building at SGBC, (2) Application sent in to SGBC, (3) Evaluation of application by SGBC, (4) Evaluation by third-party and Certification, (5) Re-evaluation after 1-2 years (Malmberg, 2015; Sweden Green Building Council, 2020b). The certification is valid as long as the SIs are still fulfilled (Sweden Green Building Council, 2020b).

Further, the SIs will be graded, bronze, silver, or gold (the grade “certified” also exists but can only be stoved upon pre-existing buildings that fall just short of a higher grade) (Malmberg, 2015).

Gold – Achieved through the application of the best available commercial technology and reaching the best function along with well- and goal-oriented cooperation between involved parties (Sweden Green Building Council, 2020b). Additionally, a questionnaire needs to be sent out to the inhabitants of the building to assure their satisfaction (Andersson & Elofsson, 2016).
Silver – Higher performance and better cooperation than bronze.
Bronze – Fulfils the minimum requirements and recommendations set up by authorities such as BBR and the Swedish work environment authority (Sweden Green Building Council, 2020b).

The building will be evaluated in 3-4 steps based on the SIs (Sweden Green Building Council, 2020b), either per room, per 20% of each floor that is considered a standard floor for the building (this is due to that different floors may house different functions and/or occupants), or per the whole building. However, evaluated areas will be the ones with the least favourable prerequisites for each SI. This means that solar heat gain for example may be measured on the top floor which is most likely to receive the most solar radiation (Malmberg, 2015). A grade will be received for each evaluated SI in each main category, being materials, energy use and indoor environment. The SIs that receive the lowest grades in each main category will become the final grade for that whole category, except if the areas with higher grades within the category consist of a higher square meterage than the areas that received a lower grade (Malmberg, 2015) or if 50% of the SIs within the category have higher grades (Sweden Green Building Council, 2020b). Subsequently, the sum of all categories’ grades will result in a final grade for the entire project or building. Nevertheless, the SIs and categories are weighted and therefore, gold does not have to be achieved at every SI, if weighted less, silver can be an adequate grade for some SIs in order to still reach the final certification level of gold (Sweden Green Building Council, 2020b).

2.5 Eco-labelling

Eco-labelling started as early as in 1978 and in 1990 the EU initiated a voluntary eco-labelling program based on LCA's called *Environmental excellence*, and around the same time an ISO standard was introduced by the *Organisation for standardisation* – ISO 14020 *series of environmental labels and declarations*.

An ecolabel is a symbol marking a product, service, or entity as less of an environmental detriment than other non-labelled objects. Often but not exclusively aimed at consumers and for guiding in making conscious decisions regarding consumption from a TBL perspective. It is also a rating and comparison tool for assessing sustainability performance in processes, services, and organisations (Porto, 2013).

Three types of environmental product labels exist. Type I - The eco-certification environmental labels, Type II – The self-declared environmental claims, and, finally, Type III – Environmental declarations (Berardi, 2012). These types are defined in ISO 14020 *series of environmental labels and declarations* (Porto, 2013).

Type I, ISO14024 – environmental labelling systems: These are third-party verified labels which label products that met their pre-determined requirements. Requirements are set from a holistic and LCA based approach (Nordic Swan Ecolabel, 2020b). The labels can be managed by both private and public entities and operate at a regional, national, or international level (ISO 140204:2018, 2018). These labels are trustworthy, transparent and product of continuous improvements (Nordic Swan Ecolabel, 2020b). Examples of Type I ecolabels are Nordic Swan and EU Ecolabel.
These ecolabels contribute to UNs SDGs 13,14, and 15 (ISO14024:2018, 2020).

Type II, ISO14021 – Self-declared environmental claims: Type II ecolabels are self-proclaimed by the company who makes a product, which they label based on their own requirements and subjectiveness. ISO 14021 define specific stipulations, terms for descriptions and appraisal methods, their guidelines confirm the validity of the declaration (ISO 14021:2016, 2020; Porto, 2013). In the end the companies own words are the only guarantee for these labelled products or services.

Examples of Type II ecolabel self-declared claims are “reduced energy/water consumption”, “Designed for recycling” and “recovered energy” etc. (Porto, 2013). These ecolabels contribute to UNs SDGs 13 (ISO 14021:2016, 2020).

Type III, ISO 14025 – Environmental product declarations (EPD): Type III ecolabels are validated by an independent party and standardised through ISO 14025 which determines standards and specifies procedures for product and EPD development (ISO 14025:2006, 2020). EPDs are product specific and aggregated documents containing LCA data such as environmental impacts and will be discussed in the next section. The information given in the EPD can be considered objective, quantified, verifiable, comparable, and credible (Porto, 2013). The use of EPDs are mainly considered as business-to-business. EPDs contribute to UNs SDG 13 (ISO 14025:2006, 2020).

Ecolabeling and EPDs can be a contributor to the UNs SDG 12 “Responsible Consumption and Production”, as ecolabeling aids in the promotion of products with a lesser environmental impact as well as making consumers more aware of sustainability and the power they possess as consumers – i.e., responsible consumption. This also ties into the Swedish EQOs (Nordic Swan Ecolabel, 2020d).

2.5.1 Environmental Product Declaration

A mediator in the quest for measuring sustainability is EPDs – assessing products regarding their environmental aspects (Berardi, 2012) or communicating LCA results (Božiĉek, et al., 2020). This method is internationally available and used for many different types of products (Berardi, 2012), but this section will focus on products related to the construction of buildings.

Products can be assessed based on potential environmental impacts such as resource use, hazardous substances and waste i.e., communicating LCA data through databases and documents. However, they do not state whether a product is environmentally good or bad, it simply states facts about the product as to enable it to be compared to a product that performs the same function (Božiĉek, et al., 2020). An EPD is assumed to at the least answer a few key questions about the product: Which materials it is or contains, how is has been manufactured, what emissions are present, how much resources are utilized, how much and type of energy used in manufacturing and transportation of the product, and lastly, waste over its lifecycle (Rosvall, 2014). In contrary to other building performance matters, EPDs seldom have any benchmarks to compare against, such as e.g., energy, daylight and structural stability has (Božiĉek, et al., 2020).

EPDs are regulated and standardised through ISO14025 (ISO 14025:2006, 2020) and EN 15804 (EN 15804 2012+A1, 2013), the methods of calculations for incorporating EPDs in LCA are regulated in EN 15978 (EN 15978, 2011). Standardisations ensure the validity of EPD documents, often by engaging institutions to provide third party evaluation. Further, the Eco Platform was established in 2019 in order to deal with EPDs and compatibility issues (Božiĉek, et al., 2020).

Noteworthy, manufacturers themselves do seldom conduct environmental evaluations of their products and the spread of EPDs are low in the construction industry according to Berardi (2012). Božiĉek et al. (2020) on the other hand states that the utilization of EPDs in SAMs stimulate the product manufacturers to provide EPDs as they give extra credit in the rating systems. Further, BBR claims that manufacturers produce EPDs themselves by following an assortment of Product Category Rules (PCR) which makes the EPDs based on the same ground criteria and are therefore comparable (given that they are in fact based on the same PCR). PCRs include detailed guidance, delimitations, methods, and basic data for each product category. The PCR and the LCA are the foundation of EPDs (Boverket, 2019). It may be presumed that the construction industry has adapted to these practices with time.

The above assumption can be supported by the following facts.
At the beginning of 2019, there were >6000 verified EPDs, including construction materials, registered worldwide. The number of EPDs are increasing and becoming more available, Božiĉek et al. (2020) believe that the increase in EPDs can be in part linked to the parallel increase in SAMs and their use of LCA in the assessment. The increase in EPDs can also in part be an indicator that they are useful, for instance, building designers can use EPDs to evaluate which materials are to be used and the environmental performance of the construction (Božiĉek, et al., 2020).
In Sweden, EPDs (or CPD – *Construction Product Declarations*) are managed by the *Association of Building Product Declaration.* According to the *Association of Building Product Declaration,* the following information should be included in the declaration of a product:

- Basic information *(name, serial number etc.)*
- Manufacturer Information *(Contact information, management types etc.)*
- Product information *(Country of end production, use, safety sheet etc.)*
- Contents *(Materials, chemicals, weights - %, CAS-no., classifications etc.)*
- Production stages *(resource use and environmental impacts of production)*
- Distribution *(Return policy, reusable packaging etc.)*
- Construction phase *(storage requirements, requirements on adjacent products etc.)*
- Operational phase *(Requirements on product or energy input in operations or maintenance, life span)*
- Demolition *(Requirements for demolition)*
- Waste management *(reuse, material- and energy recycling, waste code, hazardous waste etc.)*
- Indoor environment quality *(Emissions)*

(Rosvall, 2014)

* Commonly, the need of declaration follows the following limits (by % of weight); >2,0 % 'normal' substances, >1,0% harmful substance (cause irritation, allergenic, corrosive, cancerous), >0,1% very harmful substances (Carcinogenic, mutagenic and reprotoxic, i.e., CMRs) (iBid).

There still is a need to consider more aspects, fully cradle-to-grave, including reuse or recycling, in order to be able to assess sustainability more holistically (Berardi, 2012). A weakness is the lack of clear and easy guidance in how to assess EPDs, as it can be confusing and fall victim of subjection, which decreases the credibility of the assessment and distorts the buildings actual environmental performance (Božiĉek, et al., 2020). Construction materials have a direct impact on seven, and indirect impact on two out of the UNs 17 SDGs (Božiĉek, et al., 2020), discussed previously in Section 2.5.

2.5.2 Nordic Swan Ecolabel, “Svanen”

The Type I ecolabel Nordic Swan, *Svanen*, was established in 1989 by the Nordic Council of Ministers as a common ecolabel for the Nordic region and to aid consumers in identifying and choosing environmentally friendly products (Nordic Swan Ecolabel, 2020a; Rosvall, 2014) as well as make it easier for manufacturers to produce these products (Nordic Swan Ecolabel, 2020a). In Sweden, state-owned *Ecolabelling Sweden AB* (*Miljömärkning Sverige AB*) handles the brand Nordic Swan Ecolabel and the testing, establishing of criteria, licensing and the administrative work that is executed in the name of Nordic Swan Ecolabel.

A variety of different types of products and services are at present Nordic Swan Eco-labelled, at first household products like toilet paper and detergents were labelled. Subsequently, the label grew rapidly and now incorporates hundreds of different types of products and services (Nordic Swan Ecolabel, 2020a), e.g. tires, homes and pre-schools (Rosvall, 2014), construction materials (Nordic Swan Ecolabel, 2020b), grocery stores and investment funds (Nordic Swan Ecolabel, 2020a). Private residences, apartment buildings, pre-schools as well as extensions to these can be Nordic Swan Eco-labelled given that they fulfil requirements set on the construction process, materials, energy consumption and indoor environment (Rosvall, 2014), similarly to the SAMs. In contrast to the SAMs discussed, even though Ecolabels are not SAMs, Nordic Swan does not have grades, either the project passes and is licenced, or it fails and receives no reward.

It is possible to apply for a Nordic Swan Ecolabeling of a building given that all minimum requirements have been met and that at least 9 credits (of 22) have been achieved. Materials used must be reported and accepted by the label before use. To ease the process *Ecolabeling Sweden AB* introduced a database, *House Product portal*, where accepted materials can be registered and viewed when a new product is accepted it is registered in the database for coming projects to take part of (Nordic Swan Ecolabel, 2020b). The process is fairly simple but needs to be handled internally by the company. Control visits by Nordic Swan representatives at the site is mandatory to make sure that all restrictions are followed, upon when the licence can be granted.

In Sweden the Nordic Swan Ecolabel have had great success and effect, for example some dangerous chemicals have been removed from the printing industry (Nordic Swan Ecolabel, 2020a) and consumers know what symbol to be on the lookout for and trust the label. The brand is transparent and states themselves that products labelled with the Nordic Swan are not good for the environment as they see that almost all produced goods have some negative effect on the planet, nevertheless, the labelled products have a lesser effect than non-labelled products which have been thoroughly analysed and tested (Nordic Swan Ecolabel, 2020a).

The Nordic Swan Ecolabel provides concrete facts on how their actions impact the environment positively. A study was conducted at nine Nordic Swan Eco-labelled washeries in Sweden, calculating the positive impacts it had, e.g., the energy savings equalled the heating of ~ 1433 detached homes for a year, the reduction in CO_2-eq equalled 47 269 journeys from the very north, to the very south of Sweden by car (Nordic Swan Ecolabel, 2020c). However, there is a lack of a complete life cycle perspective as waste management and recycling are futile and the focus is clearly on chemical use (Rosvall, 2014).

2.5.3 SundaHus

SundaHus (translates to *Healthy houses*), was founded in 1990 by SundaHus I Linköping AB, a private consultancy company specialising in improvements in indoor environmental quality. The company aims to provide security through environmentally mindful material choices, through service, counselling, and databases (SundaHus, u.d.). SundaHus is not a rating system or Ecolabel but rather supplies a licence to a database with environmental information about products and counselling service, similarly to Nordic Swan but without the labelling and certification.

SundaHus's web service can be used from the design- to demolition phase. Basic information is retrieved by SundaHus from the manufacturer and/or other resources, such as product name, maintenance, safety sheet, CPD or EPD etc.
The information is then stored in the database. Information supplied for each product through SundaHus's database is as follows:

- Health and environmental hazardousness
- Resource use
- Residual demolition and waste materials
- Transparency of the products

Continuously the products are evaluated and categorised into different groupings, *chemicals*, or *Others*, and lastly classified (graded) as best to worst: A, B, C^+, C^- or D (SundaHus, 2019).
A full list of requirements can be found in the *SundaHus Assessment Criteria 6.1.5: SundaHus Material Data* (2019) report.

A –The product has no missing information and or other attributes of the C^+, C^- or D classes. The product achieves the requirements for class A which are, among others: minimal health and/or environmental impacts, do not affect indoor environment quality negatively, good transparency regarding product contents etc.

B – The product does not achieve all requirements for class A but has no missing information and or other attributes of the C^+, C^- or D classes.

C^+: Products where, during manufacturing, workers, nearby communities, and the environment are at risk of exposure to substances of very high concern, used in the manufacturing of polymers.

C$^-$ - The product has no attributes associated with class D, but have one or more factors e.g., phase-out substances, cancerous, mutagenic, reprotoxic, acute toxicity etc.

D – The product has too much missing information to be classified.

The evaluation is carried out by chemists at SundaHus. The assessment criteria are based on European Parliament and Council Regulation (EC) No 1272/2008, as well as the Swedish Chemicals Agency Priority Guide PRIO. Additionally, the European Chemicals Agency's (ECHA) C&L database is also an aid in the assessment process for SundaHus (SundaHus, 2019).

2.6 Comparison

Before comparing the three SAMs and two EPDs it is important to note that SAMs and EPDs are not the same. They do not serve the same purpose or function and therefore cannot be assessed side by side as equals, but rather, their traits can be described where similarities or dissimilarities exist.

All three SAMs were established by authorities, likewise, was Nordic Swan, whilst SundaHus is run by a private company. This influences the motive of the organisation's actions and values, as well as its aims.

Whilst Nordic Swan was the earliest initiated call for action in the late 80's, BRE's BREEAM was the first comprehensive SAM and has been a huge influence in later SAMs (Tien Doan, et al., 2017), especially on LEED compared to Miljöbyggnad. BREEAM and LEED have significant overlap with each other in terms of coverage (Rezaallah, et al., 2012) which can be overviewed in Table 3.

2.6.1 Contents

In this section the similarities and dissimilarities regarding contents and coverage of the three SAMs and two other services will be compared.

Only Miljöbyggnad seem to not take into account and customize SIs depending on the type of building, e.g., private, commercial or industrial, as BREEAM and LEED do. BREEAM and LEED have entirely different manuals for existing buildings versus new developments, as well as several other specified manuals such as for entire cities or neighbourhoods. This way they can be further tailored to get the most out of the alterations. Miljöbyggnad only has two.

It is important for non-new developments to be able to take part of these rating systems as the present building stock makes up a much greater amount than the new developments (Malmberg, 2015). The pre-existing buildings are older and therefore can be assumed to be less energy efficient, environmentally friendly and may have a lesser indoor environment quality, due to the historically lower requirements put on them, which makes it important to get them up to standards (European union, 2020).

BREEAM has the greatest number of topics (10) and SIs and therefore also covers the most aspects (Malmberg, 2015; Tien Doan, et al., 2017…). Miljöbyggnad has the least and LEED is in between the two.

Both BREEAM and LEED value the energy (1) criteria highest, whilst Miljöbyggnad value health and indoor environmental quality (1) as number one. Followingly BREEAM rank Health and indoor environment quality (2) and materials (3). LEED, followingly, ranks materials (2) and water (3) whilst Miljöbyggnad values energy (2) and materials (3) (Malmberg, 2015; Sweden Green Building Council, 2018a; Sweden Green Building Council, 2018b).

Energy

All three SAMs consider energy to a large extent, albeit Miljöbyggnad has a slightly lesser focus opposed to BREEAM and LEED. Predominantly in the three SAMs, the energy use and optimization are key, additionally, energy type, where renewable energy is the focus is also important.

LEED, Miljöbyggnad and to some extent also BREEAM measure the energy reduction or improvement in percentage, however, Miljöbyggnad's highest energy credit, connected to the grade of gold, is 60% improvement compared to the Swedish regulations in BBR. LEED and BREEAM measure the improvement and credit it up to 100%, where the highest credit given by LEED amount to 18 points, and 14 for BREEAM, before the additional weighting of 18% (Sweden Green Building Council, 2018a; Sweden Green Building Council, 2020b; U.S. Green Buikding Council, 2020).

However, the methods have been criticised for not having clear enough goals and guidelines for achieving these. The SAMs have no way of measuring how big the decrease of the impact of these measures are during the lifetime of the building, something that the establishments behind the SAMs are working continuously on doing (Rezaallah, et al., 2012).

Water

Miljöbyggnad lacks completely in considering water (usage, reuse, wastewater etc.) except for in heating where warmwater can be used. BREEAM and LEED cover water thoroughly (Sweden Green Building Council, 2018a; Sweden Green Building Council, 2020b; U.S. Green Buikding Council, 2020), underlining that Miljöbyggnad is not as comprehensive as, first and foremost, BREEAM but also LEED. Nordic Swan considers some measures regarding water (except for in energy purposes), credits are given if performance displays are fitted so the water use can be viewed by the residents and if stormwater is actively managed etc. (Nordic Swan Ecolabel, 2020e). SundaHus do not consider water in this aspect (SundaHus, 2019).

Materials

Materials becomes a large topic as it involves many aspects and is what Nordic Swan and SundaHus mainly focus on.

BREEAM, Miljöbyggnad, Nordic Swan and SundaHus all require extensive documentation of materials and processes, however, LEED does not (Rosvall, 2014). Although LEED puts much emphasis on material it does not reward documentation with credits, neither do LEED address the out phasing of chemicals and other hazardous materials. LEED includes so-called pilot points, which are SIs that are being tested for future but are not yet official LEED SIs. One of these is named “Building Material Human Hazard & Exposure Assessment” and address the need for hazard declarations and the reduction in the usage of harmful substances (U.S. Green Building Council, 2020). BREEAM and Miljöbyggnad does cover the out phasing of harmful substances and refer to EPDs in order to achieve this (Sweden Green Building Council, 2018a; Sweden Green Building Council, 2020b). Likewise, Nordic Swan has a high focus on the out phasing of certain hazardous substances and SundaHus addresses this through limit-levels as well (Rosvall, 2014). Nordic Swan works toward diminishing the use of for example copper piping in buildings (Svenskt Vatten, 2016).

LEED, BREEAM and Nordic Swan consider recycling, reuse, pollution, waste management etc. which Miljöbyggnad lacks and SundaHus, in turn, lack waste management but do require that materials be recyclable or reusable. Waste management is a mandatory requirement in LEED. Although LEED is the only SAM which rewards locality even though BREEAM highly credits responsible sourcing and purchasing, it does not consider encouraging the local economy (Rosvall, 2014).

BREEAM requires the use of BRE assessed LCA-tools as to increase the holistic perspective of the method (Sweden Green Building Council, 2018a) while LEED encourages the use of any type of LCA (U.S. Green Building Council, 2020). As for SundaHus and Nordic Swan, they do not conform to a specific standard but do consider an extensive part of each materials life cycle (Rosvall, 2014).

Innovation

Both BREEAM and LEED encourage innovation as the way forward in sustainable practices and therefore reserve credits for innovations or good practices that are not defined in their manuals. BREEAM reserve 10 credits (Sweden Green Building Council, 2018a) while LEED reserve 5 and promote their pilot credits that way (U.S. Green Building Council, 2020). Nordic swan also credit innovation by three points maximum (Nordic Swan Ecolabel, 2020e), whilst Miljöbyggnad fails to credit innovation and SundaHus is not quite adapted to consider this aspect.

Management

BREEAM encourages sustainable management practices as to change and set the sector into more sustainable manners and mindsets. This includes using LCC, engaging in stakeholder dialogues and follow-ups (Sweden Green Building Council, 2018a). Nordic Swan touches on some management aspects primarily regarding planning and knowledgeable, good relationship practices (Nordic Swan Ecolabel, 2020e). LEED does not intervein in the management of the project neither does Miljöbyggnad or SundaHus.

Health and indoor environment quality
LEED falls short in considering indoor environment quality to the same extent as Miljöbyggnad and BREEAM. LEED mainly considers air quality, and briefly touches on light and noise. A pilot point for incorporating nature into the interior design exists within LEED (U.S. Green Building Council, 2020).

SundaHus and Nordic Swan consider indoor environment quality through the effects of material emissions and therefore air quality and well-being (SundaHus, 2019; Nordic Swan Ecolabel, 2020e). Nordic Swan also addresses lighting and temperature (Nordic Swan Ecolabel, 2020e).

In summary, BREEAM is the most extensive SAM, content-wise and have high requirements on Energy, LCA's, materials, documentation, waste management and indoor environment quality. Whilst LEED is slightly simpler, setting requirements on, mainly, energy, water, recycling and reuse. Lastly, Miljöbyggnad, the least broad SAM but also the newest and least international, focuses on indoor environmental quality, documentation, and materials (Rosvall, 2014). Nordic Swan puts the greatest efforts into materials and material documentation, which is similar to SundaHus, in contrast SundaHus has fewer assessment criteria but this is stated to be due to that they only consider criteria that can reasonably measured (iBid).

The SAMs thematic content is visualised in Figures 9, 10 and 11, the calculations can be found in Appendix 1.3. The themes are based on the number of possible points attainable, indicating that there are more aspects and/or that they have more importance. Whilst this is not telling about how high the demand per point is, meaning that demands can be high but not give many points.

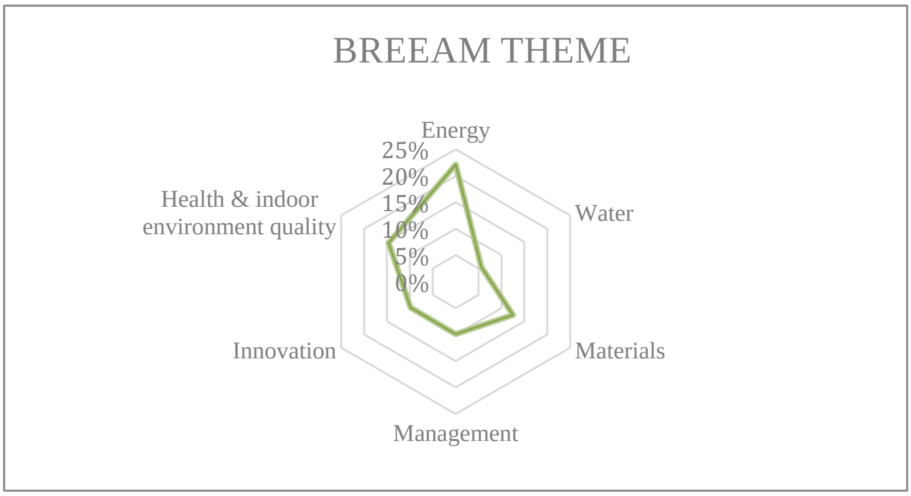


Figure 9 - BREEAM Coverage and focus. Source: adapted from BREEAM (2014).

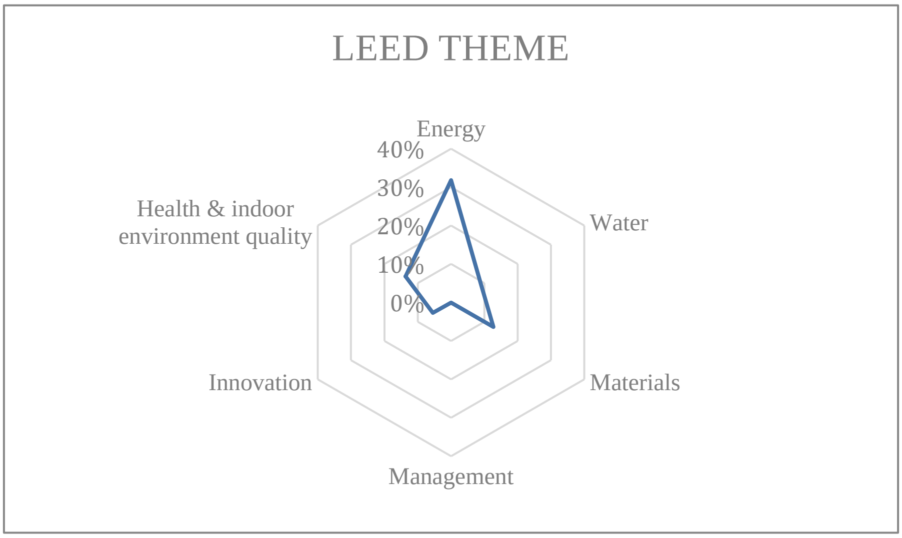


Figure 10 - LEED coverage and focus. Source: adapted from Spain Green Building Council (2019).

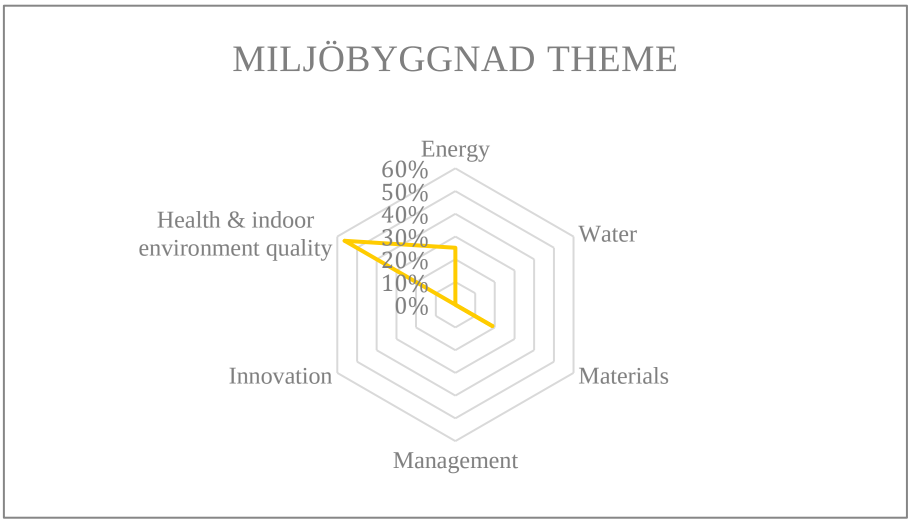


Figure 11 - Miljöbyggnad coverage and focus. Source: adapted from Sweden Green Building Council (2020e).

Extent

Nordic Swan is specific to the Nordic countries, whilst its European counterpart, EU Ecolabel, covers all of Europe (Nordic Swan Ecolabel, 2020b). SundaHus is strictly present in the Scandinavian countries, mostly Sweden (SundaHus, u.d.).

BREEAM targets the European market whilst Miljöbyggnad is exclusively Swedish, LEED is American but is the SAM who has reached the furthest globally, and is present in 167 countries (2018) (U.S. Green Building Council, 2018) compared to BREEAMs 88 (2020) (BREEAM, 2020), nearly 200% more coverage. Tien Doan et al., (2017) finds that the increased use of BREAAM in Europe, may be due to that the European market (including Sweden) already is relatively well-educated and aware of sustainability, and has been so historically, especially Sweden (U.S. Green Building Council, 2014). This is not surprising considering the EUs efforts toward sustainability. While LEED is more popular outside of Europe as it is considered more flexible and easier to get certified through (Tien Doan, et al., 2017).

BREEAM is more strict and non-flexible compared to LEED, which is viewed as more transparent (Tien Doan, et al., 2017). Whilst BREEAM can adapt to local rules, regulations and recommendations, LEED is meant to be internationally applicable without adaptation. As LEED is American, it is based on imperial units and American norms, which do not carry in all parts of the world (Rosvall, 2014). SundaHus and Nordic Swan do not strictly follow specific national norms but do not consider anything below EU standards.

BREEAM sets a numerical absolute value for most of their SIs whilst LEED assesses their SIs through percentages of improvement or reductions (Tien Doan, et al., 2017), e.g., BREEAM defines water usage in cubic meters per person and year whilst LEED base their measures on a percentage reduction. A top water usage score in LEED (40% reduction) only achieves 3 out of 5 credits (plus an exemplary score, which is not numeric) from BREEAM (Rezaallah, et al., 2012). BREEAM considered a wider picture in regard to the environmental impact (Rezaallah, et al., 2012). Albeit LEED’s lead in geographical diversity, BREEAM still boasts the most certified buildings by a large, as can be seen in Figure 12[1].

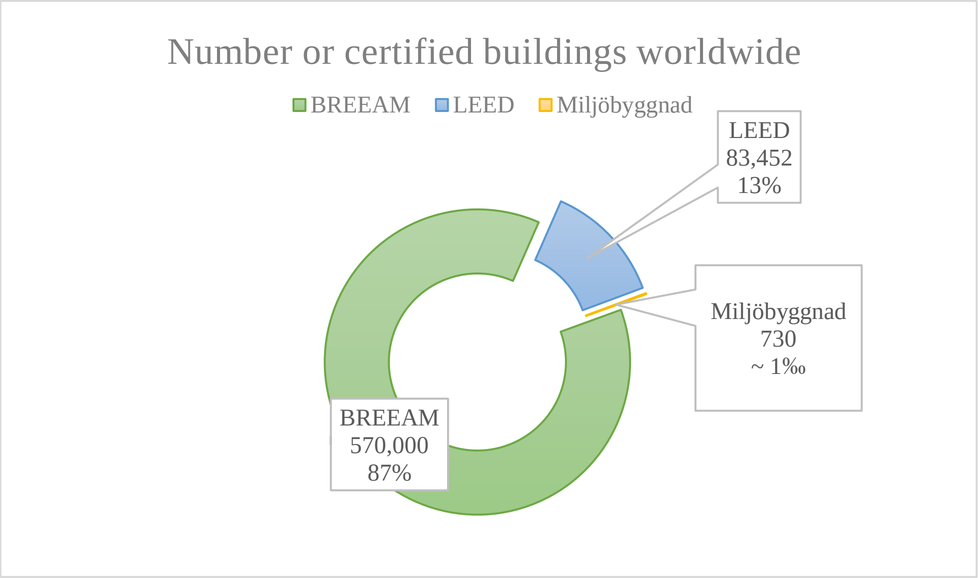


Figure 12 - Number of certified buildings worldwide. Source: BREEAM (2020), Sweden Green Building Council (2020e), USGBC (2016).

The extent of each SAM in Sweden can be seen in Figure 13, and the development of the SAMs regarding the number of certified buildings can be seen in Figure 14. In Sweden, the division between the SAMs is quite different compared to the worldwide numbers, which can be seen by comparing Figure 13 and 14. In Figure 14 the rapid advancement and adoption of SAMs in their early days can be seen by the steep gradient of the curves of BREEAM and LEED.

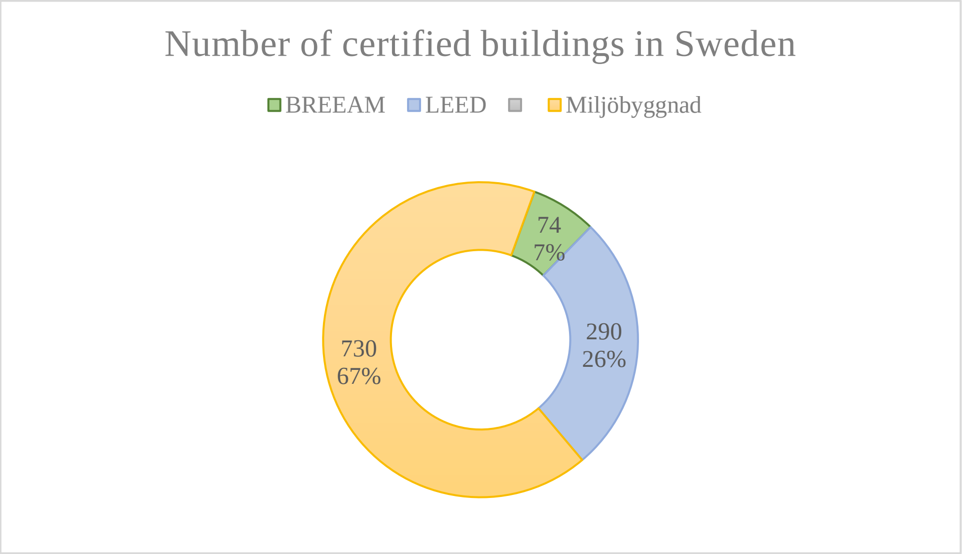


Figure 13 - Number of certified buildings in Sweden. Source Sweden Green Building Council (2020e).

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[1] Figure 12: LEEDs latest number of certified buildings is from 2016, whilst the others have up to date numbers.

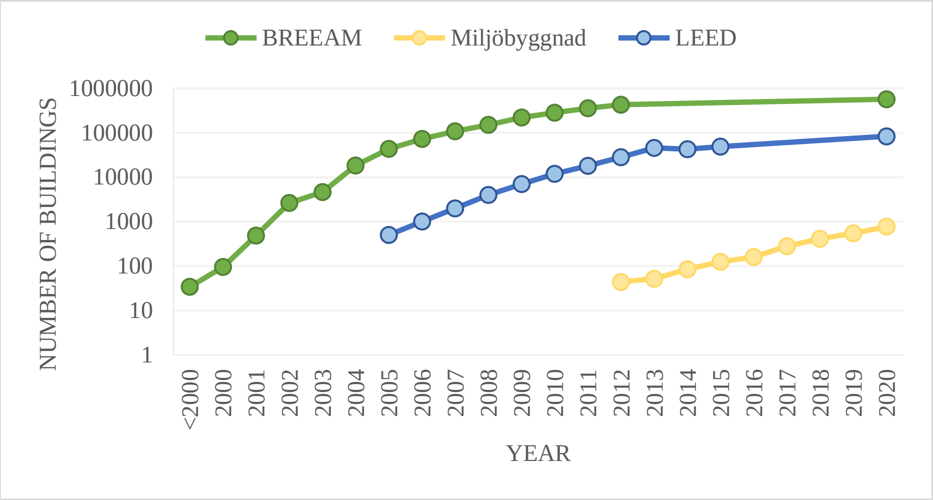

Figure 14 - Number of buildings certified worldwide over time (NOTE! Logarithmic scale). Source: BREEAM (2014), Spain green building council (2019), Sweden Green Building Council (2020e).

Between <2000 and the early 2010s they both had a steadily growing number of buildings, which in later years have abated in contrary to Miljöbyggnad which is still at the beginning of its life. Possibly the trend for Miljöbyggnad will mimic the past trends of BREEAM and LEED, flattening in the coming 3-7 years.

Certifications and Grading

The grading of Miljöbyggnad is quite vague and up for interpretation which can affect the final grade and make buildings certified by a certain grade vary in performance (Malmberg, 2015). BREEAM and LEED on the other hand follow stricter requirements for achieving their respective grades. Comparatively, BREEAM may be the hardest SAM to certify by and requires the most work while LEED may be viewed as the easiest due to the way that points are given out and its flexibility (Tien Doan, et al., 2017). The minimum score for BREEAM can be perceived as relatively low considering the scope of the method, which sparks the question in Malmberg (2015) how much better quality and lesser impact the SAM actually amounts to if only the minimum requirements are fulfilled. Similar questions have been brought up in literature previously, as mentioned by Ding (2008). On the other hand, Tien Doan, et al. (2017) establishes that BREEAM and LEED have increased their amount of mandatory and minimum scores in order to prevent greenwashing intents. In the case of Miljöbyggnad, all SIs needs to be fulfilled with the grade of bronze for the building to be certified (Sweden Green Building Council, 2020b).

While SAMs measure mostly relative factors, more absolute measurements and requirements have been established after research' critique concerning this was published. Further, research regarding SAMs identify that many of them, including BREEAM and LEED, are perceived by users as unnecessarily complicated, costly and that there is an imbalance in the assessment of different solutions (Rezaallah et al., 2012; Rosvall, 2014; Leon, et al., 2003), which in essence is why this thesis was requested. Nordic Swan has also been critisied for not being able to consider the impacts of the life cycle holistically.

It is important to note that BREEAM and LEED only rate the 'assets' which cannot answer to how the buildings will actually perform in operation through the lifespan of the building (Rezaallah, et al., 2012). However, Miljöbyggnad, for instance, conducts follow-ups at least a year into the building's life, with additional questionnaires for the residents of the building. Since Miljöbyggnad only considers aspects in direct correlation to the physical building it should consequently not be able to frame the true full effects of the building neither of the environmental nor the social or economic aspects. BREEAM and LEED has also received this critique, even though they consider more aspects than Miljöbyggnad.

BREEAM and LEED need to clarify whether a high rating is synonymous with improvement in the building's operational performance and efficiency, according to Rezaallah et al. (2012) which also state that LEED is currently working on this matter.

Toward the Sustainable development goals

As mentioned in the correlating sections Ecolabeling and EPDs contribute toward UNs SDGs: 12 – *responsible consumption and production*, 13 – *Climate action*, 14 – *Life below water* and 15 – Life on land (ISO 14021:2016, 2020; ISO 14024:2018, 2018; ISO 14025:2006, 2020; Nordic Swan Ecolabel, 2020b). Construction materials have a direct impact on seven and indirect impact on two, out of the UNs 17 SDGs (Božiĉek, et al., 2020).

SAMs also contribute towards the goals. BREEAM addresses the UNs SDGs and states that they are either indirectly or directly affecting them all, this is including all BREEAM standards and tools such BREEAM for infrastructure and QSAND (a sustainability and resilience framework developed on behalf of the red cross). BREEAM states that they have significant contribution to 10 out of the 17 goals (QSAND contributes with two extra goals, 1 and 4, in which it is stated as the sole contributor) (BREEAM, 2020a). Although BREEAM New Construction is stated to be a contributor indirectly or directly to all goals except for 3, number 5 - gender equality, 10 – reduced inequalities and 17 – partnership for the goals. A big statement and one that might be a bit far-fetched and exaggerated as e.g. their contribution to goal 2 – Zero hunger, where the target 2.4 states *" By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality"* and BREEAMs comment states *"The ecology issues within BREEAM maintain ecosystems and reduce land degradation in the surrounding area." – BREEAM 2020b*, which does not show any clear linkage between BREEAM New Construction and UNs second goal (BREEAM, 2020b).

LEED also contributes to the UNs SDGs but have motivated their impact on fewer of them compared to BREEAM, perhaps a more sensible statement. LEED is stated to affect, among others, goal 3 target 3.9 – "*By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination*.". How LEED affects this target is quite straightforward. Several SIs touch on the indoor environment quality and stipulate the need for proper ventilation as well as minimizing exposure to hazardous chemicals and air pollution. Further, targets within goal 6, 7, 11 and 15 are also mentioned to be mediated by LEED certification (Gellers, 2015).

Many SAMs contribute to the SDG in direct or indirect ways, nonetheless, two goals being affected to a higher degree by nearly all SAMs are goal 11 - *Make cities and human settlements inclusive, safe, resilient, and sustainable* and goal 12 – *Ensure sustainable consumption and production patterns*, as resource management and built environment quality are two of the fundamental purposes of SAMs. The full list of Goals and targets affected by SAMs can be found in Appendix 1.1, as well as Appendix 1.2 which includes BREEAMs assessment of which goals they affect.

As mentioned in previous sections measuring sustainability can be quite difficult and SAMs are a tool to try to put sustainability measures into qualitative measures, raise awareness and ultimately reduce climate change. Before the 2010's little research into certified buildings and their actual environmental impact had been undertaken, rendering it hard to know for sure what the benefits of certifying were. In 2015 an analysis of BREEAM Assessment data showed that BREEAM certified buildings have an average of 22% drop in CO_2 emissions (Taylor, 2015). Whilst grades Outstanding and Excellent perform vastly better with reduction in CO_2 emissions by 32-66% (Soulti & Leonard, 2016). The USGBC states that on average a LEED certified building save about 350t of CO_2 emissions per year and uses 32% less energy than a standard building (U.S Green Building Council, u.d.). Further, 65% of LEED SI contribute to reductions in CO_2 emissions (U.S Green Building Council, 2007).

However, through the monetary perspective, certifying buildings does not speak as loudly. A study in 2016, in collaboration with BRE, showed that the certifying through BREEAM can incur increases of capital costs from 0-1.71% in office and educational buildings and up to 5,5% in healthcare buildings. This can be slightly mitigated by the possible savings in operational costs (Soulti & Leonard, 2016). As previously mentioned, the long-term savings of SAMs outweigh the possible increase in short-term costs (Leon, et al., 2003).

It can be concluded that research and data collection from current green buildings along with further development of the SAMs is vital and well on its way toward creating collective measurements of sustainability and environmental impacts, necessary to future sustainable development.

Table 3 – Basic information about BREEAM, LEED, Miljöbyggnad, Nordic Swan and SundaHus. Sources: BREEAM (2020), Malmberg (2015), Nordic Swan (2020f), Miljömärkning Sverige AB (u.d.), Rosvall (2014), SGBC (2020a, b), USGBC (2020) ...

	BREEAM	***LEED***	***Miljöbyggnad***	***Nordic Swan***	***SundaHus***
Country of Origin	United Kingdom (UK)	The United States (U.S.)	Sweden	Sweden	Sweden
Founding entity	BRE (Building Research Establishment)	USGBC (U.S. Green Building Council)	Sweden Green Building Council	Miljömärk-ning Sverige AB	Sunda Hus i Linköping AB
Founding Year	1990	1998	2005	1989	1990
Latest Update	2016	2017	2017	2016	-
Present in number of countries:	89	167	Sweden	Nordics	Sweden, Norway, Denmark
Rating system	Pre-Weighted	Points system	Assessment	Points system and materials database	License to database with material assessments
Can be certified:					
New Development	X	X	X	X	X
Existing building		X	X		X
Renovation/ Addition	X	X	X	X	X
Types of buildings					
Private residence	X	X	X	X	
Apartment buildings	X	X	X	X	X
Public buildings	X	X	X	X	X
Industrial buildings	X	X			X
Indicators*					
Energy					
Energy consumption	X	X	X	X	
Energy type	X	X	X		
Solar radiation			X		
Water					
Water consumption	X	X		X	
Reuse & wastewater	X	X			
Materials					
Recycling/Reu-se	X	X		X	X
Waste management	X	X		X	
Origins &	X	X	X		X

Purchasing					
Hazardous substances	X		X	X	X
Geographic location	X	X			
Pollution	X	X		X	X
Documentation	X		X	X	X
Ground & ecology	X	X			
Innovation	X	X		X	
Management	X				
Health & quality of Indoor Environment					
Noise	X	X	X	X	
Lighting	X	X	X	X	
Air quality	X	X	X	X	X
Moisture	X		X	X	
Temperature	X		X		
Microbial contamination	X		X		
Radon	X		X	X	
Number of buildings certified	593 027	83452	768	11258	
Number of buildings preliminarily certified	+ 2 000 000	-	951	17602	
Predominantly affected SDG's [Goal(target)]*	2,3,4,6,7,8, 9,11,12,13, 14,15,16	3(3.9),6 ,7, 11, 15	-	3 (3.9), 6 (6.3,6.4,6.6), 7 (7.2,7.3), 8 (8.4, 8.7,8.8), 9 (9.4), 11 (11.3, 11.6), 13 (13.2), 14 (14.1, 14.4, 14.7), 15 (15.1, 15.2, 15.5), 17 (17.6)	-

*A selection on topics and SI have been chosen on the frequency of occurrence between the three SAMs and two EPDs. * SGDs based on each organisation's stated impact.

In summary, BREEAM is the most extensive and covering SAM, considering the impacts furthest back in the supply chain. However, this consequently makes BREEAM the least flexible and transparent, (due to the more advanced calculation methods) and therefore most difficult SAM to adhere to, nevertheless, it is well known and has the advantage of status and trustworthiness (Rosvall, 2014).

LEED is viewed as the simplest SAM which is both an advantage and disadvantage as it may reach afar and have many buildings certified (although BREEAM still has far more), but also it may be used as an object of fashion rather than to truly make amends on the climate. There is some difficulty in comparing Miljöbyggnad to BREEAM and LEED in the context of global use and adoption as it is only present in Sweden. Miljöbyggnad has the least coverage of the three and is additionally the most subjective in its grading. Notably, it is also much newer and therefore has not had the time and field testing as the two others.

All three SAMs and two EPDs are constantly being updated to fit the changing times and to improve. Nevertheless, all SAMs need to further establish the true effects of their SIs and what impact certifying buildings truly have, how this is to be measured is another question in need of further research and development. As is for the present, certifying buildings and using EPDs and Ecolabels are more of a market requirement than a competitive advantage or investment, however, this may very well come to change.

Before this Section is concluded, RQ2 and RQ3 can be answered.

RQ2: What factors are the criteria/sustainability indicators of sustainability assessment methods grounded on?

As previously mentioned, it is unclear exactly what factors SIs are grounded on, but they constantly change and improve, following the research trends.

RQ3: Do the sustainability criteria/sustainability indicators aid toward the UN's sustainability goals, are they connected?

As previously discussed, the SIs are partly grounded on the UN's SDGs. SAMs cannot cover all topics of the 17 SDGs but in the areas where they do, the SIs are appropriate to support the achievement of the subjected SDGs.

In the upcoming section the aim is to answer RQ1.

3 Empirical data

During this section of the thesis, two case studies will be introduced and the sustainability of different solutions in terms of Global Warming Potential (GWP) measured in CO_2 emissions will be investigated.

3.1 Case study 1

This case study aims to investigate and compare whether the installation of heat exchangers with the purpose of recycling residual heat from the wastewater of changing room showers are greater than other solutions such as e.g., sourcing only green energy which would otherwise have been simpler to design.

3.1.1 Introduction

The project in question is an industrial service centre for garbage trucks, undertaking e.g., oil-refills, changing of tires, and general service, and repairs of containers through e.g., welding, sandblasting and repainting etc. The client is active in the energy- and recycling- sector and therefore their ‘green’ reputation needs to be maintained (Törngren, et al., 2020).
The site is situated in the north of Gothenburg, Sweden and is an industrial building covering 7855 m^2 (A_{temp}) (Aljundi, 2020), the service area consists of one storey, high ceiling industrial workshop whilst the rest consists of a two-storey (same height as service area) office space with separate changing rooms for shift workers (Törngren, et al., 2020). The project is still in the design phase but is set to be completed in late 2022 (iBid).

3.1.2 Sustainability Assessment Method and Sustainability Indicators

The building aims to be certified through BREEAM, and the aim is to reach *Good* or *Very good* (iBid) which entails achieving ≥ 45 -55 % of the top score (Sweden Green Building Council, 2018a). Becoming BREEAM certified will also tick the project goal of becoming Europe’s first BREEAM certified workshop (Törngren, et al., 2020).

One important BREEAM SI to reach is reducing the energy consumption of the building (Ene 01), this will partly be done through the recycling heat from the wastewater of the showers and reclaiming the heat created by the air compressors used for repairs. This is done by installing a wastewater heat exchanger from the showers and two heat exchangers for the two compressors (iBid).

This measure falls under the BREEAM category of energy and its purpose is stated to be *“This category encourages the specification and design of energy efficient building solutions, systems and equipment that support the sustainable use of energy in the building and sustainable management in the* *building's operation. Issues in this section assess measures to improve the inherent energy efficiency of the building, encourage the reduction of carbon emissions and support efficient management throughout the operational phase of the building's life." – BREEAM-SE New construction manual (2017) p. 137.*

The subcategories are: Reduction of energy use (1), Energy monitoring, a, (2), Energy-efficient lighting (3), Low carbon design (4), Energy-efficient cold storage (5), Energy-efficient transport systems (6), Energy-efficient laboratory systems (7), Energy-efficient equipment (8) and lastly, Drying space (9). (1) has the most credits by far, 14 credits, which can be obtained if perfectly executed, additionally this SI is mandatory and also adhere to the BBR requirements. For the purpose of this case study the SI (1) will be looked closer into and compared to the SI requirements mentioned in Section 2.4.1.1.

For SI (1) a.k.a Ene 01 – Reduction of energy use, the aim is stated as "To recognise and encourage buildings designed to minimise operational Energy demand" - *BREEAM-SE New construction manual (2017) p. 137.* and is a mandatory SI within BREEAM. The only prerequisite is to follow the BBR and to fulfil the *Current Standards Building Energy Performance Index* (CSBEPI). No further information is given on why this qualifies as an SI and what the environmental effects can be.

Drawing from the criteria for SI set up by Waer and Sibley (2005), the SI Ene 01 is relevant even though no guarantee of an actual effect, and the extension of which can be given, but the SI can be assumed, in the isolated case, to reduce energy use. The SI is easy to understand as the relevant information and evaluation strategies are given in the BREEAM manual. The information provided is reliable as BBR gives different CSBEPIs for different types of buildings as well as possibilities to further calculate the specific building's prerequisites that change the CSBEPI. The question on accessibility is divided. The little data necessary to evaluate the criteria is easily available, however, the effects of which are not easily available neither is historic, or data based on previously assessed buildings. Clearly, the SI in and of itself is acceptable and easy to act on but the actual effect it has, additionally in regard to the effort put in is unclear and needs to be studied further and defined.

Further, to gain optional extra points the BREEAM target MAN02 – *Life cycle cost and service life planning,* have been undertaken and up to 4 points can be acquired. The aim, according to the BREEAM manual is *"To deliver whole life value by encouraging the use of life cycle costing to improve design, specification, through-life maintenance and operation, and through the dissemination of capital cost reporting to promote economic sustainability.".* Therefore, a LCC for the project has been made.

3.1.3 Energy performance of the Service centre

To realise the SI Ene 01, which is mandatory, the predicted energy consumption of the building need to be calculated in order to compare it to the CSBEPI. The energy usage or consumption of the prospected building has been calculated by a qualified energy modelling engineer and is called the *Predicted Building Energy Performance Index* (PBEPI) or Primary Energy Index. The difference (i.e., improvement), between the PBEPI and the CSBEPI, set by BBR in BFS 2019:2 BBR 28, becomes the percentage that BREEAM credits accordingly. The PBEPI is an estimation and may vary from the actual needs when the building is in operation due to deviations between the model and actual construction (Törngren, et al., 2020).

The buildings Primary Energy Index, EP_{pet}, is composed by the energy consumption of the building, E_{cool} – energy for cooling, E_{hw} – energy for hot water, E_e – energy for electricity and E_{heat} - energy for heating, which have been adjusted by a geographical factor - F_{geo}. The summation of these factors is multiplied by a weighting factor and distributed over A_{temp} [kWh/m^2 and year], the calculations are given in BBR BFS 2019:2 BBR 28, p 140 (152), see equation (3).

$$\text{EP}_{pet} = \frac{(\sum_{i=1}^{6}(\frac{E_{heat,i}}{F_{geo}} + E_{cool,i} + E_{HW,i} + E_{e,i}) \cdot W_i)}{A_{temp}} \tag{3}$$

To earn the full 14 credits in BREEAM the energy improvement of the building needs to be +100% in comparison to the CSBEPI which will, in turn, earn the grade Outstanding. The minimum energy usage improvement given by BREEAM is 3% and earns a credit of 1.

The energy required for heating has been denoted by a geographical factor, 0,9 for Gothenburg. The energy consumption and thereby the PBEPI of the building has been estimated by the consultancy and the aggregation of contributing factors can be seen in Table 4.

Table 4 - Aggregation of contributing factors towards the PBEPI. Source: Aljundi, 2020 Table 1.

	ENERGY PURCHASED [KWH/YEAR]	**SPECIFIC BUILDING ENERGY CONSUMPTION [KWH/M^2, YEAR]**	***PREDICTED BUILDING ENERGY PERFORMANCE INDEX* [KWH/M^2, YEAR]**
FANS	114 000	14,5	23
LIGHTING	11 800	1,5	2
PUMP ELECTRICITY AND AUTOMATION	15 700	2,0	3
ELEVATOR	16 500	2,1	3
DOWNPIPE DE-ICING	3500	0,4	1
HEAT: VENTILATION	40 800	5,2	9
HEAT: RADIATORS	58 700	7,2	13

HOT WATER	20 900	2,7	4
COOLING: VENTILATION	700	0,1	0,1
COOLING: CHILLED BEAM	0	0	0
COOLING: INSTALLATION ROOM	3000	0,4	0,6
SAFETY MARGIN 15%	43 900	5,6	9
TOTAL:	**336 800**	**43**	**71**
ENERGY FROM OPERATIONS	173 800	22	
ENERGY FROM OPERATIONS: HOT WATER	56 400	7	
OPENING OF GATES: HEATING ENERGY	66 300	8	
CURTAIN HEATER, ELECTRICITY	1100	0,1	
TOTAL OPERATIONS:	**297 600**	**38**	
GRAND TOTAL	**634 400**	**81**	

According to the energy calculations done by the consultancy, the building utilises 71 kWh/ m^2 and year which is better than the requirements set by BBR28, see the calculations below. The total energy consumption per year equates to 557 705 kWh/year. The CSEBPI is calculated through equation (4) and stated in BFS 2019:2 BBR 28, additionally, the CSEBPI have been mitigated by the increased external airflow rate (above 0,35 l/s, m^2). The Improvement of energy utilisation is calculated in equation (5).

$$80 + 70 \cdot (q_{medel} - Q_m) = 80 + 70 \cdot (0{,}88 - 0{,}35) \approx 117\ kWh/\mathrm{m}^2, \mathrm{y} \quad (4)$$

q_{medel} $-$ $Avarage\ external\ airflow\ rate$ [l/s, m^2]
Q_m – minimum external airflow rate [l/s, m^2], set by BBR as 0,35 l/s, m^2

$$\frac{CSBEPI - PBEPI}{CSBEPI} \cdot 100 = \text{Improvement } [\%] \qquad (5)$$

The improvement in energy consumption of the building is 39% which amounts to 9 BREEAM-credits and is the minimum requirement for the grade Outstanding, however, 40% improvement would have secured yet another point (Sweden Green Building Council, 2018a).

3.1.4 Performance of the Heat exchanger

In Sweden, about 9 TWh/year of warm water is simply flushed away after use in our e.g., showers, baths and taps, an energy amount which equals heating around 740 000 Swedish villas during a full year (Rörmontage, 2015). Recycling heat from wastewater could save up to 7,5 TWh/year in Sweden alone (Svenskt Vatten, 2017).

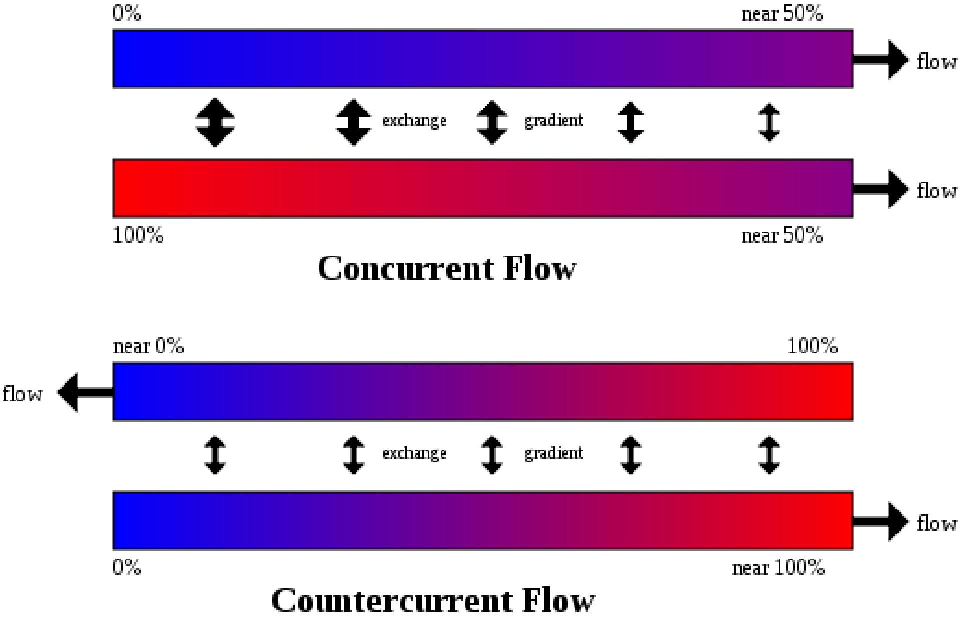

Figure 15 – visualisation of counter-current and concurrent flow for the exchange across a gradient of material property. Source: Svgmaker, public domain.

The HVAC system and heat recovery system have been fitted with a wastewater heat exchanger (MM-växlare) with a 25% efficiency. The wastewater heat exchanger has been tested specifically for showers (efficiency could possibly be higher due to the higher water usage at the site, shift workers shower at the same time), generating about 5kW in heating power, according to SP Technical Research Institute of Sweden (2015). The heat exchanger works through counter-current heat exchange, see Figure 15.

Heat, (i.e., energy) is exchanged from the warm wastewater to the inbound cold water, destined for the boiler. By reverting the hot wastewater from e.g., showers through the heat exchanger where the cold inbound water is led, the hot wastewater will heat the cold water which decreases the need for further heating, thus saving energy. No additional energy is required to run the heat exchanger (Karlsson & Karlsson, 2020). The manufacturer of the heat exchanger predicts a pay-off time of 8 years and a lifespan of 40 years (Rörmontage, u.d.). The building uses geothermal heat to heat the hot water (Törngren, et al., 2020).

In the building, the designer predicts an inbound cold-water temperature of between 8-14°C depending on the season, an average temperature of 10°C

(T_c) has been assumed. The showers are predicted to run at between 37-40 °C in operation, the temperature from the showerhead (T_t) will be 40°C. The water needs to be pre-heated to at least 50 °C due to the risk of legionella and will therefore be kept at 55°C (T_h), as a safety measure (Cordic, et al., 2020), see Figure 16.

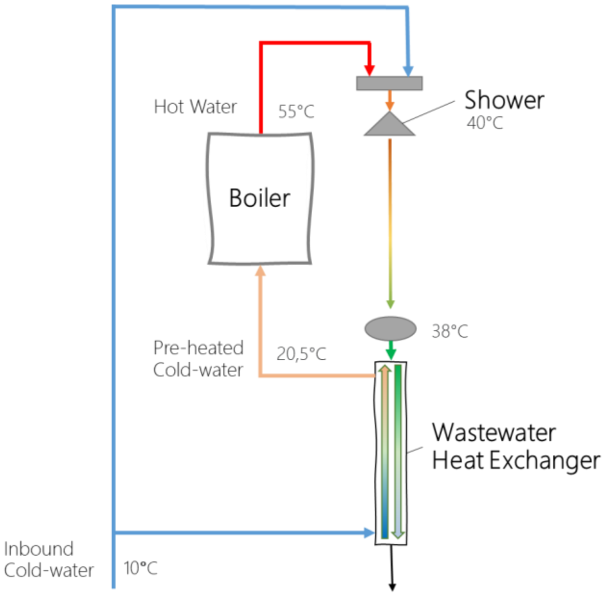

Figure 16 - The wastewater heat exchanger system. Source: By author.

The wastewater flow is predicted to be 2 l/s (V_w). The remaining water flows can be calculated through temperature and the estimated flow from each shower, assumed that 20 showers are in operation simultaneously (Cordic, 2020a). According to the qualified estimations of the project design engineers regarding system temperatures and water flows, the residual water flows can be calculated through the relational assumptions presented in equation (6) and (7). Full calculations can be found in Appendix 1.4.

$$V_h \cdot T_h + V_c \cdot T_c = V_w \cdot T_w \tag{6}$$

$$V_w = V_h + V_c \tag{7}$$

$T_c - Temperature\ inbound\ cold\ water\ [°C]$
$T_h\ -\ Temperature\ hot\ water\ [°C]$
$T_w\ -\ Temperature\ wastewater\ \ [°C]$
$V_c\ -\ Cold\ water\ flow\ [l/s]$
$V_h\ -\ Hot\ water\ flow\ [l/s]$
$V_w\ -\ wastewater\ flow\ [l/s]$

Putting equations (6) and (7) together results in a cold-water flow of ~0,67 l/s and hot water flow of ~1,3 l/s. Additionally, the showers are used two times a day, after each shift and for about 30 minutes each shift-end, 5 days a week, 45 weeks a year. The results are used in the equation for thermal store of energy, equation (8) to calculate the heating energy-need, with and without a wastewater heat exchanger.

$$E_{ch} = \frac{m \cdot c_{pw} \cdot \Delta T}{3600} \tag{8}$$

E_{ch}- Energy consumption for heating [kWh]
m - Mass of water [l, kg]
c_{pw} $-$ Water's specific heat capacity $[kJ/(kg \cdot K)]$
ΔT $-$ Temperature difference $[K]$

The energy captured from the wastewater (25%) can be directly pushed into the hot water flow, reducing the ΔT of the water coming into the boiler.

The energy-need without a heat exchanger is calculated to be ∼56 430 kWh/year and the energy available for reuse is calculated to be∼14 108 kWh/year with a heat exchanger. Which results in a decreased energy use down to 42 323 kWh/year.

Further, to find the temperature that the cold-water has after pre-heating, T_{v2}, the same formula, equation (8), is used to find the temperature after pre-heating using the input temperatures T_t and T_c, or simply finding the pre-heated cold water temperature trough multiplying the efficiency with that ΔT[2]. T_{v2} is calculated to be 11,25 °C, which, using equation (8) again, results in a decrease in heating power need of 25%. The power need output for heating is found through denoting the above calculated power consumption by a factor of 3, due to the properties of geothermal power. This results in an electricity need of ∼14 108 kWh/year, saving nearly ∼ 4 703 kWh/year.

3.1.5 Additional components of the wastewater heat exchanger

To be able to get an as close to the truth estimation of the sustainability of either solution, heat exchanger or procuring only green power, further analysis of the heat exchanger and its components need to be undertaken. Alongside the installation of the heat exchanger, which is mainly made from copper, additional copper piping for tap water needs to be installed and with them condensation insulation. Further, additional drainage piping and a variety of valves will also be installed as an effect of the installation of a wastewater heat exchanger (Powell, 2020).

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[2] To note, the efficiency can be interpreted in different ways effecting the following calculations. Either the efficiency can be assumed to be directly correlated with a, in this case 25%, lower total energy use, or it can be assumed to be the amount of energy available for recycling in the wastewater. The first mentioned method has been used at it is the method stated by the manufacturers. Either way the results are, in this instance, roughly the same.

Copper

To begin, the heat exchanger is made from copper and is since recently manufactured without insulation *(Rörmontage, u.d.)* although the insulation will be added in the installation phase *(Powell, 2020)*. Copper is a controversial material due to its two-faced nature. Copper is vital to our health *(Copper Development Association, 2018a)* and has beneficial properties for use in different applications thanks to its high electrical and thermal conductivity as well as being corrosion-resistant *(Copper Development Association, 2018b)*. On the other hand, potentially harmful elements like sulphur is contained within copper ore and the relatively energy-intensive production of copper products emit these elements as well as CO_2 from the auxiliary chain *(Kuckshinrichs, et al., 2007)* which is a major contributor to emissions *(European Copper Institute, 2012)*.

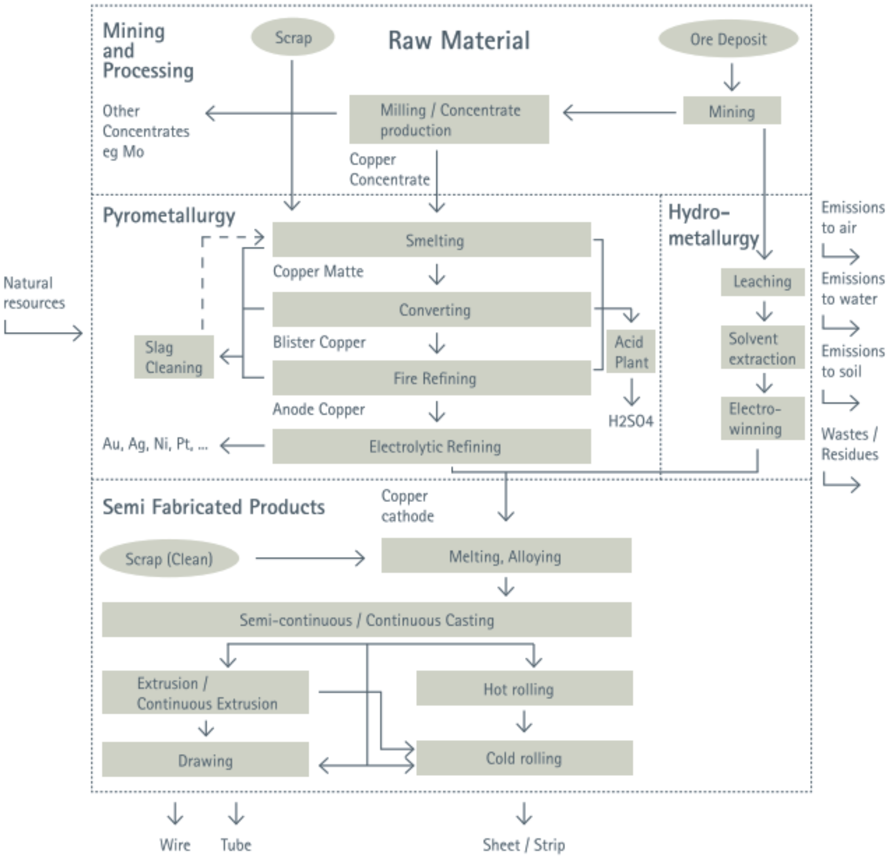

Figure 17 - Production Process for Copper in Europe. Source: The European Copper Institute (2012), p. 6.

Too much copper in nature and in organisms like ourselves can cause acute toxicity causing problems in the respiratory and digestive systems, and even death for smaller organisms like fish. The production of copper emits sulphur dioxide which contributes to acid rain and naturally the mining process destroys natural habitats, the pollution from machinery and heavy metals and other bi-products poisons animals and water sources (GreenSpec®, 2020; The Earth's Riches, 2019). The European Copper Institute conducted a full LCA of the European copper production in 2012. The copper production process can be seen in Figure 17 taken from the LCA report.

The European Copper Institute found that the two first production stages, ore extraction and processing have the largest impact followed by the power usage. Improvements are being made across upstream milling and concentrate production processes with the purpose of cutting losses and improving yields, partly through new technologies (European Copper Institute, 2012). It is prevalent that the different methods of extracting and obtaining the ore from various metals, e.g., copper, during mining have different environmental footprints. Where hydrometallurgy (extraction by aqueous solutions) has a larger environmental footprint than the pyrometallurgy method (thermal treatment to obtain the ore). This is mostly as an effect of the amount of energy used (Norgate, et al., 2006). Alongside the industry working hard in reducing their effect on the climate more and more copper is being recycled and reused (Kuckshinrichs, et al., 2007).

According to the LCA conducted by the European copper association the manufacturing of copper sheets and tubes i.e., piping, have a lesser environmental impact as these, in contrary to copper wires, can be made with recycled materials to a larger extent. Some European manufacturers could use 100% recycled copper in their production. Additionally, the European Copper Institute (2012) claims that “Generally speaking, using more copper saves energy and reduces CO_2 emissions” this statement is mainly based on the reduction in energy use through the advantageous qualities of copper (European Copper Institute, 2012). Simply, adding more copper to a product is not the solution but rather a careful LCA comparison between copper and other materials that could possibly be used should be undertaken. Additionally, the source of the copper plays a large role in its GWP.

It was predicted that CO_2 emissions linked to copper production would rise during the 2000th century, however, the incline in emissions would be lesser than the surge in demand and production increase, meaning that CO_2 emissions per kilogram of the product were predicted to decrease. On the downside the increase in copper popularity (Kuckshinrichs, et al., 2007) will lead to troubles ensuring stock for the future generation, further measures to reuse and recycle along with considerable investments will be necessary according to the European Copper Institute (2012).

Only around 12% of global copper mining is located in Europe, with the biggest mines located in Russia, Poland, Sweden, Germany, Spain, etc. (European Copper Institute, 2018c). Further, ¼ of global copper production comes from one specific mine in Chile (The Earth's Riches, 2019). Working conditions vary largely from country to country but generally third world mining operations falls behind and fails to present adequate working conditions, and health and safety is neglected for both workers and nearby habitants to the mine (GreenSpec®, 2020). The gender equality in many copper mines is low, only males work in the Chilean mines. The only female presence is a pre-recorded female voice in the speaker systems, aimed to calm the working men (The Earth's Riches, 2019). Nevertheless, the copper industry has made Chile one of the most stable Latin American countries, the GDP per capita is higher than both the one for Brazil and Argentina (Desjardins, 2017).

Polypropene

The drainage pipes are made from polypropene (PP), a common thermoplastic polymer, deemed non-harmful by the Swedish Environmental Agency. It is often used as packaging of food, in toys, medical implants and piping, making it one of the top five most-produced plastics in the EU (the Swedish Environmental Protection Agency, 2020). The manufacturer of the specific drainage pipes has had the product externally verified and an EPD made, which will be the foundation of further analysis of PP. The pipes are made from 71% PP, 26% talc and the rests are EPDM and additives, 0% of the raw material is recycled. The EPD considers the product from raw material to a disposal, including, among others, transportation, reuse, and installation etc. The pipes are manufactured in Europe, which is also the main market, however, distribution to Asia is also existent. For transportation, the EPD states that transportation within Europe is estimated to be handled by class euro 5 and 6 lorries and the distance travelled is on average 800km, loading weight 8 tonnes per lorry. The environmental impact in GWP is mainly found at the disposal and raw material phases and power usage is a big contributor as mostly non-renewable power is used. Very little hazardous waste is rendered during manufacturing (Stucki, 2019).

Rockwool

Rockwool, a type of Mineral wool (a synthetic inorganic glass similar (amorphous) silicate fibres), is a thermal insulation material mostly made up by air, hence its low density. However, the tangible material is often basalt or dolomite which are types of volcanic rock. The material is made, basically, like candy floss, through melting basalt etc. and additives into a homogeneous mixture in a furnace after which it is directed into a fiberizer which spins it off of discs at a high speed resulting in thin strands i.e., fibres (Adamczyk, et al., 2017).

The material is commonly used in insulation of buildings, prefabricated elements, pipes and ducts (Erlandsson, 2019). Working with rockwool is governed by exposure limits set by national authorities. In Sweden, the occupational exposure limit for respirable fibres in air-borne dust from mineral wool is 1 fibre /cm^3 (Rockwool, 2013). The material has production facilities in Sweden which reduces transportation and regulates the work environment.

Like PP, manufacturers of rockwool have had EPDs drawn and the following exposition will be based on the EPDs. The EPDs considers the production chain from raw material to end-of-life residues, similarly to the PP EPD. On the contrary, to the production of PP drainage pipes, the power used in the production of rockwool in Sweden and Finland is 100% hydropower (Erlandsson, 2019) which is likely to impact the final GWP. The EPDs shows that 85% of the CO_2 emissions occur during the phases of raw material, transport, and manufacturing i.e., during the production process at the site. The reason for this is mainly as an effect of the combustion of all energy carriers used in production on-site, about 21% of that is due to auxiliary upstream processes in the power supply chain.

The entire process releases some harmful substances such as ammonia, 18%, sulphur dioxide (SO_2), 60% and Nitrogen oxides (NO_x), 45% (per m^3 produced material). Ammonia and NO_x emissions contribute to Eutrophication (iBid) – over exposure to nutrients or fertilizers (European Commission, 2020). Exposure to SO_2 can be harmful to the respiratory system due to the inhalation of fibres which irritate and can cause sensitization (Kupczewska-dobecka, et al., 2020). Further, SO_2 can also cause acid rain and damage the foliage of plants (United States Environmental Protection Agency, 2019). Nevertheless, manufacturers of rockwool claims it to be harmless, except for that it can cause itching, in the product Safety Data Sheet. In the same document however, they recommend usage of protective clothing, good ventilation and avoiding dry sweeping, as well as stating the possibility of higher exposure level than the allowed limit and that problems with respiratory organs can appear etc. They also state that rockwool has no negative environmental impacts and that the product can be re-used (Rockwool, 2013),statements that are partly contradictive and debated in research (European Commission,2020; Kupczewska-dobecka, et al., 2020; Rockwool, 2013…).

Energy

Energy can be produced in multiple ways. Through non-renewable resources such as oil and coal or in renewable ways such as through hydropower and wind power. Whilst the firstly mentioned methods weigh heavy on the environment in forms of pollution and exploitation the latter have a lesser effect in that sense but do not come as clean as the power producers would like to admit either. In the Nordic countries the common power distribution, 'residualmixen', contains about 5,31% renewable sources, 48,17% nuclear power, and 46,52% non-renewable sources (2019) (Sweden Energy Market Inspectorate, 2020b) although many energy producers chose to provide a mix without non-renewable sources. The shares fluctuate slightly yearly. Figure 18 describes the CO_2 emissions from the least impactful sources of power.

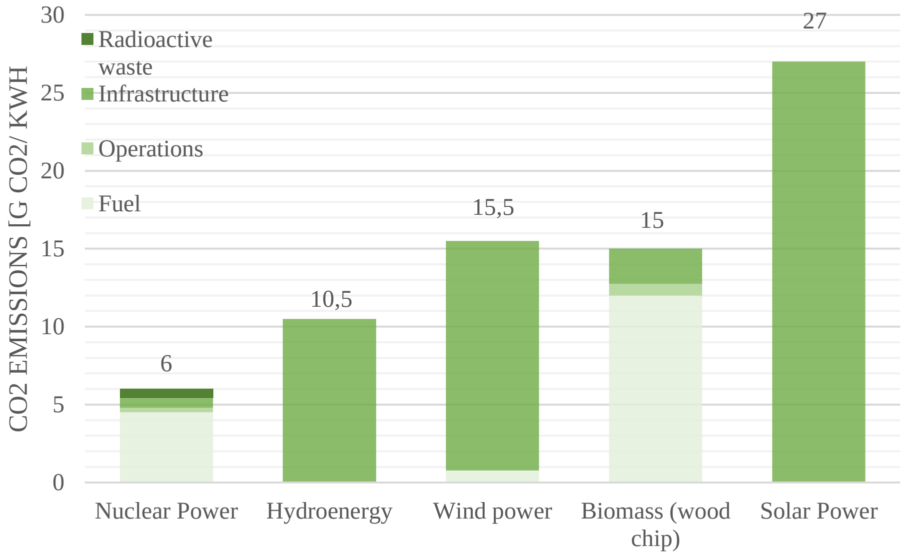

Figure 18 - CO_2 emissions from green sources. Source: Vattenfall, (2020), Vattenfall, (2018), Vattenfall, (2016)

To be noted is that ‘residualmixen’ has a much higher CO_2 footprint than the sources in Figure 18, due to its non-renewable sources, but neither renewable nor non-renewable sources are spotless, and all aspects cannot be portrayed in CO_2 emissions. A large Nordic power producer has investigated the loss of biotopes due to the establishment and exploitation of various power plants, nuclear, water and wind, which all show a decrease in critical and rare biotopes, hydropower is presented in Figure 19. The seizure of natural habitat toward technotope vary from 25-70%, 70% being seized to make way for wind power. In all cases critical biotope do not reach above 1%, likewise, for rare biotope with the exception of hydropower which is stated to have 8% rare biotope remaining (Vattenfall, 2020a; Vattenfall, 2018a; Vattenfall, 2016). It is the need for infrastructure to be built that pushes the loss of habitat and therefore also loss of biodiversity. Additionally, the fragmentation of the habitat caused by erecting structure at different locations, causes the movement and spread of fauna to be compromised.

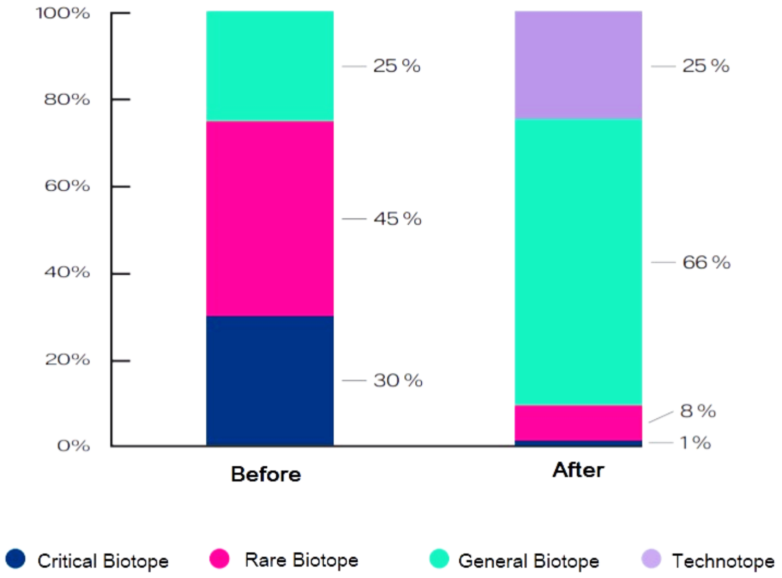

Figure 19 - Loss of biotope due to exploitation to make way for hydropower. Source: Vattenfall (2018b), p.5.

These are problems often associated with power plants; however, they are also linked with pollution due to the use of herbicides and dust repellents in solar power parks as well as the reflections causing damage to birds. In hydropower the water quality, upstream and downstream flows as well as mineral and sediment composition are changed and impact the surrounding fauna, sometimes dramatically. We rely heavily on ecosystem services provided by these biotopes and the loss of one can be devastating and hard to make amends.

Wind power is shown to have little effect on the fauna with the biggest risk being bat/bird-wind generator collisions. Nevertheless, none of the renewable power sources are directly linked to overexploitation however the effects of overexploitation can still emerge through these practices if not managed holistically. Renewable power sources are key to a sustainable future and greener economy, meaning that the problems discovered and faced must be solved and not overlooked in order to advance in the clean energy area (Gasparatos, et al., 2017).

3.1.6 Carbon dioxide footprint

The different alternate solutions: using the heat exchanger supported by either green power or a common power mix or only using either power sources will be compared in the coming section. The additional equipment needed to install the heat exchanger will also be considered. The aggregation of CO_2 emissions will result in a comparison of the GWP of the different and combined alternatives.

The heat exchanger can be presumed to be a two-meter-long arbitrary copper pipe with a wall thickness of 5mm, which would result in a weight of about 6 kg (copper material weight). Further, 35m of Ø54mm copper piping had to be installed in order for the heat exchanger to be functioning with an additional 40mm thick condensation insulation (rockwool). Additionally, 10m Ø160mm drainage pipe and a handful of valves and meters will also have to be installed. The above-mentioned materials, as well as the electricity productions CO_2 emissions or GWP can be seen in Table 5.

Table 5 - CO_2 emissions per material. Sources: Rockwool International A/S, 2019; European Copper Institute, 2012;OneClickLCA, 2020; Stucki, 2019; Sweden Energy Market Inspectorate, 2020b; Vattenfall, 2020.

Materials	**Weight**		**CO_2 per unit**		**Total CO2-footprint/ GWP**	
Copper	103	kg	2,4-3,3	kg/kg	340	kg
Rockwool	11	kg	2	kg/kg	8,3	kg
Polypropene	24,4	kg	6,3	kg/kg	154	kg
Power mix	18810	kWh/year	0,34	kg/kWh	6,4	kg/year
Green power	18810	kWh/year	0,007-0,009	kg/kWh	0,17	kg/year
Equipment						
Control valve	3	piece	41	kg/piece	123	kg
Shutter valve	2	piece	0,99	kg/piece	1,98	kg
Watermeter	1	piece	5,92	kg/piece	5,92	kg
				Total CO_2-emissions*	646	kg

*** for heat exchanger and installation, excl. power**

To estimate the GWP of the energy consumption the CO_2 emissions from the production of electrical power per kWh needs to be established. Due to the vast fluctuation in CO_2 emission from electricity manufacturing per year only an average estimation can be made. During the years 2005-2009 GHG emissions have fluctuated between 89-131 CO_2-eq /kWh (Martinsson, et al., 2012) but later numbers, calculated with a sounder method, *Issuance based method*, suggest Nordic electricity production (a mix of renewable and non-renewable electricity sources) can emit up to 500 CO_2 g/kWh, this number is based on mainly fossil fuels. Whilst most energy produced in Sweden is renewable, the energy used is based on a mix between mainly nuclear and renewable power (Sweden Energy Market Inspectorate, 2020b). The fluctuation in CO_2 emissions from the Nordic electricity production over time can be viewed in Figure 20.

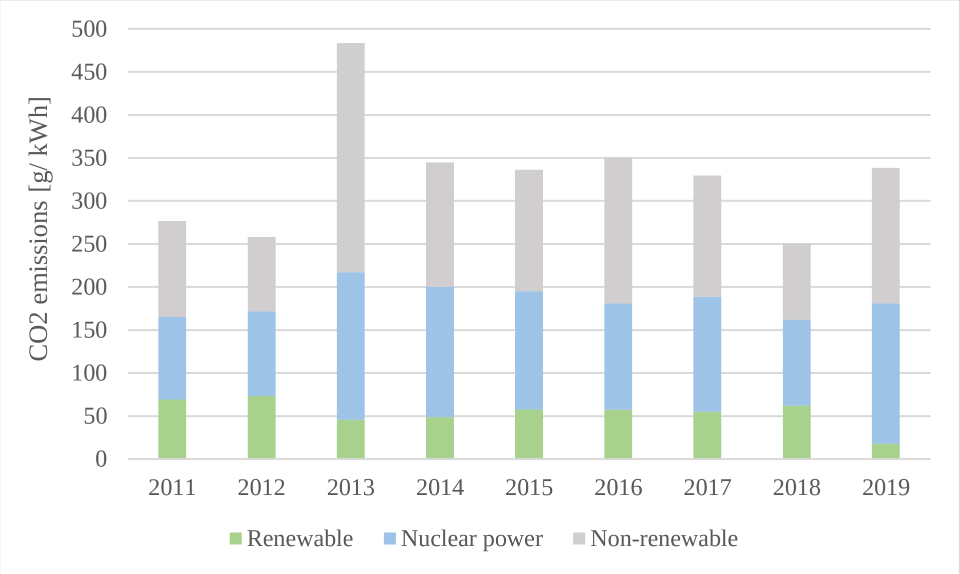

Figure 20 - Impact of Nordic electricity production in CO2 g /kWh and dependent on the percentage of renewable or non-renewable sources. Source: Sweden Energy Market Inspectorate (2020b)

The latest CO_2 g/kWh has been stated to be 338,52 CO_2 g/kWh in 2019 (Sweden Energy Market Inspectorate, 2020a). The mean over time becomes ~340 CO_2 g/kWh and will be used in further calculations.
In 2018 the emissions from the Swedish electricity and district heating were 4.9 Mt CO_2-eq or 8% of total GHG emissions in Sweden. Sweden makes electrical power mainly from water-, nuclear-, wind power and biofuels (Sweden's Environmental Protection Agency, 2019). In contrary, a type of green electricity mix, *BraMiljöval* (a sort of ecolabel), sold in Sweden is stated by the manufacturer to emit 7-9 CO_2 g/kWh, this is said to be including the impact of the whole life cycle (Vattenfall, 2020). Emissions per type of green energy can be seen in Figure 18 and strengthen the statement that green energy emit about 5-10 CO_2 g/kWh.

The CO_2 footprint is calculated simply through the emitted kg of CO_2, per kg material or kWh power, CO_2, multiplied by the weight of materials or energy consumption, W, see equation (9).

$$CO_2^{footprint} = W \cdot CO_2 \qquad (9)$$

The heat exchanger and its complementary equipment yield a certain CO_2 footprint which is predicted through the summarisation of the calculated CO_2 footprints from Table 5. The sum of CO_2 emissions, hence, become ~ 646 CO_2 kg. The manufacturers of the heat exchanger state a life span of 40 years, the predicted CO_2 emissions can thus be assumed to cover a 40-year period. During these 40 years, the additional $31°C$ required after the heat exchangers addition can be either powered by a common power mix or a green power mix. The question becomes whether only procuring green power, and not installing the heat exchanger, is more favourable i.e., emits less CO_2 emissions than the heat exchanger and any of the two sources of electrical power. The energy required to heat a year's consumption of water from an incoming $10°C$ to the legionella safe zone of $55°C$, using equation (8), with a green electricity mix would emit ~132– 169 CO_2 kg/ year. This would be an improvement of a reduction in CO_2 emission of about 97-98% in comparison to using a common power mix which emits close to ~6390 CO_2 kg/ year. Therefore, any alternative using a power source with a high degree of non-renewable sources, like coal, even in combination with a heat exchanger, is far to emission rich and there is no need for further inclusion.

The CO_2 footprint of green power only versus the heat exchanger and green power over a 40-year period can be viewed in Figure 19. Since the starting point of the heat exchanger plus a common power mix is higher than the endpoint of both green power and the heat exchanger plus green power, it will not be included in Figure 21 and the conclusion that green power only is a more sustainable option than to install a heat exchanger and heating the residual number of degrees using a common power mix.

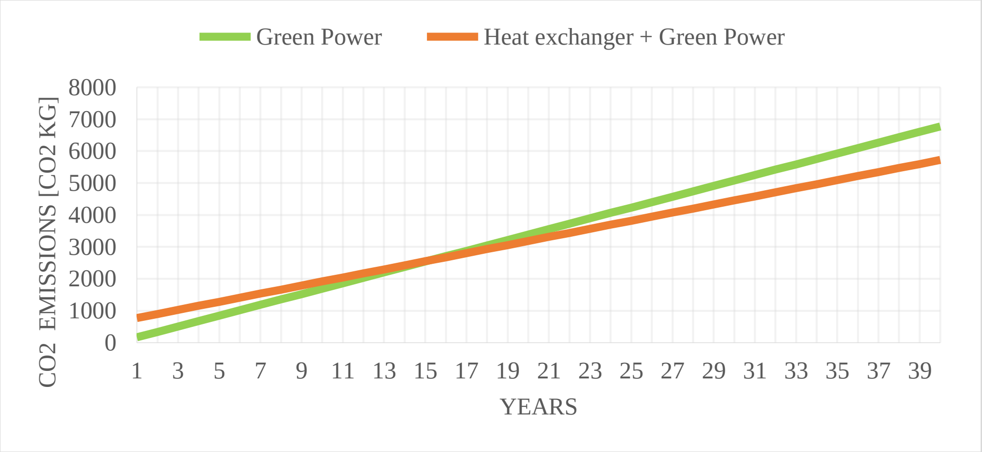

Figure 21 - GWP of Green power and Heat exchanger plus green power over the lifespan of the heat exchanger.

As the above figure shows using a heat exchanger and green power is slightly more favourable i.e., emits less CO_2 emissions. The difference between purely green power and a wastewater heat exchanger supported by green power during the lifespan of the heat exchanger is ~15%. The two alternatives intersect after ~ 15 years creating the payback time in terms of CO_2. 15 years is a substantial payback time, on the other hand, using the residual power mix instead gives a payback time in under one year, see Figure 22.

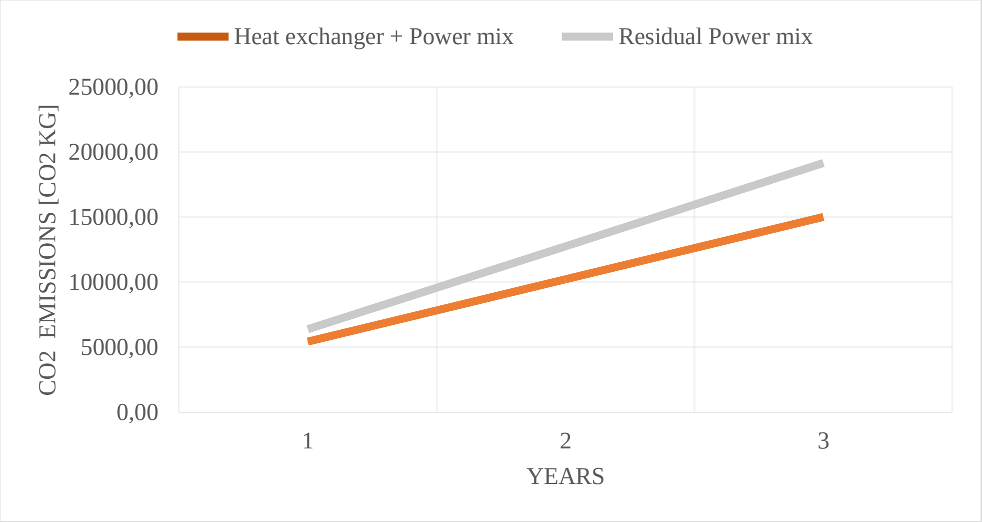

Figure 22 - CO_2 emissions from the residual power mix and heat exchanger.

Nevertheless the total CO_2 footprint from using the residual power mix is considerably larger, as can be seen by comparing Figure 22 to Figure 21.

3.1.7 Results

The results show that CO_2 emission-wise the alternative containing the wastewater heat exchanger supported by green power is the most beneficial with about a 15% lesser CO_2 footprint over a 40-year period. Any alternative using non-renewable power sources contributes to a vastly higher CO_2 footprint, nearly the double, making this non-viable even with a heat exchanger.

However, there are also other aspects to consider. For example, working conditions in production of the materials for the heat exchanger is poor in many countries. The heat exchanger itself is produced in Borås, Sweden and can be assumed to follow the Swedish regulations providing an adequate social standard of work and living. Anyhow, an EPD for the heat exchanger does not exist and therefore the above aggregation of material's EPDs will be the basis of analysis. In this case, the copper can be procured in Sweden along with the Rockwool and remaining materials can be procured from factories around Europe. This ensures adequate working conditions, at least on paper, and reduces transportation emissions.

Given that the above assumptions are true, the conclusion to the case study becomes that the most sustainable alternative is to install a wastewater heat exchanger and procure Nordic green power labelled with *BraMiljöval*.

3.2 Case study 2

This case study aims to investigate and compare whether the installation of heat exchangers with the purpose of recycling residual heat from the compressors generating compressed air are greater than other solutions such as e.g., sourcing only green energy which would otherwise have been simpler to design.

3.2.1 Introduction

The second case study revolves around the same project as the first case study, an industrial service centre for garbage trucks, undertaking e.g., oil-refills, the changing of tires, general service, and repairs of containers through welding, sandblasting and repainting etc. See more information in Section 3.1.1. The heat generated from the compressors while compressing air to be used in the paint booth, wash booth, and for sandblasting etc. shall be recycled and recirculated into the heating system of the building.

The system consists of two compressors which shall cover the need of the service centre. These have been fitted with heat exchangers in order to recycle and reuse the residual heat toward the hot water heating system of the building. The compressors achieve 7,5 bar respective 12 bar and are fitted with two heat exchangers, air management system and condensation averter tank (Cordic & Hansson, 2020). The installation and operations of the heat exchangers requires some extra equipment shown in Table 6.

3.2.2 Sustainability Assessment Method

The same BREEAM requirements apply to these measures as described in Section 3.1.2.

3.2.3 Energy Performance of the compressor heat exchanger

The heat exchangers are brazed plate heat exchangers and are stated by the manufacturer to be able to achieve a 76% hot water efficiency, and a payback time of ½-2 years (Wigert, 2020). The system works by directing the cold water and the residual hot air produced by the compressors into corrugated hollow plates. Commonly, every other plate carries the hot medium respective cold medium, allowing for a transfer of heat to take place. The structure of the plates allows for a larger amount of surface area on a smaller footprint, and create a turbulent flow, increasing the efficiency of the heat exchanger (WCR Sweden AB, u.d.).

Nearly all the energy generated by the compressors are converted into heat, 2-4% of the energy remain in the compressed air and 2% radiate into the surroundings, leaving 94% to be reused (Kaeser Compressors, 2014). Additionally, the use of an air management system can reduce energy demand by 6% per bar reduced (Kaeser Compressors AB, 2016).

The heat exchanger can according to the manufacturer's invoice recycle a maximum of 48kW of usable heating power (Wigert, 2020). However, the compressors are not always running at maximum power but can be approximated to run at an average of 30% of max power during working shifts. The compressors would then produce 20kW of power and are predicted to be used 16h hours a day, 5 days a week, 45 weeks a year, resulting in an energy consumption of 144 000 kWh/year. 76% of that, 109 440 kWh/year can be recycled as heat from the two heat exchangers, which would otherwise correspond to 36 580 kWh/year in electric power due to the characteristics of thermal heat. The hot water demand is calculated in Section 3.1.4 to be ~56 430 kWh/year which results in that the heat recovery from one of the heat exchangers for compressed air can amount to ~97% of the hot water demand per year. Nevertheless, the compressors are not in use constantly and do not recover any heat when not in use. Specifically, when hot water demand peaks, at the change of shifts, compressors are not at all in use (Cordic, 2021), which conclusively renders the heat recovery, at this point, invalid. Additionally, all recovered heat is not always directed directly toward the hot water system but parts, such as the energy surplus generated if both heat exchangers are running, can be directed towards recharging the geothermal borehole (Hansson, 2021) which contributes towards better efficiency in the late days of the boreholes life (Granryd, et al., 2013). Theoretically, if a balance between withdrawals and recharge of the borehole can be achieved the life expectancy can become infinite (Hansson, 2021). The recycled heat could also be directed towards the general heating demand of the building which can be withdrawn from Table 4 and is about 99 759 kWh/year. The recycled heat may well cover this expense with a surplus that could be pushed into the borehole.

3.2.4 Additional components of the plate heat exchanger

The heat exchangers require some additional components and piping etc. to be installed, see Table 6. The plate heat exchangers are mainly made out of stainless steel with copper soldering (Kaeser Compressors, 2014a). Information on the environmental profile of copper is described briefly in Section 3.1.5.

Stainless steel and Steel
Stainless steel is produced from either scrap materials or carbon and iron ore and is then smelted into a liquid either through the burning of coal or use of electricity (Norgate, et al., 2006). Nowadays smelting through the use of electricity is estimated to represents 80% of new stainless steel production. Stainless steel is also considered to be 100% recyclable and it is estimated that 85% of materials are being recycled (ISSF, 2019). After the smelting, the material is transferred to an argon-oxygen decarburization vessel (AOD vessel) which refines and reduces impurities in the material (Norgate, et al., 2006). The molten stainless steel is then cast into sheets or plates which can later be rolled etc. or cast into ingots which are made into e.g., wires (ISSF, 2019; SSINA, u.d.). The demand for stainless steel is constantly growing and to part, the availability of scrap materials curb the supply. It is estimated

that about 50% of recycled stainless steel is used in the production of new stainless steel (ISSF, 2019). The life cycle of stainless steel bare close resemblance to the life cycle of steel except for that the production of steel requires limestone as an input as well. The life cycle of stainless steel can be visualized in Figure 23. The main environmental impacts come from the mining and burning of iron ore which realises NO_x, CO_2, SO_2 and CO (carbon monoxide) into the atmosphere, soil, and water (ISSF, 2019). Likewise, both mining and smelting are very energy intensive. Like copper, iron ore is an ending resource thus supply and demand cannot continue to rise forever (Norgate, et al., 2006).

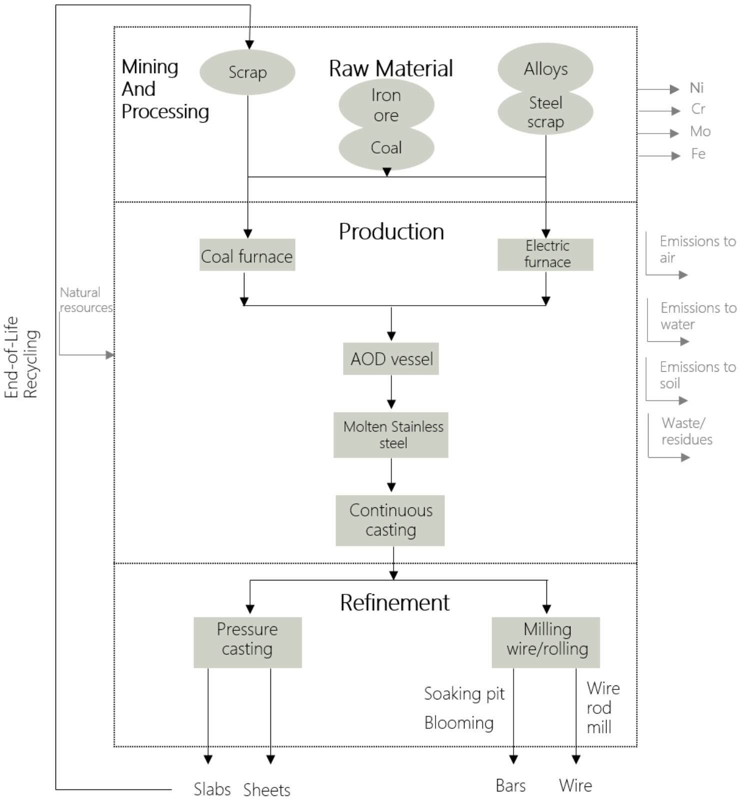

Figure 23 - Life cycle of Stainless Steel. Source: own, adapted from ISSF (2019), SSINA (u.d).

Valves

Valves come in many different types, designs and materials that each have their own environmental impacts. However, most valves have one thing in common, being that an improperly functioning or maintained valve can lead to leakages and even accidents which can have horrendous effects on both the environment and people alike. Faulty valves can leak which can increase the risk of toxins entering the environment or even explosions if certain gases are involved. This could lead to any kind of pollution and hazard, which is why valves need to be properly designed, produced, chosen, fitted, and maintained in order to avoid accidents (Stanley, 2019). The Norwegian EPD Foundation (2020) estimates a GWP, measured in CO_2 -eq, for valves, in general, to be about 14,7kg CO_2 / kg of valve from raw material to end-user shipping (The Norwegian EPD Foundation, 2020).

3.2.5 Carbon Dioxide footprint

A comparison between the CO$_2$ footprint of the plate heat exchanger with all additional equipment, a common power mix (part non- and renewable resource) and green power as well as the combination of the two needs to be made to evaluate the impacts of all alternatives.

The plate heat exchanger can be presumed to be a made mostly out of stainless steel with copper soldering, the product is estimated to weigh 9,5kg. A further, 60m of *Ø*50mm steel piping had to be installed in order for the heat exchanger to be functioning with an additional 80mm thick condensation insulation (Rockwool). Additionally, a handful of valves and meters will also be installed along with other equipment. The above-mentioned materials and equipment, as well as the electricity productions CO$_2$ emissions can be seen in Table 6.

Table 6 - CO$_2$ emissions per material. Sources: OneClickLCA, 2020; Norwegian EPD Foundation (2020), *Rockwool International A/S, 2019; Sweden Energy Market Inspectorate, 2020b; Vattenfall, 2020.*

Product/materials	**Weight**		**CO$_2$ per unit**		**Total CO2-footprint/ GWP**	
Steel pipes	73	kg	1,83	kg/kg	133	kg
Rockwool	68,6	kg	2	kg/kg	20,5	kg
Power mix	18240	kWh/year	0,34	kg/kWh	6	kg/year
Green power	18240	kWh/year	0,007-0,009	kg/kWh	161	kg/year
Equipment						
Plate heat exchanger	2x9,5	kg	16,4	kg/piece	312	kg
Control valve	6	Pieces	41	kg/piece	246	kg
Shutter valve	12	Pieces	0,99	kg/piece	11,9	kg
Energy-meter	1	Piece	5,92	kg/piece	5,9	kg
Reflux valve	5	Pieces	13	kg/piece	65	kg
Safety valve	9	Pieces	0,99	kg/piece	8,9	kg
Distributor valve	4	Pieces	52	kg/piece	208	kg
Pump	3	Pieces	640	kg/piece	1920	kg
Temperature sensor	10	Pieces	3	kg/piece	30	kg
Thermometer	9	Pieces	2,5	kg/piece	22,5	kg
Accumulator tank	97,7	kg	16,4	kg/piece	1600	kg
				Total CO$_2$-emissions*	4700	kg

*** for heat exchanger, excl power usage.**

Note, there is a huge difference in available EPDs and other sources stating the CO$_2$ emissions per products or materials, e.g. The Norwegian EPD Foundation (2020) states in one of their EPDs that one kg of any valve, in general, have on average a CO$_2$ footprint of 14,7 kg CO$_2$ -eq, whilst sources like OneClickLCA (2020) specify many valves to have an impact of around 40-50 kg CO2 -eq/ piece, a vast difference. The same goes for most other stated objects.

The same methods are used in this Section as in Section 3.1.6, and Equation 9 is the base of calculations.

Since the heat recovery from the compressors is pure surplus, in the sense that no further power needs to be added to it in order for any function of the service centre to work, the GWP of the plate heat exchangers will be compared to the GWP of the possible energy savings. Likewise, as in Section 3.1.6, any alternative including non-renewable sources will not be featured as the GWP is simply far greater than for green alternatives. The GWP over time is presented in Figure 24.

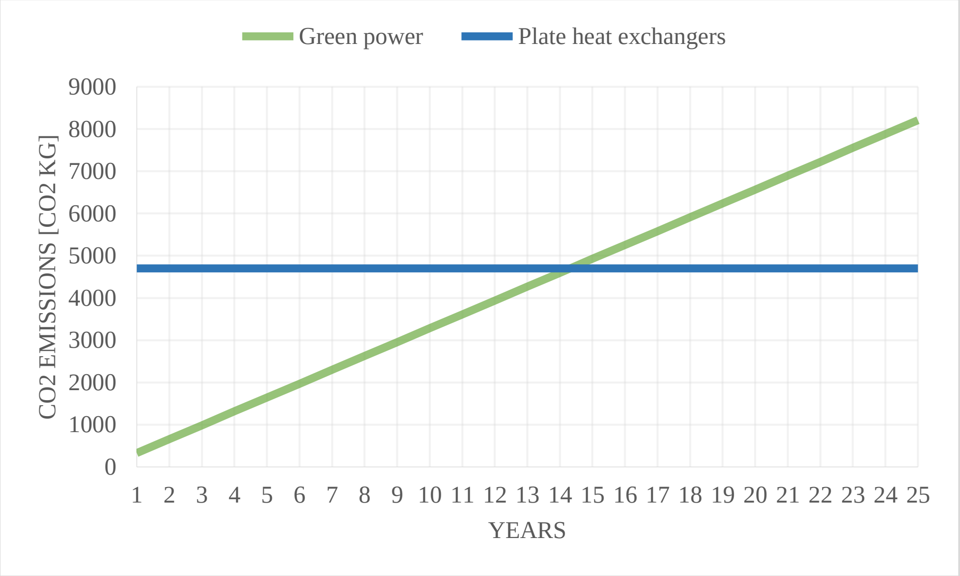

Figure 24 - GWP of green power and Plate heat exchangers.

The payback time CO_2 footprint-wise is just beyond 14 years. Alternatives using the residual power mix have a payback time of under a year but also has a considerably larger CO_2 footprint.

3.2.6 Results

The results show that the plate heat exchanger will have a higher CO_2 footprint up until 14 years when green power surpasses its CO_2 footprint. Any alternative using non-renewable power sources contributes to a vastly higher CO_2 footprint, making this non-viable even with a plate heat exchanger.

However, there are also social aspects to consider. Working conditions to produce the materials for the equipment needed is poor in many countries. Whilst much of the smaller equipment like pumps and valves have been sourced from Swedish manufacturers, the raw materials may still be produced with lacking health and safety standards around the world. The plate heat exchanger is produced in Germany and can be assumed to follow the EU regulations providing an adequate social standard of work and living. Anyhow, an EPD for the heat exchanger does not exist and therefore the above aggregation of materials’ EPDs will be the basis of analysis. Likewise, as in case study 1, copper can be procured in Sweden along with the Rockwool and remaining materials can be procured from factories around Europe. This most likely ensures adequate working conditions, at least on paper, and reduces transportation emissions. However, it may be unlikely that all raw materials originate in Europe and therefore no conclusions can be drawn on social aspects of the origins of the materials.

4 Discussion

Can one put a price on CO_2 emissions? What decides the price on different objects? Perhaps it is difficult to accurately portray the effects of CO_2 emissions in monetary value, but if done, CO_2 emissions should be a pricey commodity. Monetary value on CO_2 is already set through the taxation of emissions in Sweden. However, due to the lacking sustainability mindset, education and/or heavy dependencies of some countries on e.g., fossil fuels, such an act as taxation on emissions would seem impossible. Additionally, all aspects from the TBL are not portrayed in the value of GWP, social aspects such as working conditions are hard to evaluate and differ greatly from nation to nation, even factory to factory as elaborated on by GreenSpec® (2020) and in The Earth's Riches (2019). Nevertheless, global CO_2 emissions must decrease, and it is not up to a single country, instead all countries must act together. As the two case studies indicate, SAMs are a step in the right direction. The GWP of each material or equipment has been chosen within a large spectrum of EPDs, all stating different CO_2 emission due to manufacturers' different calculation methods and practices. For the purpose of these case studies, a larger GWP has been chosen rather than a lower in order to be closer to the worst-case scenario than the best-case. However, this has not changed the results which still show that these measures taken toward a lesser energy consumption are still favourable and beneficial.

Are payback times upward of 15 years, within industry, viable? Can it be assumed that monetary payback times and environmental payback times cannot be compared? It would not be far-fetched to assume that they could not in fact be compared as the two bears little resemblance to one another and are not based on the same values or objectives. Capital is most often a number in a bank account, an asset only viable in the social system. Even if it may impact people's lives greatly it does not go beyond the societal system such as natural capital does. The ability of monetary capital to have direct consequences for people (providing the individual with security, prosperity, and freedom) is what gives it the upper hand, the higher prioritisation, historically and still. It is also a concept that people are accustomed to and have knowledge about. Everyone knows what consequences having no money has, but few know what consequences destroyed ecosystem services or other natural capital has. If the climate changes continue, and they will if change does not come soon, these consequences will make themselves known.

The longer payback time for environmental investments may be well adjusted to the slow rebound of the planet. Yet, again, as asked in beginning of this thesis, the question is if natural capital can really be exchanged in similar ways to monetary capital? Let us say a whole lot of entities made large investments, with high initial carbon emissions at the same time. The payback time would not really matter in this instance as the earth's resources or climate may not suffice or bare that spike in emissions all at ones. The traditional mindset surrounding 'payback' is not viable in the natural capital sense. Even if long payback times can be viewed as a symbol of that earth recovers slowly (and only during the right circumstances) and encourage investors to be more mindful when using natural resources, it is not a sustainable mindset.

There is still a possibility that some measures induced by SAMs are not beneficial, even if the project's or building's total environmental impact may still be positive. SAMs are a small piece in the big puzzle of creating a more sustainable world, yet still one step in the right direction. What lies ahead is to further systemize and research which SI have the greatest climatic effect and the true environmental effect of the buildings certified. SAMs need to clarify the actual environmental effects of the SIs and what the SIs are based on. Can SIs even be based on something since the building's performance in operations and subsequently the environmental impact that it comes to have cannot be measured accurately? Further, ISO 14044 describes the weighting used in some SAMs as "not being scientifically based but rather as a value-choice process, and therefore should not be used in comparative assertions disclosed to the public". This suggests that the prioritisation methods of some SAMs needs to change toward a more scientific and measurable method.

The UNs 17 SDGs address some of the questions surrounding how to impact the planet positively and how these actions should be measured. BREEAM and LEED openly state that they do work towards many, in fact almost all of the SDGs (if also considering indirect and what could be perceived as farfetched measures). BREEAMS assessment can be seen in Appendix 1.1 and a general list of goals and targets affected by SAMs can be viewed in Appendix 1.2. Overall, SAMs affect Goal 11 and 12 the most and it is perhaps these goals they have their origin in. No entity can effectively affect all goals and therefore to claim that that they affect most of them is just exaggerated and unnecessary, instead focus on the ones where the largest impact can be made and work on improving the SIs in line with the SDGs. The most important SDGs for Sweden out of UNs goals have been stated in Section 2.3.1 to be, goals 4, 7, 10, 12, 13 and 14, with a selection of specific targets. The only targets that align between the SAMs and Sweden's priorities are target 11.2, 11.4, and 11.5. These address responsible consumption, the management of hazardous substances and waste prevention. Whilst the other goals that do not align addresses e.g., life below water and reduced inequalities, aspects where SAMs have little to no direct effect.

A lot of SAMs work continuously with improving the SIs generally and toward aiding the SDGs. The authorities behind the SAMs, USGBC and BRE for example work with and promote research into Green Buildings and sustainability. Nevertheless, there is still need for further efforts to be put into analysing the performance of currently certified buildings and how the SIs affect the environment, as well as research into future solutions and improvements in order to get the SAMs to be more adjustable and accurate.

It is commonly said that every building and construction project is unique, therefore it may not be surprising that creating SAMs that can be applied to all construction projects is difficult. The hardship lies, partly, in that most SAMs do not adjust to project-specific characteristics like size, location, and type of activities meant to be undertaken when in operation. This lack of adjustment leads to that some SIs have been perceived as extreme, useless and to not make a difference. When this occurs project team efforts may become bleak, unwilling, and non-understanding and all in all leads to frustration. Some of these measures, such as measuring water runoffs from all surfaces may cost more than it yields as meters should be fitted to every possible area where water is present even though the contribution to the data is minuscule the cost of the equipment is higher than the savings that it contributes to. Although these are small parts of the bigger picture, they create frustration and impact the trustworthiness of the SAMs. Another example is the requirement to measure the presence of substances. A project in an urban area has the same requirements as a project in a rural, natural area. In a metropolitan area, pollutants can be measured e.g., on roofs, facades and in ventilation and water but in natural areas these substances would be very low, if present at all, and the equipment and work needed to fulfil this requirement is likely more detrimental to the environment than possible rewards. A manager at the commissioning company commented this with *"are we supposed to measure the amount of bird poop we get on the roof?",* which rather amusingly depicts the concern for the application of some of the SIs.

Certifying buildings have the potential to reduce costs, e.g., costs related to energy, water consumption waste as well as environmental costs. The long-term savings could be anywhere from 6-30% according to an array of different research. However, certifying does not equal capital savings and the earlier a SAM is incorporated into the building design the better the odds of keeping short-term costs down and increasing long-term savings. Overall, most studies show that short-term costs increase whilst long-term costs decrease. However, putting less emphasis on the economic capital and instead incorporate and increase the value in natural capital i.e., green buildings and a lesser environmental effect, would benefit the whole world and will likely yield higher monetary returns in time as pollution and emission rates are increasingly being taxed. Making natural capital equal, or ideally more valuable than monetary capital is a measure that should be aimed for in the future. As for now certifying buildings maybe seen more as a competitive advantage or even a reputation elevator rather than an economic investment, even if there is potential for that as well. Certified buildings can in some cases claim higher rents and be more attractive for prospective clients and buyers.

Albeit the trend in SAMs, the number of certified buildings per year is decelerating (see Figure 14 on the older and more established SAMs, LEED and BREEAM). However, about 5 years after the market introduction of BREEAM and LEED they had heavy increases in the number of certified buildings per year for about 7 years, after which they started to slow down and normalise. Will Miljöbyggnad follow this trend? Likewise, Miljöbyggnad saw a rapid increase in certified buildings 5-7 years after its launch and the tangent is still steep, but will it start to slow down in the coming years? Is it possible that digitalisation and new technologies will decrease the advancement sooner or let it live longer due to updates etc.?

SAMs are essentially a tool for louring the industry into more sustainable ways through enticing them with the prize of certification. SAMs would not be as necessary if companies or clients would want to make the changes and be more sustainable on their own behalf. Additionally, a large benefit of the SAMs is that the work of identifying which SIs to use has already been done, having that said the hope lies in the accuracy and effectiveness of the SIs and the knowledge of the people behind them.

In order for SAMs to thrive the benefits need to be realised and tangible, such as capital cost savings and a lower environmental impact. Significant energy savings can be made through the implementation of SAMs and SIs, however the greatest effect occurs, as concluded through case study 1 when this is paired with the use of a green energy source. The monetary gain is present but not as significant as the reduction of the carbon dioxide footprint as energy is fairly cheap but the CO_2 emissions from fossil fuels are much greater than that of green and renewable energy.

Regarding the future of the world and its sustainability, something needs to be done, it needs to be done now and it needs to be extensive. The sustainability problem needs to be attacked from a larger perspective, not just through a reduction in CO_2 emissions in buildings or specific industries. Not only should all possible energy be used to its fullest through recycling etc. but so should water and other resources. There is no need to flush our toilets with high-quality drinking water, and some water treatment could be done in the home before the water goes to the water treatment plant, increasing its usability rate. Highly processed (energy-intensive) and high-quality water should be reserved for uses where it is strictly necessary. Letting energy escape is a lost opportunity.

In a larger perspective, the swap to a separated wastewater and stormwater system is beneficial but costly and time-consuming, however, this should be considered for the development of new urban areas, and in the meantime, stormwater needs to be handled through storm water beds and other mechanisms to utilize and manage it. These measures will increase water treatment facilities capacity, save energy, and promote a more sustainable society.

The concretization of SAMs can among many other things, be done through the use of monitoring technology and data collection, software like ARC (mentioned in Section 2.4). Digital Platforms measuring and tracking the building's performance should be standard, in that way the data can show whether or not enough water and energy etc. is being saved to actually make a difference on climate change. It can also be used to benchmark what SAM grades should require, as well as being real-life references instead of computer-generated models, as these do not accurately portray a building over time. Additionally, giving the residents access to this information can affect their actions and in turn, change their behaviour towards consuming less energy and water. These are factors that can be predicted fairly accurately whilst improvements in resident/employee performance and well-being, which studies claim also benefit from green buildings is a less easily predicted result, this topic is subject to the need of further research.

Concludingly, great prospects lay in strengthening the notion of that SAMs are beneficial both environmental-wise and monetarily and research is underway with achieving this. However, research is not always enough, and larger, comprehensive measures need to be taken in order for society to change its mindset into a more educated and sustainable one, where natural capital is valued equal to monetary capital. Strategies for what measures can be allowed to be emission rich and which cannot, and how these emissions will be distributed and handled, need to be made. No easy feat, but a necessary one and one that requires cooperation worldwide.

5 Conclusion

There is no straightforward solution for all SAMs or all projects wishing to certify to any of these. The literature review and case studies imply that in general SAMs contribute to buildings keeping a higher sustainability standard and a lesser impact on the environment. The lesser impact comes through reductions in energy use, smarter material choices leading to less CO_2 released into the atmosphere and a healthier built environment with less hazardous materials and emissions. Resources like power and water consumption are managed more carefully as well. Within projects however, there can be small exceptions where measures taken to adhere to minor targets will have a larger impact due to additional material use than the contribution yielded by the target prerequisites themselves. In these cases, a solution could be for the SAM representative to be able to make or approve minor deviations from the SI where these are deemed to not contribute to the whole picture. For instance, not to measure water consumption or runoffs from surfaces that are deemed negligible as the equipment (e.g., water meters etc.) have a larger CO_2 footprint than the returns of the measure.

It will still be important for the SAMs to not go too far in their requirements as capital yield (or at least not loss of capital long-term) is probably still a driving force for clients. This can not only be done through direct capital profit but through raising the reputation of certified buildings and SAMs as well as gaining attraction of green building from tenants and buyers.

Additionally, most SAMs affect the UNs SDGs, mostly through goal 11 and 12. There is not much use in SAMs trying to state their impact in all 11 of UNs goals, the greater benefit lies in improving and perfecting the SIs where they can influence most directly and with the largest impact.

Regarding the case studies, the results are not conclusive but rather a vague indicator toward energy saving solutions for a more sustainable practice, a first step into the “natural step” (Figure 4) that is practices within the realm of sustainability. The case studies imply that energy saving measures through heat exchangers are beneficial. Nevertheless, payback times are long and may not even be representable of the environmental impact inflicted by the measures. They can very well remain a net negative for the environment even once the payback time has passed. However small the benefits are at present, if they are invested in, they will advance along with science, improve, and develop new ways to become more efficient and beneficial.

Therefore, the concluding remark is; certifying a building does not guarantee a sustainable building but research indicates both long-term capital cost savings and lowered CO_2 emissions. Certain SIs may not live up to their full potential in every construction scenario as the SAMs are not adjusted for specific characteristics of each project. In certain scenarios it is therefore likely that the environmental cost of material use and equipment is larger than that of their relative yield. A thorough investigation into the environmental impacts over time of the prospected building should be done, e.g., through LCA, EPDs, sustainability indexing and energy modelling. Collecting enough data on the environmental impacts and sustainability of buildings after certification will both create benchmarking for the SAMs to be based on and could prove the benefits with specific SAMs which would be a huge incentive for developers to certify.

5.1 Sources of error

The CO_2 emissions have been highly arbitrary as every product and manufacturer produces a different footprint and even then, those footprints are at best calculations based on estimations as well. In some cases where product EPDs have not been available the footprint of the main material has been calculated and used in its place, which will adamantly result in a divergence from the truth.

Transportation and recycling possibilities have a great impact on many products and have the greatest differentiation between manufacturers. This renders the case study results partly inconclusive as the specific products used in the project have no EPDs and therefore the CO_2 footprint is not accurate to the truth.

Additionally, the calculations made both by the consultancy and in this thesis are based on estimations and can therefore also vary from the true numbers once the project is finished. Additionally, temperatures and flows etc. are not constant in reality as they are in the calculations and will fluctuate over time. However, the result presented in the case studies, that energy-saving methods are beneficial, still stands. Although, there remains a suspicion that some SAM induced measures may still be unfavourable dependent on the specific project characteristics is still unanswered.

More research and work towards mapping the GWP in the supply chain all the way, cradle-to-grave (including recycling), creating easily available and trustworthy EPDs are essential.

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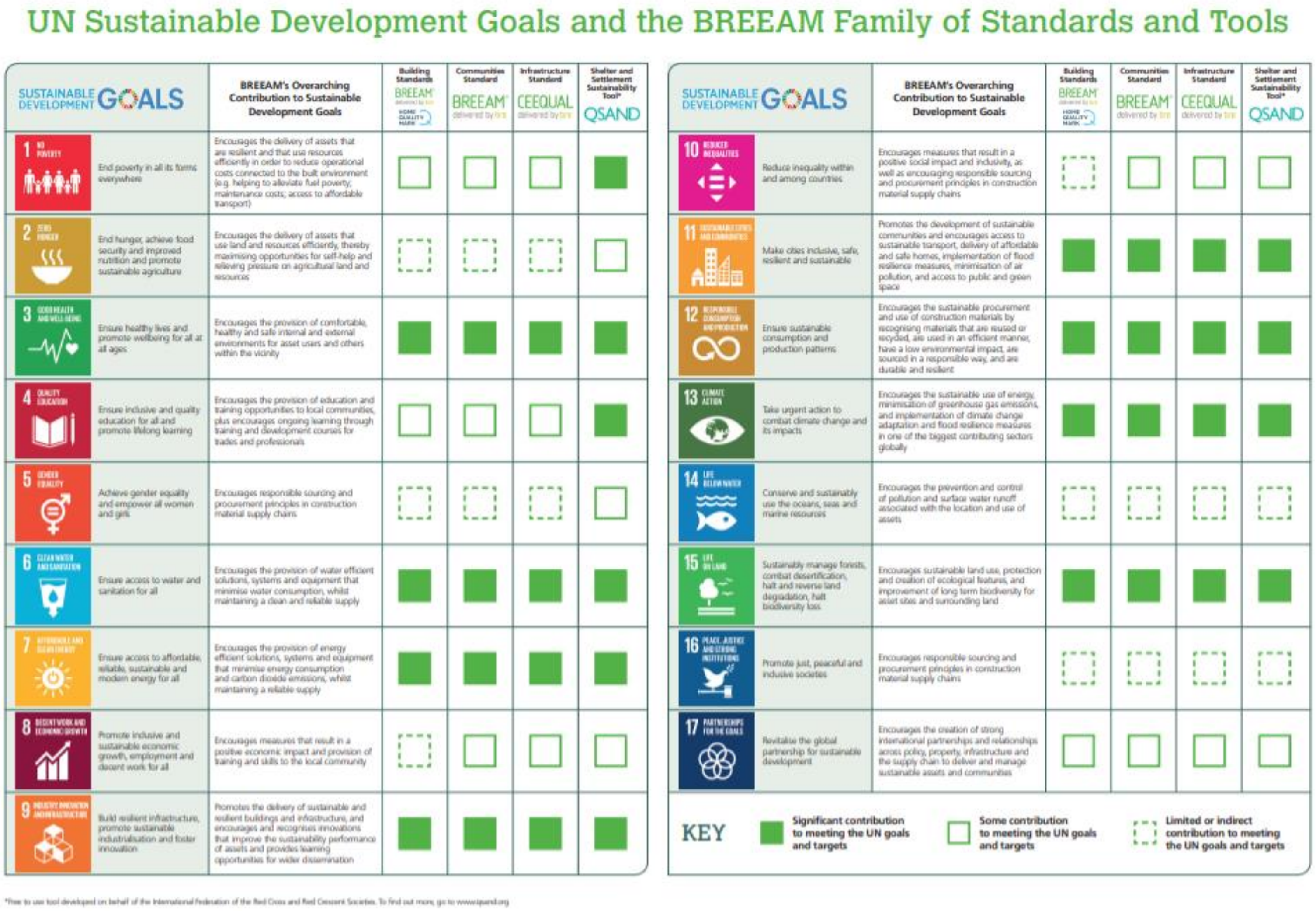
Appendix

Appendix 1.1 – BREEAMs assessment of affected Sustainable development goals.



UN Sustainable Development Goals and the BREEAM Family of Standards and Tools

SUSTAINABLE DEVELOPMENT GOALS		BREEAM's Overarching Contribution to Sustainable Development Goals	Building Standards BREEAM HOME QUALITY MARK	Communities Standard BREEAM delivered by bre	Infrastructure Standard CEEQUAL delivered by bre	Shelter and Settlement Sustainability Tool* QSAND
1 NO POVERTY	End poverty in all its forms everywhere	Encourages the delivery of assets that are resilient and that use resources efficiently in order to reduce operational costs connected to the built environment (e.g. helping to alleviate fuel poverty; maintenance costs; access to affordable transport)	☐	☐	☐	🟩
2 ZERO HUNGER	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Encourages the delivery of assets that use land and resources efficiently, thereby maximising opportunities for self-help and relieving pressure on agricultural land and resources	⬚	⬚	⬚	☐
3 GOOD HEALTH AND WELL-BEING	Ensure healthy lives and promote wellbeing for all at all ages	Encourages the provision of comfortable, healthy and safe internal and external environments for asset users and others within the vicinity	🟩	🟩	🟩	🟩
4 QUALITY EDUCATION	Ensure inclusive and quality education for all and promote lifelong learning	Encourages the provision of education and training opportunities to local communities, plus encourages ongoing learning through training and development courses for trades and professionals	☐	☐	☐	🟩
5 GENDER EQUALITY	Achieve gender equality and empower all women and girls	Encourages responsible sourcing and procurement principles in construction material supply chains	⬚	⬚	⬚	☐
6 CLEAN WATER AND SANITATION	Ensure access to water and sanitation for all	Encourages the provision of water efficient solutions, systems and equipment that minimise water consumption, whilst maintaining a clean and reliable supply	🟩	🟩	🟩	🟩
7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all	Encourages the provision of energy efficient solutions, systems and equipment that minimise energy consumption and carbon dioxide emissions, whilst maintaining a reliable supply	🟩	🟩	🟩	🟩
8 DECENT WORK AND ECONOMIC GROWTH	Promote inclusive and sustainable economic growth, employment and decent work for all	Encourages measures that result in a positive economic impact and provision of training and skills to the local community	⬚	☐	☐	☐
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote sustainable industrialisation and foster innovation	Promotes the delivery of sustainable and resilient buildings and infrastructure, and encourages and recognises innovations that improve the sustainability performance of assets and provides learning opportunities for wider dissemination	🟩	🟩	🟩	🟩
10 REDUCED INEQUALITIES	Reduce inequality within and among countries	Encourages measures that result in a positive social impact and inclusivity, as well as encouraging responsible sourcing and procurement principles in construction material supply chains	⬚	☐	☐	☐
11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities inclusive, safe, resilient and sustainable	Promotes the development of sustainable communities and encourages access to sustainable transport, delivery of affordable and safe homes, implementation of flood resilience measures, minimisation of air pollution, and access to public and green space	🟩	🟩	🟩	🟩
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns	Encourages the sustainable procurement and use of construction materials by recognising materials that are reused or recycled, are used in an efficient manner, have a low environmental impact, are sourced in a responsible way, and are durable and resilient	🟩	🟩	🟩	🟩
13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts	Encourages the sustainable use of energy, minimisation of greenhouse gas emissions, and implementation of climate change adaptation and flood resilience measures in one of the biggest contributing sectors globally	🟩	🟩	🟩	🟩
14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources	Encourages the prevention and control of pollution and surface water runoff associated with the location and use of assets	⬚	⬚	⬚	⬚
15 LIFE ON LAND	Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss	Encourages sustainable land use, protection and creation of ecological features, and improvement of long term biodiversity for asset sites and surrounding land	🟩	🟩	🟩	🟩
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Promote just, peaceful and inclusive societies	Encourages responsible sourcing and procurement principles in construction material supply chains	⬚	⬚	⬚	⬚
17 PARTNERSHIPS FOR THE GOALS	Revitalise the global partnership for sustainable development	Encourages the creation of strong international partnerships and relationships across policy, property, infrastructure and the supply chain to deliver and manage sustainable assets and communities	☐	☐	☐	☐

KEY

- 🟩 Significant contribution to meeting the UN goals and targets
- ☐ Some contribution to meeting the UN goals and targets
- ⬚ Limited or indirect contribution to meeting the UN goals and targets

*Free to use tool developed on behalf of the International Federation of the Red Cross and Red Crescent Societies. To find out more, go to www.qsand.org

Appendix 1.2 – Sustainable development goals and targets generally affected by Sustainability Assessment Methods

Removing the goals and targets where it is not very clear how SAMs can contribute results in the following list:

- Goal 3 – Ensure healthy lives and promote well-being for all ages.
  - Target 3.9 *"By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination."*
- Goal 6 – Ensure availability and sustainable management of water and sanitation for all.
  - Target 6.3 *"By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally."*
  - Target 6.4 "*By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity."*
  - Target 6.5 "*By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate."*

- Goal 7 – Ensure healthy lives and promote well-being for all ages.
  - Target 7.2 *"By 2030, increase substantially the share of renewable energy in the global energy mix."*
  - Target 7.3 *"By 2030, double the global rate of improvement in energy efficiency."*

- Goal 8 – Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

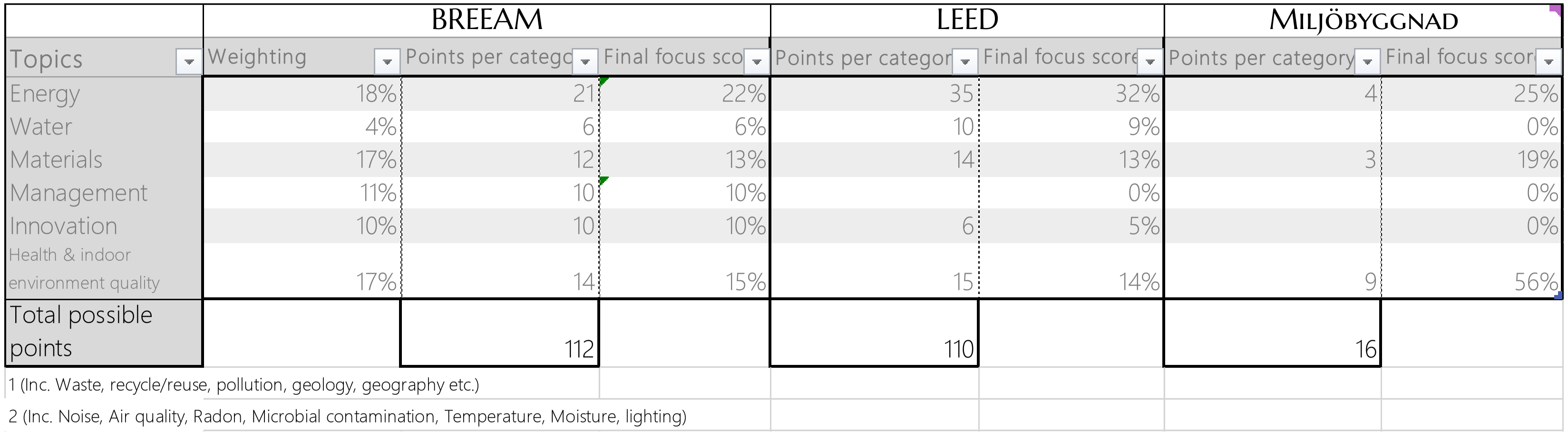
  - Target 8.4*“Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead.”*
  - *Target 8.7 “Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, including recruitment and use of child soldiers, and by 2025 end child labour in all its forms.”*
- Goal 11 – Make cities and human settlements inclusive, safe, resilient, and sustainable.

  - Target 11.3 *“By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.”*
  - *Target 11.6 “By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.”*
  - Target 11.a *“Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning.”*
  - Target 11.b *“By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.”*
  - Target 11.c *“Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.”*

- Goal 13 – Take urgent action to combat climate change and its impacts.

  Target 13.3 *“Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.”*

Appendix 1.3 – Thematic content calculations for BREEAM, LEED and Miljöbyggnad



	BREEAM			LEED		Miljöbyggnad	
Topics	Weighting	Points per catego	Final focus sco	Points per categor	Final focus score	Points per category	Final focus scor
Energy	18%	21	22%	35	32%	4	25%
Water	4%	6	6%	10	9%		0%
Materials	17%	12	13%	14	13%	3	19%
Management	11%	10	10%		0%		0%
Innovation	10%	10	10%	6	5%		0%
Health & indoor environment quality	17%	14	15%	15	14%	9	56%
Total possible points		112		110		16	

1 (Inc. Waste, recycle/reuse, pollution, geology, geography etc.)

2 (Inc. Noise, Air quality, Radon, Microbial contamination, Temperature, Moisture, lighting)

Appendix 1.4 Full calculations for case study 1 and 2

All Inputs:

Showers: 20
Work shifts: 2/per day, 8h/shift, 5 days / week, 45 weeks/ year
Shower time: 2x 30min

$t\ -\ Time\ in\ use\ [\ s/year]$

$T_c - Temperature\ inbound\ cold\ water\ [°C]$
$T_h\ -\ Temperature\ hot\ water\ [°C]$
$T_w\ -\ Temperature\ wastewater\ \ [°C]$
$V_t - Shower\ tap\ waterflow[l/s]$
$V_c\ -\ Cold\ water\ flow\ [l/s]$
$V_h\ -\ Hot\ water\ flow\ [l/s]$
$V_w\ -\ wastewater\ flow\ [l/s]$
E_h- Energy consumption without heat exchanger [kWh/ year]
E_w- Energy consumption with heat exchanger [kWh/ year]
E_{ws}- Energy savings with heat exchanger [kWh/year]
m - Mass of water [l, kg]
$c_{pw}\ -\ Water's\ specific\ heat\ capacity\ [kJ/(kg \cdot K)]$

$\Delta T\ -\ Temperature\ difference\ [K]$
W – product weight [kg]
y – years in use [years]
$CO_2gp\ -\ green\ power\ footprint\ [kg\ CO_2/kg\ ]$
$CO_2w\ -\ heat\ exchanger\ footprint\ [kg\ CO_2/kg\ ]$

Calculations

Case Study 1 – Wastewater Heat exchanger

Step 1: Flows of different temperature water.

Aided by known dependencies. We have a continuous hot water flow.
Temperatures are set and known. Physical aspects known.

Input:

$Showers\ =\ 20$
$V_t = 0{,}1\ l/s$
$T_h = 55°C$
$T_c = 10°\mathrm{C}$
$T_t =\ 40°\mathrm{C}$

$$V_w = showers \cdot\ V_t\ \rightarrow 20 \cdot 0{,}1 = 2\ l/s$$

Wastewater flow: $V_w = 2\ l/s$

$$V_c + V_h\ = V_w$$
$$T_cV_c + T_hV_h = T_wV_w = T_w(V_c + V_h)$$
$$10V_c \cdot 55V_h = 40(V_c + V_h) = 55V_h - 40V_h = 15V_h = 40V_c - 10V_c = 30V_c$$
$$V_h = \frac{30}{15} \cdot V_c = 2V_c$$
$$V_c + V_h\ \ = V_w = 2 = 3V_c$$

$$V_c = \frac{2}{3} = 0{,}666 \ldots\ l/s \qquad V_h = 2 \cdot \frac{2}{3} = \frac{4}{3} = 1{,}333\ldots l/s$$

$Cold\ water\ flow:\ V_c = 0{,}666\ l/s$

$Hot\ water\ flow: V_h = 1{,}333\ l/s$

Step 2: Energy consumptions.

Flows known, physical aspects known, efficiency of wastewater heat exchanger known.

$\eta = 25\%$
$V_c = 0{,}666\ l/s$
$V_h = 1{,}333\ l/s$
$V_w = 2\ l/s$

$$2 \cdot 0{,}5 \cdot 5 \cdot 45 = 225\ h/year = 225 \cdot 60 \cdot 60 = 810\ 000\ s/year$$

Time in use: t = 810 000 s/year

Energy consumption without heat exchanger

$$E_h = \frac{m \cdot c_{pw} \cdot \Delta T}{3600} = \frac{t \cdot V_h \cdot c_{pw} \cdot \Delta T}{3600}$$

$$E_h = \frac{0{,}81 \cdot 10^6 \cdot 1{,}33 \cdot 4{,}18 \cdot (55-10)}{3600} = 56\ 430\ kWh/year$$

Energy consumption without heat exchanger: E_h = 56 430 kWh/ year

Energy consumption with heat exchanger

Wastewater heat exchanger energy saving = E_{ws}

$$E_{ws} = \frac{t \cdot V_w \cdot c_{pw} \cdot \Delta T}{3600} \cdot \eta = \frac{0{,}81 \cdot 10^6 \cdot 2 \cdot 4{,}18 \cdot (40-10)}{3600} \cdot 0{,}25 = 14\ 107{,}5\ kWh/\ year$$

$$E_h - E_{ws} = E_w$$

$$E_w = 56\ 430 - 14\ 107{,}5 = 42\ 322{,}5\ \text{kWh/ year}$$

Energy consumption with heat exchanger: E_w = 42 322,5 kWh/ year

25% reduction in energy demand

Or to find temperature changes

$$E_{ws} = \frac{t \cdot V_h \cdot c_{pw} \cdot \Delta T}{3600}$$

$$\Delta T = \left(\frac{E_{ws}}{\left(\frac{t \cdot V_w \cdot c_{pw}}{3600}\right)}\right) = \left(\frac{14\ 107{,}5}{\left(\frac{0{,}81 \cdot 10^6 \cdot 1{,}33 \cdot 4{,}18}{3600}\right)}\right) = 11{,}25\ °\text{C}$$

Alternatively

$$\eta * \Delta T = 0{,}25 * (55 - 10) = 11{,}25°\text{C}$$

11,25 is recycled from the wastewater flow into the pre-hot water flow. The boiler needs to heat from 21,25°C to 55°C, instead of from 10°C to 55°C.

Step 3: Carbon dioxide footprint and comparison.

y – years in use

$CO_2w = 645{,}8\ kg\ CO_2/kg$

E_w = 43 363 kWh/ year

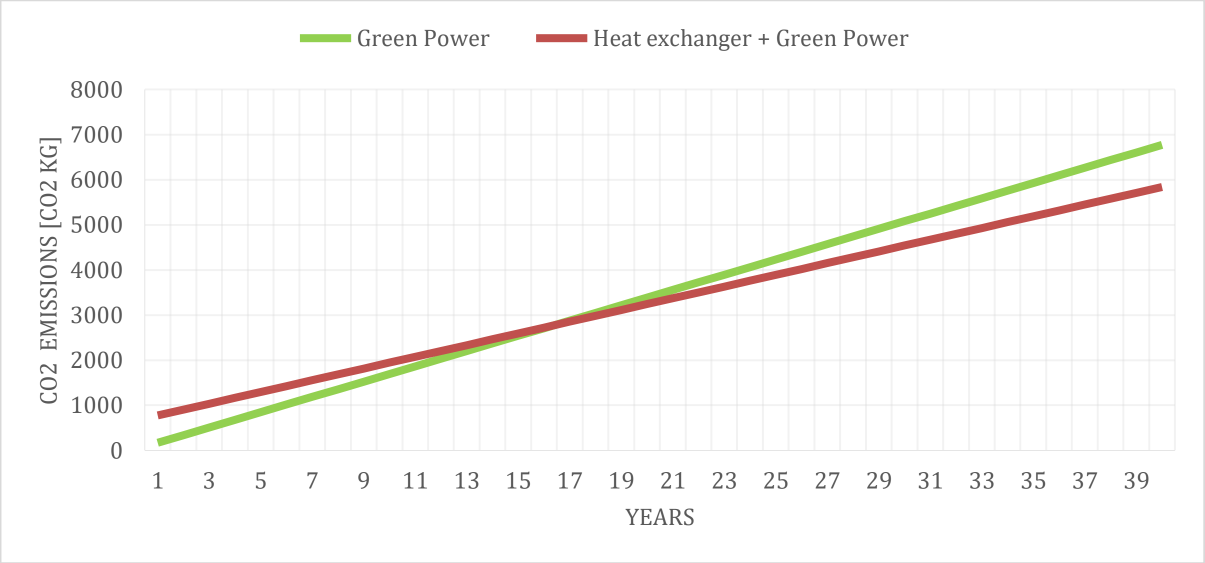
E_h = 56 430 kWh/ year $CO_2gp = 0{,}009\ kg\ CO_2/kWh$

$$CO_2^{footprint} = y \cdot W \cdot CO_2$$

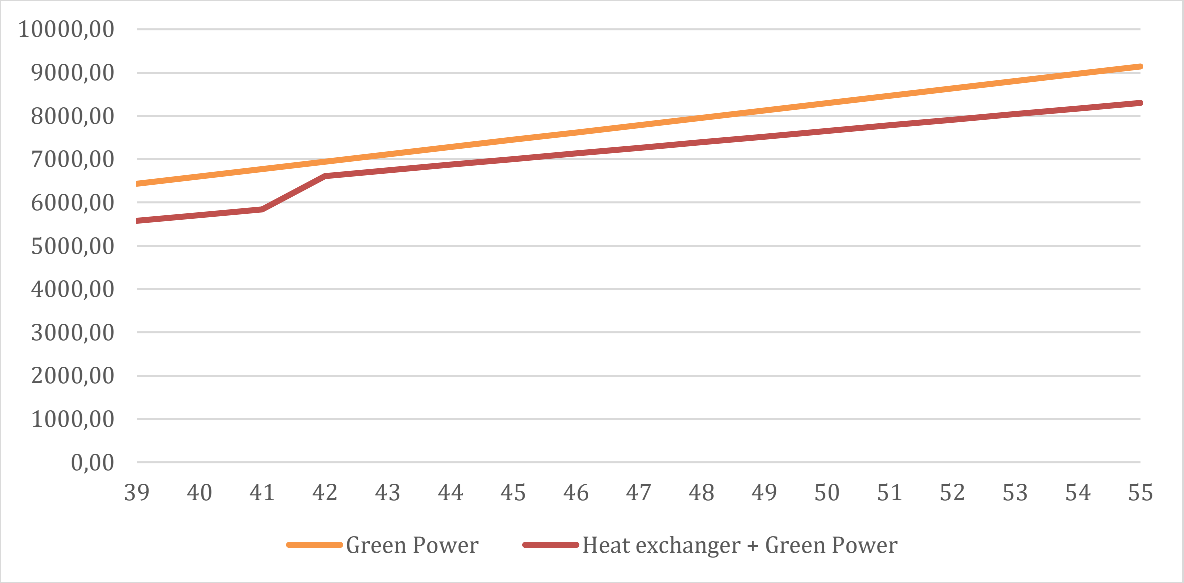
$$CO_2^{footprint}gp = y \cdot 56\,430 \cdot 0{,}009$$

$$CO_2^{footprint}w = (y \cdot 43\,263 \cdot 0{,}009) + 645{,}8$$

Plot



Intersect = Payback= 16,35 years
Savings after 40 years = 15,5% (24,7% if only residual power mix is used, although carbon footprint is 97% larger)



after 40 years plus new heat exchanger
at 55 years 9% lower emissions.

All Inputs:

Compressors: 2
Plate heat exchanger: 2
Work shifts: 2/per day, 8h/shift, 5 days / week, 45 weeks/ year

$t - Timeinuse[h/year]$

η_p – Efficiency plate heat exchanger [%]

η_c – Efficiency daily use of compressors [%]

E_w – *Energy consumption with plate heat exchangers* [kWh/year]

$E_{w/0}$ – *Energy consumption without plate heat exchangers* [kWh/year]

E_r – *Recycled energy from plate heat exchangers*COP – Denotation for thermal energy to electricity transfer.

Calculations

Step 1: Energy consumption/ savings

Compressors are assumed to run at 30% efficiency, resulting in an average of 20 kW efficiency.

$$t = 8 \cdot 2 \cdot 5 \cdot 45 = 3600\ h/year$$

t = 3600h /year

Energy consumption without plate heat exchangers

$$E_{w/0} = \eta_c \cdot t \cdot 2 = 20 \cdot 3600 \cdot 2 = 144\,000\ kWh/\ year$$

$E_{w/0} = 144\,000\ kWh/\ year$

$$\eta_c \cdot \eta_p = 20 \cdot 76\% = 15{,}2\ kW$$

E_r = 15,2 kW
Denoted by COP=3
Electricity needs w/o = 48 000 kWh /year

Energy consumption with plate heat exchangers

$$E_w = E_r \cdot t \cdot 2 = 15{,}2 \cdot 3600 \cdot 2 = 109\,440\ kWh/year$$

$E_w = 109\,440\ kWh/year$
Denoted by COP=3
Electricity needs w. = 36 480 kWh /year

Hot water demand; w. = 38560,5 kWh/year, w/o. = 56430 kWh/year
Other heating (from table 4.) = 99758,5 kWh/year (given A_{temp}=7855 m^2)

Cover complete heating demand and residual 9681,5 kWh/ year to borehole.
Step 2: Carbon dioxide footprint and comparison.

Covers some hot water, what can be stored in tank.

CO2 emissions from plate heat exchangers, no additional energy needed.

$$CO_2^{footprint} = y \cdot \sum W \cdot CO_2$$
$$CO_2^{footprint} gp = y \cdot 36\,480 \cdot 0{,}009$$
$$CO_2^{footprint} w = y \cdot \sum W \cdot CO_2 = y \cdot 4700$$

Payback time 14,8 years