LAPPEENRANTA–LAHTI UNIVERSITY OF TECHNOLOGY LUT
School of Energy Systems
Department of Environmental Technology
Sustainability Science and Solutions
Master's thesis 2021

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# CONTINUOUS ENERGY EFFICIENCY IMPROVEMENT IN BUILDING CARPENTRY PRODUCTION – CASE JELD-WEN FINLAND

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# TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT
School of Energy Systems
Ympäristötekniikan koulutusohjelma
Sustainability Science and Solutions

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**Energiatehokkuuden jatkuva parantaminen rakennuspuusepäntuotteiden valmistamisessa - CASE JELD-WEN SUOMI OY**

Diplomityö

2021

80 sivua, 33 kuvaa, 4 taulukkoa ja 1 liite

Työn tarkastaja: Professori, TkT Risto Soukka, Professori, TkT Mika Luoranen
Työn ohjaaja: Professori, TkT Risto Soukka, Professori, TkT Mika Luoranen

Hakusanat: jatkuva parantaminen, energiatehokkuus, energiatehokkuusjärjestelmä, energiahallintajärjestelmä, energiansäästö kohdekatselmus, puutuoteteollisuus

Tämän työn tavoitteena on kuvata notkean energiatehokkuusjohtamisjärjestelmän luominen rakennuspuusepän tuotteita valmistavalle yritykselle, joka haluaa täydentää jo olemassa olevia jatkuvaan parantamiseen perustuvia johtamisjärjestelmiään energian osa-alueille. Johtamisjärjestelmän luominen on ensiarvoisen tärkeää energiankäytön ja -kulutuksen hallitsemiseksi ja suorituksen systemaattisen parantamisen mahdollistamiseksi. Systemaattisen energianhallinnan ja energiatehokkuuden parantamiseksi pitkällä tähtäimellä yrityksen tarpeisiin ja nykyiseen johtamiskulttuuriin valittiin sopivimmaksi malliksi koettu kansallinen energiatehokkuusjohtamisjärjestelmä, ETJ+. Tämän lisäksi soveltuvia standardeja johtamisjärjestelmälle olivat ISO 50001, sekä ETJ.

Energiankulutuksen analysointi luo tietoa ja auttaa yritystä tunnistamaan myös heidän energiankulutuksestansa aiheutuvia ympäristövaikutuksia. Energianhallinta ja energiatehokkuustyö luovat hyvää perustaa jatkuvan parantamisen ulottuvuuden laajentamiselle myös ympäristövaikutuksien ja hiilijalanjäljen selvittämiselle.

Rakennuspuusepän tuotteita käytetään rakennusteollisuudessa, jonka hiilipäästöjen pienentämiselle on ilmastonmuuton hillitsemiseksi suuri tarve, sekä paine toiminnanharjoittajille kansallisista ja EU:n ilmastotavoitteista aiheutuen. Rakennettavien talojen hiilijalanjäljen pienentämiseksi koko elinkaaren ajalta myös rakennusten komponenttien hiilijalanjälkeä tulee pienentää, missä valmistusprosessien energiatehokkuudella on merkittävä rooli.

# ABSTRACT

Lappeenranta–Lahti University of Technology LUT
LUT School of Energy Systems
Degree Programme in Environmental Technology
Sustainability Science and Solutions

Susanna Käsnänen

**Continuous energy efficiency improvement in building carpentry production – case JELD-WEN FINLAND**

Master's thesis

2021

80 pages, 33 figures, 4 tables & 1 appendices

Examiner: Professor, D.Sc. (Tech.) Risto Soukka, Professor, D.Sc. (Tech.) Mika Luoranen
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Keywords: energy efficiency, energy efficiency management system, energy savings audit, continuous improvement,

The aim of this study is to provide recommendations for establishing engaged and agile energy efficiency management system through continuous improvement for businesses manufacturing constructional products. Establishing energy management systems is essential for controlling and understanding the environmental impact of any company, due to the energy's strong connection between anthropogenic greenhouse gas emissions from energy consumption and climate change. As the pressure intensifies from national and EU level legal commitments, the building industry is facing new challenges to meet the targets regarding carbon intensity throughout its supply chain. The need for reducing climate impact of building products during their manufacturing phase is a significant part of reducing the overall climate impact of buildings during their lifetime, as the finished buildings carry the carbon footprints of their components as well.

In order to systematically control the energy consumption of manufacturing the constructional products in question, applying some energy management system was needed for engaging in long-term achievements. There were three alternatives for energy management system: ISO 50001, EES+ and EES, and the task was to choose the best fit to complement the current organizational management system and culture. This was conducted through literature analysis, while the data and information needed for establishing such system was gathered through interviewing the upper management of the organization and via energy audit. The main goal for this study is to provide insight and recommendations for the case-company about their energy use and efficiency, while integrating energy management as part of their own system and into the cycle of continuous improvement that is the key in their own management model as well.

## ACKNOWLEDGEMENTS

First I would like to present my gratitude for JELD-WEN Oy and Jyrki Leppänen for giving me this amazing opportunity and believing in me. I am incredibly thankful for all that I got to learn from my supervisor Jukka Savolainen and the whole energy efficiency team. Warm thanks go to Risto Soukka and Mika Luoranen for sharing your ideas and expertise with me and for all of the inspiration.

I thank you all for all the guidance and support I got from you on this journey.

In Lappeenranta 11 June 2021

Susanna Käsnänen

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $B_{ec}$ | annual energy consumption of a building | $[\frac{kWh}{m^2a}]$ |
| $Q_{spaces}$ | annual energy demand for heating spaces | $[\frac{kWh}{a}]$ |
| $Q_{ventilation}$ | annual energy demand for heating the air in ventilation | $[\frac{kWh}{a}]$ |
| $Q_{hot\ water}$ | annual energy demand for heating the hot water supply | $[\frac{kWh}{a}]$ |
| $Q_{cooling}$ | annual amount of cooling energy for the air conditioning appliance | $[\frac{kWh}{a}]$ |
| $W_{spaces}$ | annual consumption of electricity for the space heating system | $[\frac{kWh}{a}]$ |
| $W_{ventilation}$ | annual consumption of electricity of the ventilation system | $[\frac{kWh}{a}]$ |
| $W_{water}$ | annual consumption of electricity for the water supply system | $[\frac{kWh}{a}]$ |
| $W_{appliances}$ | annual consumption of electricity for the appliances | $[\frac{kWh}{a}]$ |
| $W_{lighting}$ | annual consumption of electricity for the lighting | $[\frac{kWh}{a}]$ |
| A | Total heated area of the building | $[m^2]$ |
| $E_{savings,i}$ | Energy reduction target | [MWh] |
| $Volume_{2018}$ | Number of produced doors in the baseline year | [units] |
| $E_{consumption,_{i,}}$ | Nominal energy consumption | $[\frac{kWh}{unit}]$ |
| OEE | Overall Equipment Efficiency | [%] |

**Abbreviations**

| | |
|---|---|
| EU | European Union |
| EED | Energy Efficiency Directive |
| EES | Energy Efficiency System |
| EES+ | Energy Efficiency System + |
| GHG | Greenhouse gas (emissions) |
| LNG | Liquefied Natural Gas |

# 1 INTRODUCTION

There are five main subsystems that together form our climate system on earth: atmosphere, hydrosphere, cryosphere, lithosphere, and the biosphere. These systems combined together form one highly complex and connected climate system. Due to the connected nature, changes in one system affects the whole system. These changes can be result of either their own natural, internal variabilities or external forcing. (IPCC 2014, 121-123). As the concentration of the greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, grows in the atmosphere due to human activities, it causes disturbance in the natural greenhouse effect of the atmosphere. (Field 2012, 125). As it can be seen from Figure (1), these anthropogenic emissions resulted from fossil fuel combustion and land-use changes are contributing most to the global warming. The annual amount of the anthropogenic carbon dioxide emissions resulted from fossil fuel combustion has been growing rapidly, and it has been dominating the shares clearly since 1950's. (IPCC 2014, 6-3).

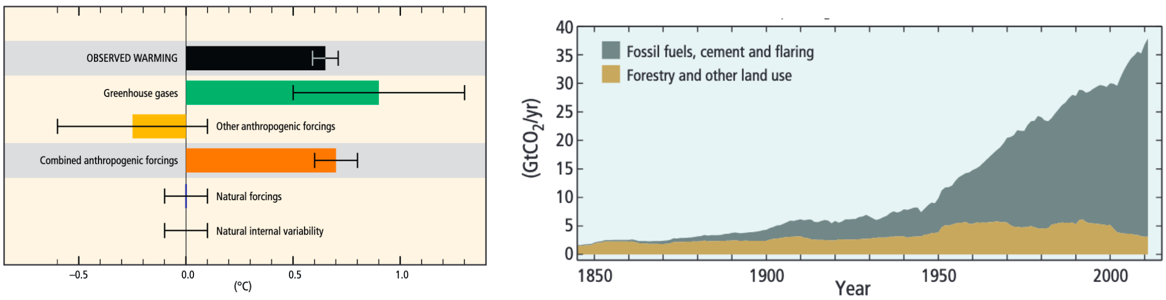

**Figure 1.** Observed warming effect of external forcings during 1951-2010 (left) and global anthropogenic carbon dioxide emissions (right). (IPCC 2014, 3-6).

Direct causes of climate change are for example polar ice sheet shrinkage, species extinctions, amplified erosion, rising sea levels, ocean acidification, drought, flooding and higher occurrence of extreme weather conditions. All of these risks pose severe threat to the ecosystems and all the living things in the planet. If the imbalance in terms of anthropogenic greenhouse gas emissions is not fixed in time by 2100, and the global temperature rises over 2 °C when compared to the state to pre-industrial era, climate change will also become irreversible. (IPCC 2018, 5, 17-29). Indirect impacts of climate change include increased risk of fires, pest and diseases, and increase appearance of social issues arising from unlivable local conditions due to drought, flooding or other climate change induced phenomenon leading to unsafe living conditions, causing displacement of people and animals to migrate, forcing them to flee from their homes by insufficient food-, or water resources. (IPCC 2014, 73) In these kind of areas climate change has been experienced to stem also conflicts from unstable social and political situations, which have been unfortunately resulted already into even armed violence, as the partially drought-driven Syrian conflict presented in 2016 (Sellers et al., 2019).

As the climate change is depended on the released greenhouse gas emissions altogether, limiting warming caused by human action should be done be decreasing the amount of emitted greenhouse gases. Taking action is essential to both avoid the negative consequences to biodiversity, ecosystems and economic development, and to ensure the food and human security for the growing population. (Russel et al., 2018). The total world energy supply from the year 2018 is presented in the Figure (2). It can be seen that mostly oil, coal and natural gas are used for meeting the global energy demand. This shows also how reliant the current energy system is on fossil fuels and gives perspective on how massive structural change has to occur in order to retain from the use of fossil fuels. (IEA 2020).

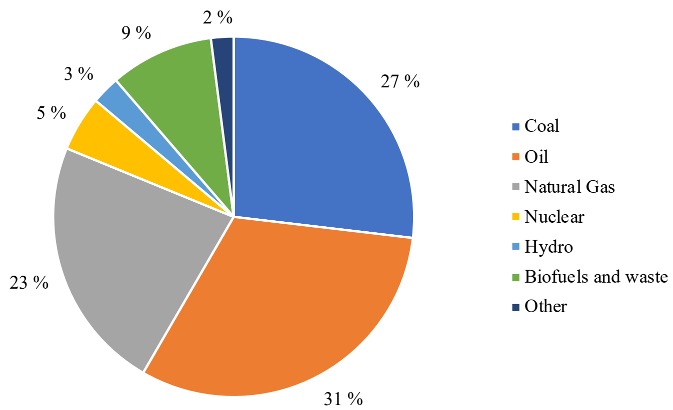


**Figure 2.** Global total energy supply by fuel in 2018. Includes international aviation and international marine bunkers. Peat and oil shale are aggregated with coal. Geothermal, solar, wind, tide/wave/ocean, heat and other sources are categorized in the “Other”. (IEA 2020).

Decarbonizing the energy supply and greenhouse gas emission control have been the key themes during the last decade in the regulations and laws. The Paris Agreement has already driven the needed large-scale changes towards more sustainable societies and obligating each party of the agreement to plan and fulfill their own strategy for contributing to reaching the common target regarding needed massive cuts in the anthropogenic GHG emissions to restrict the global warming to be well below 2 °C, preferably 1,5 °C relative to pre-industrial era. (UNFCCC, 2015). EU has declared the target of climate neutrality by year 2050 as their long-term climate target, which means that mitigation efforts have to take place in every major sector in every member state. Regarding this political commitment to become part of legal obligation, the European Climate Law was proposed in 2019 as part of the European Green Deal, which aims to make EU's economy sustainable, throughout all the sectors. (European Commission 2019).

The societal dependence on fossil fuels must be broken to limit the climate risks that are arising from the GHG emissions, which are released due to energy production and consumption. This means that also the transformation has to essentially take place not only in the side of energy production but throughout the energy system, to cut the emissions from all the places where energy sector overlaps with others like transport and the built environment. The transition faces both drivers that accelerate the transition, and barriers that inhibit the change. (Meadowcroft, 2016).

In terms of decarbonizing the energy system, using clean energy and decreasing the energy consumption are the main principles. Shifting to these causes change across the sectors and forces the actors in the demand-side (buildings, industry, transport) of the transformation to co-evolve accordingly. This co-evolving is driven by the changes in the business environment, for example due to political regulations, tariffs and pricing regimes, and the behavior of users and adopters. (Sovacool, 2016). However, in addition to the decarbonizing goals, EU has the target of reducing energy consumption by 32,5 % by 2050 and while shifting to clean energy decreases emissions from the energy consumption, it does not necessarily reduce the amount of energy consumption. This should be done by minimizing the energy demand, where improving energy efficiency has significant role. (Eurostat, 2019).

Buildings consume approximately 40 % of the final energy consumption in EU, which answers for 36 % of the $CO2$ emissions that accelerate the climate change, yet the carbon footprint for buildings has been voluntary in EU. Life-cycle assessment of buildings is needed to reduce the climate impact and to make more efficient buildings, which in practice level enables comparing not only the whole buildings but its components, and identifying best eco-design solutions. (Asdrubali and Desideri, 2019). Buildings and construction sector have significant role on restricting global warming, and choosing low carbon and low energy solutions already during design phase of construction project is essential to minimizing the carbon footprint of the finished building. Until recently the trend has been to focus on minimizing the climate impact of buildings by minimizing the energy consumption from the use phase of the building, but now the view will be extended to consider the impact all the way from raw materials to demolition phase. As the whole life-cycle of a building is considered already in the planning phase of construction, pressure is on the suppliers to decrease their share of carbon footprint by minimizing the carbon footprint of their own components (Pasanen & Miilumäki, 2017).

Regulations are not enough as holistic approach is inevitable in order to solve the sustainability challenges of energy use, as the responding to environmental changes goes hand in hand with economic and social changes. Organizations, especially in energy intensive fields of business, are powerful actors, that can either hinder or accelerate the sustainable energy transition. Main question then remains as how businesses make profit, yet deliver true social and environmental benefits at the same time. (Bocken et al. 2014).

The case company JELD-WEN Finland operates in woodworking industry, and it manufactures doors both for construction projects as well as for individual customers. Doors are part of the building envelope components, which connects the case-company as a supplier to face the challenges of decarbonizing the buildings. The case-company is interested in decreasing their environmental impact, while increasing their energy efficiency in manufacturing sites. Partially this is due to expected pressure from the construction customers, and partially as it is likely that carbon footprinting of new buildings will become generalized procedure in Finland, and since having small climate impact is likely to interest customers, as they have experienced already with the competition in their field of business about the energy-efficiency of doors during the use phase. When considering the carbon footprint of product, large share is due to energy consumption needed to manufacture the product. Energy consumption can be decreased by improving energy-efficiency of manufacturing, as less energy is needed for same output than before.

## 1.1 Objective of this study

The aim of this thesis engages the case-company in the long-term continuous energy efficiency improvement by establishing energy management system and documenting the phases needed to maintain cycle of continuous improvement. The energy management system established was chosen to be done according to national standard Energy Efficiency System:2014 (EES+). This study provides recommendations for JELD-WEN Finland Oy for identifying hidden energy efficiency improvement potential in the processes, buildings, and people and verifying the progress that will be made over time by keeping the cycle going on. As an example for executing this cycle on operative level, the first cycle for reaching the first target of 2791 MWh decrease in energy consumption by 2025 is used to illustrate the basic practice level phases like energy efficiency calculations, making energy efficiency action plans and measuring progress with energy data that are needed to be repeated after the first target is reached.

Without knowing the starting point, the made progress is difficult to measure. Energy data used for identifying energy efficiency improvement potential and observing the performance consists of both qualitative and quantitative data, which were combined to create realistic picture of the starting point and the distance to the first target. The case sites in question are door- and windowsill manufacturing facilities located in three cities, Kuopio, Alavus and Vääksy, and the data in question was collected from all of them. The qualitative data was collected with workshops arranged with representatives from all sites. Sessions included a walkthrough inside the factory to see the processes and checklist-method guided discussions during the workshop. The quantitative data about the energy consumption was retrieved from both primary and secondary data sources. The primary data was available for the key performance indicator values measured at the sites, while the energy consumption data was retrieved from billing histories given from the energy providers.

## 1.2 Structure and limitations

The scope of this study includes all the direct energy demand flows the energy consumption during the product manufacturing processes has to meet. The energy demand and consumption of separate buildings like offices for sales personnel or storage terminals, or energy demand of transportation are not included to this study. The overall schematic for the manufacturing process is presented in the Figure (3). The implementation of processes at the practice-level can be different from the details between sites, due to different products being manufactured, or designs, but the main key operations needed to produce the products are generally the same. In the beginning, main structure of the door is assembled, which is then followed by installing the needed components to the sides and finishing the look by surfacing and furnishing processes that are chosen by the designs. It was calculated that before the energy efficiency actions the total energy input needed for one output unit varies between sites 34 – 60 kWh.

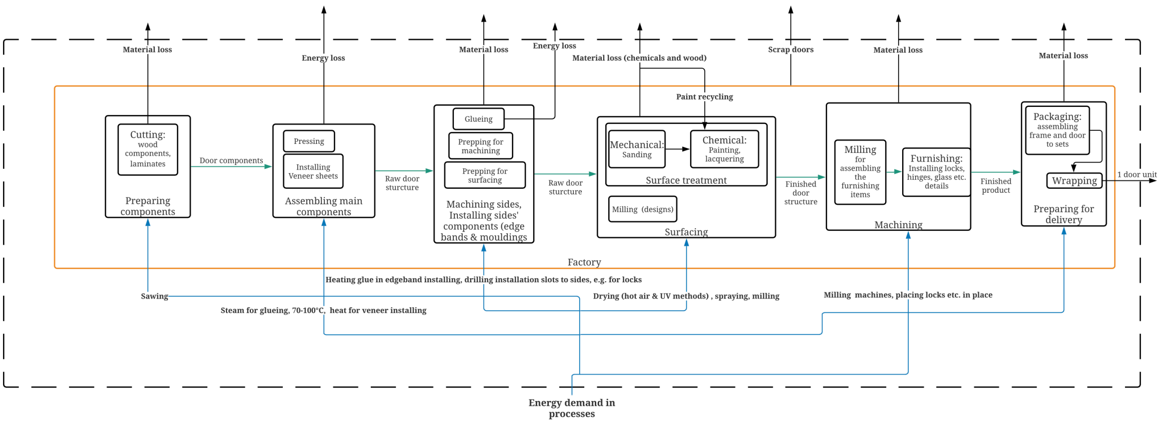


**Figure 3.** Illustration of the significant process phases and inputs and outputs for producing one finished unit. Please note that the figure shows only the principle, and flows are not scaled to present the amounts.

As the case-company JELD-WEN Finland is part of global company JELD-WEN Inc, this study is widely applicable for driving the change through the whole organization to arrange their energy efficiency management, as they have multiple similar locations as these three case-sites. This study gives insight about their opportunities and responsibilities as major global actor for solving the societal challenges and driving the sustainable energy transition needed in the decarbonization of the construction sector.

# 2 ENERGY DEMAND OF RAW MATERIAL PRODUCTION AND BUILDINGS

Energy intensity describes the ratio between the energy demand and one unit of produced gross domestic product (GDP) and it can be used for measuring energy efficiency of an economy (Eurostat 2019). When comparing energy intensity by country in the EU, and Finland belongs clearly to the six most energy intensive countries among the EU member states in 2018, as Figure (4) shows, while most of the Nordic peers like Sweden, Norway and especially Denmark had lower scores. One reason behind the energy intensity of Finland is the geographical location. As comparing the Figures (4) and (5), large share is resulted from the energy consumption of buildings, which then largest share comes from space heating. Prominent share of space heating is likely related to geographical location, as from the Figure (4) two of the most northern member states, Iceland and Finland, show higher energy intensities than others. (Eurostat, 2020).

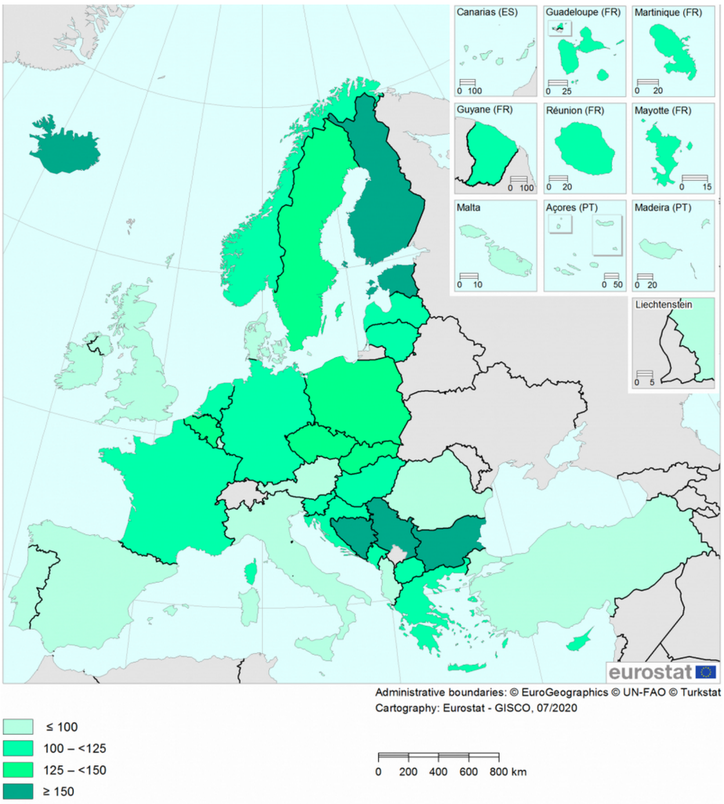


**Figure 4**. Energy intensity of economy among EU member states in 2018. [kilogram of oil equivalent per 1 000 EUR PPS] = gross inland consumption of energy divided by GDP PPS. (Eurostat 2020).

Partially the high energy intensity can be explained with effect of the geographic location to the temperature, as it appears that closer the north, higher intensity there is. In 2018, the heating demand alone was responsible for half of global final energy consumption, and 90 % of it was produced with fossil fuels. Largest share of the heat was for meeting the industrial heating demand, yet buildings consumed respectively 46 % for space heating and domestic hot water production. (Slorach and Stamford, 2021).

Similar trends can be seen in the final energy consumption of Finland in 2018, Figure (5), where industrial actors, transport and built environment do answer for most of the Total Final Energy consumption in Finland. This however does not take into account the actual production phase or energy that is used by the energy sector itself. Produced energy is not equal to final energy consumption also because part of the energy goes to waste, and grows the annual energy consumption unnecessarily. These losses take place throughout the energy system, beginning at the production phase, followed by grid-losses in the distribution phase and at the end-user for example due to process, structural losses, or just behaviour of the user.

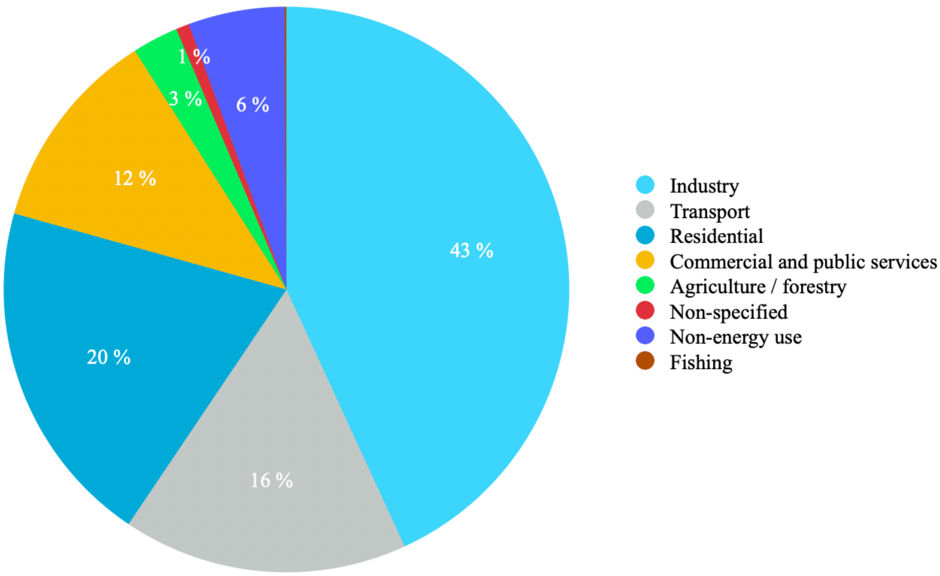


**Figure 5.** Shares of Total Final Energy consumption in Finland 2018. Adapted from (IEA 2020).

The share of industrial total final energy consumption is higher when compared to the EU, which however is not very uncommon when considering the Finland has large share of energy intense production at the industry, Figure (6), where significant share is consumed at forest industry, paper and wood manufacturing processes. Other main consumers are residential and transport sectors, where space heating and passenger cars dominate the largest consumption. (IEA 2020). Actors on these energy intensive industries face big challenges throughout their value chain to adapt to the EU's climate neutrality and requires significant efforts for reducing their carbon footprints, while supporting the transition by developing sustainable business models and adopting clean technologies. Production can become cleaner with process optimization, product designing, monitoring, training and management, and they should be applied in all industrial sectors. Cleaner production aims to preferably prevent, or minimize the emissions resulting from the operations by adapting practices like re-use, mitigation, or other actions that decrease emissions otherwise resulted from the operations. (Klemeš et al., 2012).

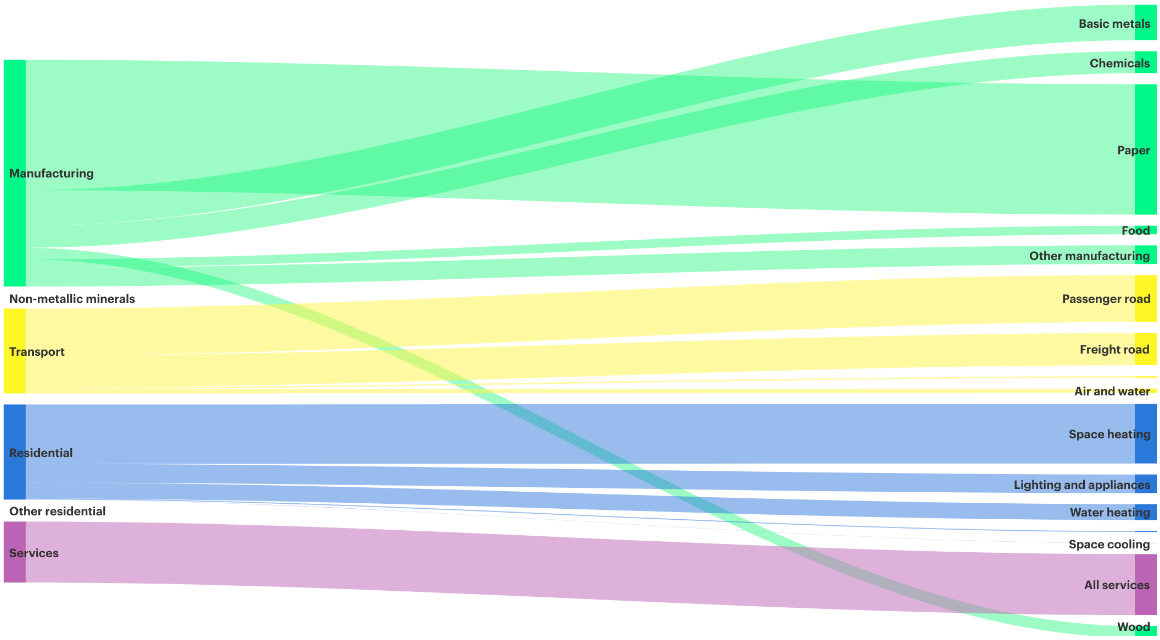


**Figure 6**. Final energy consumption by end use in Finland 2020. (IEA 2020).

The dominating share of energy consumption in forest industry is partially due to the significance of the industry to the local economy as well. In 2018 sales for the whole forest industry was approximately 46 billion euros, including the sales regarding mechanical forest industry of 8,2 billion euros. The whole forest industry alone answered for 20,8 % of all exported products, from Finland. From the Figure (7) it can be seen that most of the incomes from the imports of forest industry was from pulp and paper industry (77 %), followed by woodworking industry (21 %) and furniture industry (2 %). Same year nearly half of the exported woodworking products were saw wood (47 % of exports by value), followed by builders' carpentry (15 %). (Metsäteollisuus 2020).

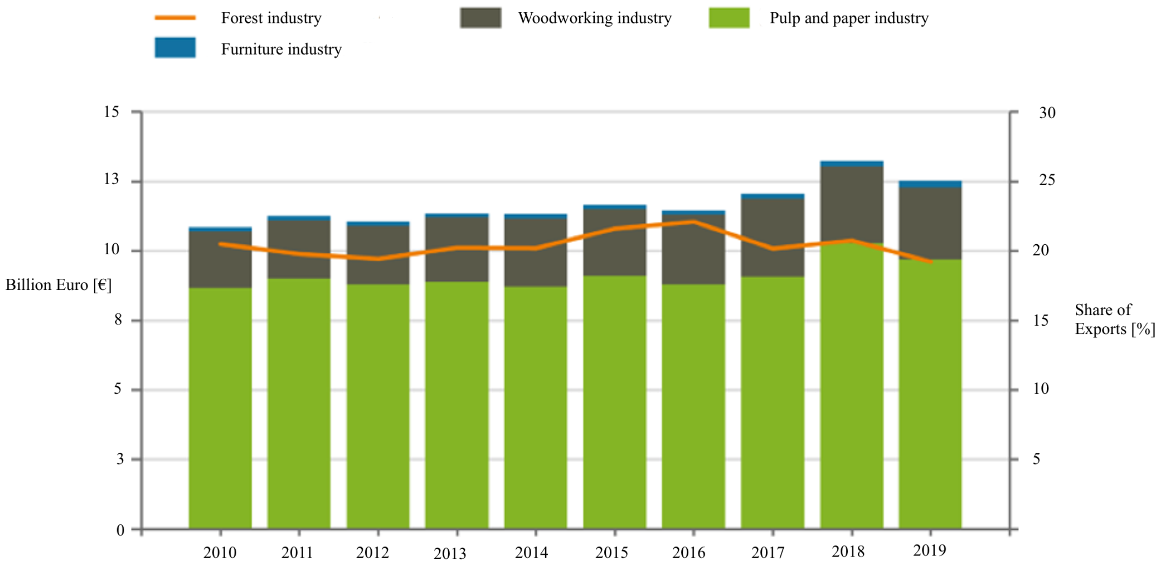


**Figure 7.** Share of exported forest industry products from Finland during 2010-2019. (Metsäteollisuus 2020).

The buildings' purpose is to provide the wanted service of the building, e.g, keeping proper indoor climate and providing shelter to the users, which takes energy. This energy demand sets the limits for energy consumption, which is sum of the energy flows needed to meet the energy demand, which can vary in addition to the type of the building for example due to location of the building, time and user behaviour. (Soares et al., 2017). For example, at summer when the outdoor temperature is higher, energy demand for space heating decreases. Serving energy demand includes technical building systems that are used for producing and maintaining the wanted conditions regarding the building, as presented in Figure (8).

The technical building systems that are installed for maintaining the proper conditions have to be dimensioned. In Finland, the designing of indoor environment of buildings is done in accordance with the values and principles set in National Building Code (RakMK-103174, 2–6). Additionally, to national laws and standards such as SFS-EN 15251, which presents the criteria for the parameters regarding the energy calculations and indoor environment evaluation, there is international standard ISO 7730:2005 as well for the ergonomics of the thermal environment, providing guidance on dimensioning of technical systems for building, regarding heating, cooling and ventilation systems applied to maintain thermal environment and comfort.

The desired maintained conditions, such as temperature, ventilation, and lighting, as well as the design, type and use of the building and building systems set the framework for the technical systems needed to be applied to meet and keep up the desired state. The desired state is affected by the characteristics of the building itself as well, like occupancy and processes taking place at the building or operational hours of the building. For example, office spaces, restaurants and domestic houses have each their own suitable target values, regarding for example the qualities or quantities for the criteria's applied for designing proper indoor environment. Criteria includes target values for temperature (each for seasons winter and summer), Air quality and ventilation, humidity, lighting, and acoustics. (RT 07-11299, 5–9).

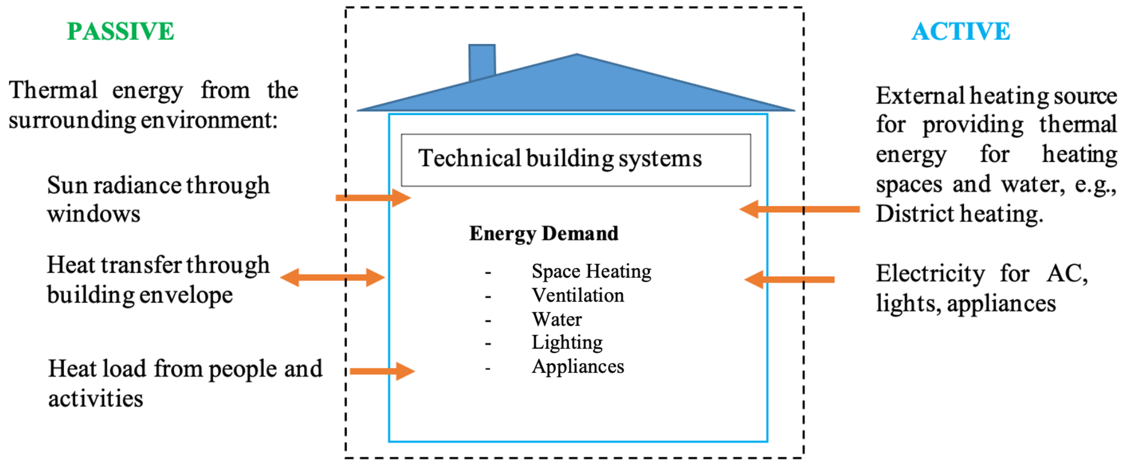


**Figure 8.** Principle of energy demand of buildings. (RT RakMK-103174 2020, 6).

The annual energy consumption of a building ($B_{ec}$) depends significantly by the indoor environment of a building, and it can be calculated with the Equation (1). Variables affecting these values are presented in Figure (9). Variation to the values are formed due to the passive energy flows, such as material of structures and location of the building, or sourced energy forms and efficiencies of the energy transfer appliances like for example district heat pipes between the energy provider and the receiving building. While external heating effect from the sun provides extra heat for the building, especially easily through the windows, some heat losses happen as well through the building envelope and output air flow. These losses have to be taken into account when sizing the input heat, in order to maintain the wanted temperature throughout the year. (RakMK-103174, 7-16).

$$B_{ec}=\frac{Q_{spaces}+Q_{ventilation}+Q_{hot\ water}+Q_{cooling}+W_{spaces}+W_{ventilation}+W_{water}+W_{cooling}+W_{appliances}+W_{lighting}}{A} \quad (1)$$

where

$B_{ec}$ annual energy consumption of a building $[\frac{kWh}{m^2a}]$

$Q_{spaces}$= annual energy demand for heating spaces $[\frac{kWh}{a}]$

$Q_{ventilation}$= annual energy demand for heating the air in ventilation $[\frac{kWh}{a}]$

$Q_{hot\ water}$= annual energy demand for heating the hot water supply $[\frac{kWh}{a}]$

$Q_{cooling}$= annual amount of cooling energy produced in the air conditioning appliance $[\frac{kWh}{a}]$

$W_{spaces}$= annual consumption of electricity for the appliances of space heating system $[\frac{kWh}{a}]$

$W_{ventilation}$= annual consumption of electricity for the appliances (HVAC) of ventilation system $[\frac{kWh}{a}]$

$W_{water}$= annual consumption of electricity for the appliances in the water supply system, e.g. circulation pumps $[\frac{kWh}{a}]$

$W_{appliances}$= annual consumption of electricity for the appliances used in the activities, e.g., domestic machines, like ovens and fridges, or industrial like CNC-machines $[\frac{kWh}{a}]$

$W_{lighting}$= annual consumption of electricity for the lighting $[\frac{kWh}{a}]$

A = Total heated area of the building [$m^2$]

By minimizing the uncontrolled wasted energy, for example decreasing the heat loss through building envelope by e.g. improving insulation of its components, more energy can be passively sought inside, and the less energy is needed to meet the wanted level of heating inside the building, which is really great especially in colder seasons when consumption is higher and energy price is higher. Heat losses however take place across supply- and demand-side, which both affect the energy efficiency. Need for external energy supplier and bought energy can be decreased by installing also own active energy production appliances like solar panels, that substitute the supply. (Cullen et al., 2011). This however would not necessarily decrease the amount of energy consumed, but the amount of greenhouse gases resulted from meeting the energy demand of the building would decrease. Modern IoT technologies and smart-grids make it even possible for buildings to sell back their excess energy to the network for other buildings, resulting in higher utilization rates of energy. (Bulut et al., 2016).

# 3 SUSTAINABLE ENERGY TRANSITION AND BUSINESS

Energy efficiency provides a way to improve energy security while decreasing the emissions, as with better efficiency, less resources is needed to meet the growing energy demand. The consumption trends for primary and final energy have been growing in the EU since 2014, while the amount of fossil fuels available is limited. However, due to COVID-19 pandemic the energy consumption dropped by the effect of the pandemic to the economy during 2020. If the necessary actions are not taken regarding achieving higher energy efficiency, the consumption is likely to bounce back following the recovery of the economy (European Commission, 2020).

While improving efficiency by definition means improving the resource use in a way that enables smaller amount of resource needed for upkeeping the consumption, higher efficiency has actually been connected to increasing energy consumption. When comparing the consumption of energy after the efficiency improving actions to the state of the consumption before them, the originally gained reduction potential in amount of fuel is exceeded by the increased consumption. This conundrum is, partially misleadingly, called Jevons Paradox, even though the rebound effect causing the rise in consumption is not inevitable, hence the paradox being actually logically solvable. (York and McGee, 2016).

The rebound effect in practice stems from the connection of economic growth and productivity, both through direct and indirect pathways to increase the energy consumption. Basically, when the efficiency is improved, marginal costs to using it get smaller. It is cheaper to produce with the better efficiency, than it would be without the improving actions, thus allowing increase production with smaller costs -and resulting in higher consumption that are in risk to even offset the originally gained reductions in energy use. (Sorrell, 2009).

This however is an example of direct rebound effect, where the increased energy consumption is done in purpose with clear intentions to amplify the productivity of the process using the energy. Alas, there are also harder to identify, indirect rebound effects related to the paradox, making it more difficult to prevent. For example, when the energy efficiency is improved, saved funds are left for another purpose, leading to spending it on other services or goods that include energy use during their lifecycle, causing just shifting the responsibility of energy consumption and emissions to elsewhere. (Sorrell, 2009). Regardless of the nature of the rebound effect, the overall rebound effect consists of both. It has been also found to be challenging to determine whether or not the efficiency improving actions were the root cause of increased energy consumption, especially when the rebound effect is small. (York and McGee, 2016).

Paradox dates back to 1865, when William Stanley Jevons observed the relationship between the increased consumption of coal and increased efficiencies, suggesting that when energy price is fixed, energy consumption will rise more upon better energy-efficiency than it would without the improvements (Alcott, 2005). This implies that energy efficiency would do more harm than favour in terms of reducing emissions formed by energy consumption in industrial activities, as the higher level of production in firms would not be possible without enhanced efficiency. While the mechanism of rebound effect maintains correct, the case-specific and empirical magnitude of the rebound effect is what matters in terms of whether or not the energy efficiency improvement results to smaller emissions or not. The magnitude is complex to assess as well, as it varies between sectors and countries and the real amount of decreased emissions has to be calculated carefully considering all the rebound effects that occur due to efficiency improvements. (Chakravarty et al., 2013)

One reason for this can be found in the income of the countries. In 1992 it was found that the emissions of countries form hill shaped curve, Environmental Kuznets Curve, as the low-income countries have lower emissions, countries with middle income have higher, and surprisingly the high-income countries have lower emissions. This is explainable by policies they practice, one of which being greenhouse gas emission based CO2 -taxation and subsidies for greenhouse gas reducing actions. (Brännlund et al., 2007) Supporting this statement (Font Vivanco et al., 2016) conclude that appropriate, economy-wide legislation such as energy and carbon taxes, cap-and-trade systems, have been found to have significant impact on avoiding unwanted rebound effects and environmental trade-offs, that otherwise would be linked to energy efficiency improvements.

Improving energy efficiency and cutting energy demand would provide significant cuts in these global carbon emissions. However, this requires sustainable transition among the sociotechnical energy service systems, like heating, lighting, and mobility. These systems are sociotechnical due to their connected nature between social and technical components, including not only the applied technologies, but as well the context where they are applied, considering the markets, industries, policies, infrastructures, habits and customs of the users, and societal discourses as well. (Geels et al., 2018).

## 3.1 Legislative drivers shaping demand-side of energy use

In addition to the Paris Agreement, complementing legislative structures are needed to be applied to drive the change throughout the energy system. In 2012, the EU set the Directive 2012/27/EU on energy efficiency, which lays the common framework of measures needed to take for meeting the 20 % improvement target in energy efficiency for the EU by 2020. This Directive 2012/27/EU has then been revised and in 2018 the new amended Energy Efficiency Directive came in force with even more ambitious target of 32,5 % improvement in energy efficiency by 2030.

In addition to setting national targets, the EED (2012/27/EU) in 8 Article obligates large companies to carry out energy audits at least every fourth year in order to gain better insight into their energy consumption and energy demand management. Through the audits they are able to recognize the main energy demands and can then better understand and improve their energy performance. However, if the company has European or International Standard certified energy or environmental management system these audits are not mandatory. In Finnish Energy Efficiency Act (2014/1429) 8 § it is stated that with the compliance to ISO 150001 or 14001 is sufficient to meet this requirement for avoiding the four-year cycle of mandatory energy audits.

In order to manage energy efficiency in the industrial sector, the policies have to include all aspects of energy use thoroughly, due to interconnected nature of energy efficiency and the rebound effects. The main legislations regarding energy efficiency are presented in the Figure (9). Addressing energy consumption as a whole requires for both the parties that use, or provide energy, and parties that manufacture the appliances that use energy in order to have impact on the whole category of industrial use of energy on the operative level. On more strategic level the legislation also has to lay the common ground regarding controlling energy use nationally and between countries, as for example is practiced with emission trading. EU- wide legislations provide conformity to the calculating the actual energy savings, as with common rules, all of the countries calculate their energy savings with same principle making it possible to estimate more accurately the actual saved emissions from the energy efficiency actions and the rebound effects affecting between countries.

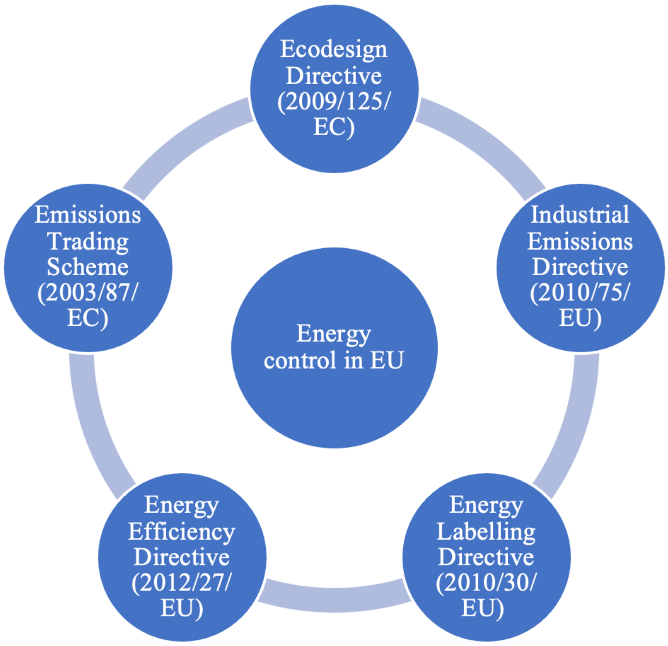


**Figure 9.** Main EU wide directives controlling industrial energy use in the member states.

Regarding ways of improving industrial energy efficiency in Finland there are energy efficiency requirements for the appliances, e.g. considering energy labels of equipment, energy auditing and establishing energy management systems. The common target for improving the energy efficiency in all EU member states is 32,5 %. Additionally, there is set annual national mandatory energy saving targets for member states, which for Finland is approximately 1,90–2,36 TWh/a during the years of 2021–2030. (Työ– ja elinkeinoministeriö, 2018).

The energy efficiency enhancing program has been implemented through voluntary means, instead of applying national legislative or other coercive force. Voluntary methods include the industry-wide energy efficiency agreements, that any actor from each type of industry, municipal or property sector, is able to sign up for voluntarily and thus be obligated to aim for enhancing their energy efficiency. Voluntary agreement has been found to be flexible way to engage different sectors to improve their energy efficiency, while still providing significant energy consumption reductions. For example, regarding the current agreement period that lasts until 2025, the amount of annual energy savings from 551 companies and 96 municipalities was already 7 TWh in the end of 2019, resulting in 1 577 million tons of carbon dioxide less emitted into the atmosphere annually. The conditions of the contracts and the Action Plans for each branch of industry are set between the government and representative industrial associations of these industries. (Motiva, 2020).

## 3.2. Responsibility of businesses in sustainable energy transition

Organizations are powerful actors that can either hinder or accelerate sustainable transition. Business Models for addressing sustainability, Sustainable Business Models (SBM), give businesses opportunity to gain competitive advantage and challenge their competitors to meet their sustainable performance, as they integrate the sustainability to their purposes and processes, which then stakeholders like customers, societies, suppliers, policymakers etc. respond positively. (Brennan and Tennant, 2018) Main question then remains as how to make profit, yet deliver true social and environmental benefits. A holistic approach is needed in order to solve the sustainability challenges, as the responding to environmental changes goes hand in hand with economic and social changes. The core of SBM's is to address the demands of all stakeholders instead following the traditional way of prioritizing the expectations of the shareholders. (Bocken et al., 2014).

Trend of overconsumption in industrial societies has resulted in depleting natural resources and the climate change. (Thakore et al. 2013). Opposing to earlier transitions, where transitions were driven on the basis of price or an abundance of resources, now scarcity and the unaffordability of resources are likely to be the drivers of future transitions. (Sovacool, 2016).

Considering from the business point of view, currently how their business environment is regulated, abundance of resources, infrastructures, customers' needs, and business opportunities evolve. For surviving, or even benefitting, from these impacts of techno-societal changes arising from the global battle against sustainability challenges, businesses have to adapt to changes. To adapt to the shifts arising from sustainable transition, they need to adjust their old business models (Hallin et al. 2021). On the other hand, this effect of the sustainable transition works in both ways, as developing sustainable business models can also boost the transition in the societal systems (Proka et al. 2018).

External environment sets the context for business model, and it can drive or limit the designing of business model, Figure (10). Four main areas that shape the business models are market forces, industry forces, key trends and macro-economic forces. Together these force the business model to evolve during time. Key trends include external drivers like regulations, technologies, societal and cultural trends, and other socioeconomic trends that shape business models to adapt to them. This means that there must be established such management structures that allow the re-assessing, evaluating and adapting even the business model itself in accordance with the market reaction (Osterwalder et al. 2010, 132–235).

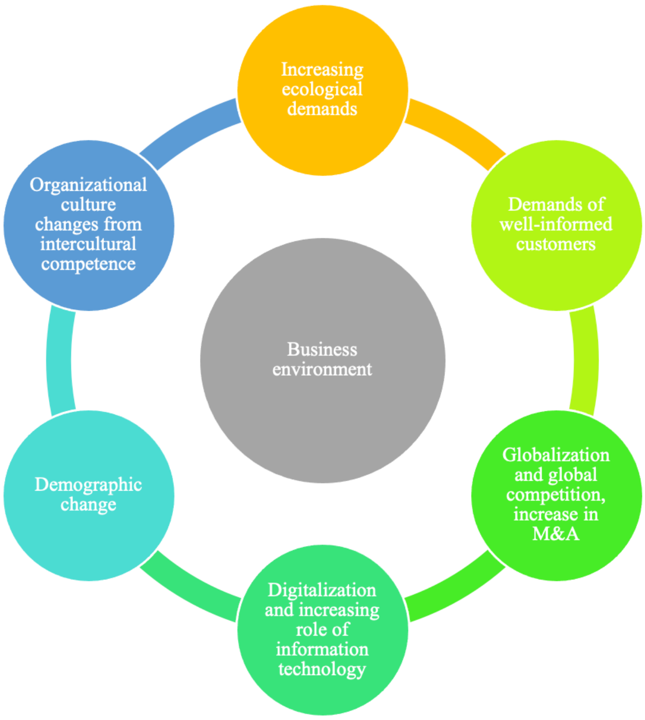


**Figure 10.** Shaping forces of business environment. Adapted from (Osterwalder, Alexander, and Yves Pigneur 2010,132-157).

Innovations and innovation process are necessities for the sociotechnical system and its components to evolve towards sustainable energy systems. These innovations include for example new technologies, organizational arrangements, social practices and behaviours, that serve the purpose for improving energy efficiency, or reducing energy demand.

Innovation process drives the co-evolving of the technologies, environments, and user practices, as presented in the Figure (11). (Geels et al., 2018).

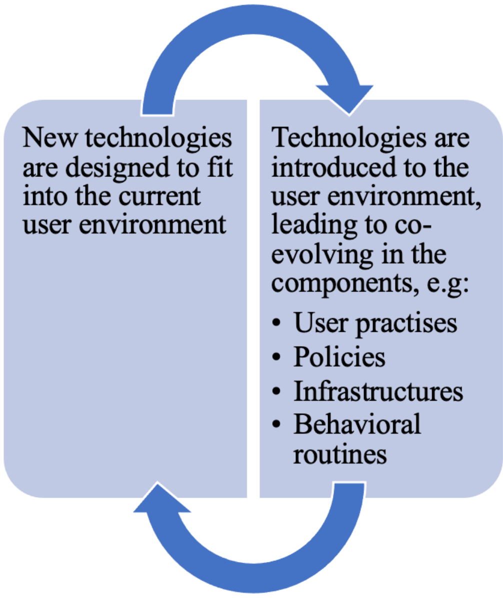


**Figure 11**. Co-evolving between technology and user environment. (Geels et al., 2018)

While low-carbon innovations are essential for driving the transition in energy service systems, yet their becoming mainstream is hindered by the current regime, as the already existing sociotechnical systems dominate the field. The role of political conditions is significant when considering how to accelerate the transition in energy service systems. External shocks and crises are considered to play a part to pressure the current socio-political priorities to accelerate the adopting low-carbon policies, while the public opinion and the strive of companies to gain benefit in low-carbon innovations also create pressure for the policymakers to set stronger regulations and laws that support the shift towards sustainability on the long-term. (Meadowcroft et al. 2016).

The ability to survive through changes is called resilience, which naturally is not exclusive term only for organizational activities but rather such a characteristic that also organizations can have or not. Resilience can be categorized into two phenomena: absorption and adaption. In terms of absorption organization’s ability to sustain their operations through changing conditions and bounce back to as it was before change. Adaption however means that the organization has the ability to update and modify accordingly its operations when they get the pressure from changing conditions. Aspects affecting the resilience of an organization are for example knowledge, flexibility and reactivity, openness, usable resources (both in terms of quantity and quality) and their supporting networks. (Miceli et al. 2021).

While traditionally manufactures have been seen as the largest contributor to carbon emissions inside the supply chain, the total emissions are larger and take place throughout the supply chain. This has led to a realization that the green efforts solely taken by the manufacturers are not sufficient to deliver the sustainable value for the whole chain behind the products. Shifting the point of view from manufacturing operations to look at the product sustainability widens the perspective to consider the whole life cycle of the product, taking into account the emissions from the raw material production and acquiring, assembling and disposal. This shares the responsibilities in sustainability development between the three main parties: supplier, manufacturer and retailer. The sustainability pressure inside the supply chain is presented in Figure (12). Supplier answers for the component manufacturing, manufacturer for assembling the final products. Retailer works in the interface between the green consumers, follows the development of sustainable products in supply and demand, which then is used as basis for quantity of orders for the manufacturer. Manufacturer has to both oblidge to the pressure from their customers and also to the demand their suppliers to adjust to the pressure. (Qiao et al., 2021)

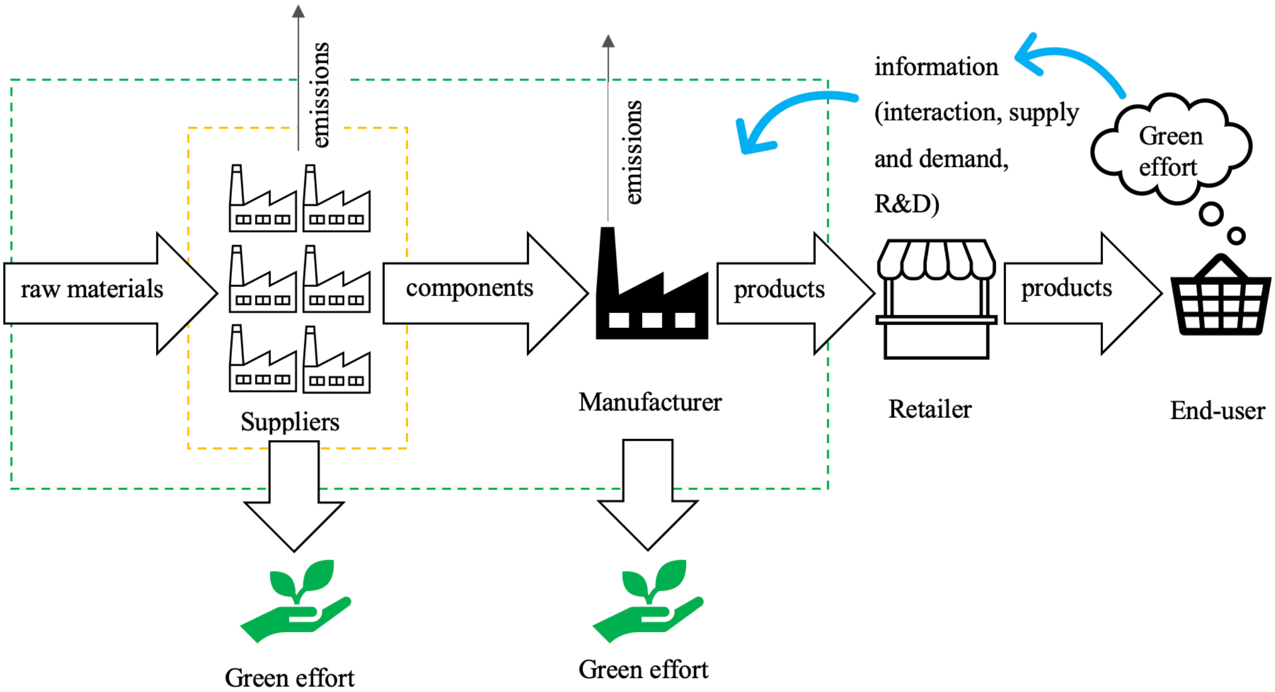


**Figure 12.** Sustainable manufacturing, adapted from (Qiao et al., 2021).

## 3.3 Impact of sustainable energy transition to construction industry

Legal pressure of energy efficiency of buildings has focused in the operation phase of the life-cycle of a building, which has accelerated the evolution of construction products and systems as well as created new IT and supporting tools for designing more energy efficient buildings. Adapting to the pressure to improve energy efficiency for the operations of a building has resulted in decreased energy demand for the buildings, which then has awakened interest to broaden the perspective to include other phases of the life-cycle as well. (Röck et al., 2020). According to the European standard of Sustainability of Construction Works (EN 15978:2011) these phases of the life-cycle can be categorized in four main phases: products, construction processes, use and end-of-life, as presented in the Figure (13).

The standards EN 15643-1 to 15643-4 standards give the framework for assessing the sustainability of construction works, while the EN 15978 presents the calculation method for the Life Cycle Assessment needed to calculate the carbon footprint upon conducting LCA study for buildings. The first part of the standard EN 15643-1 lays the general framework for sustainability assessment, which is supplemented by following parts regarding assessing environmental, social and economic performance (SFS-EN 15643-1).

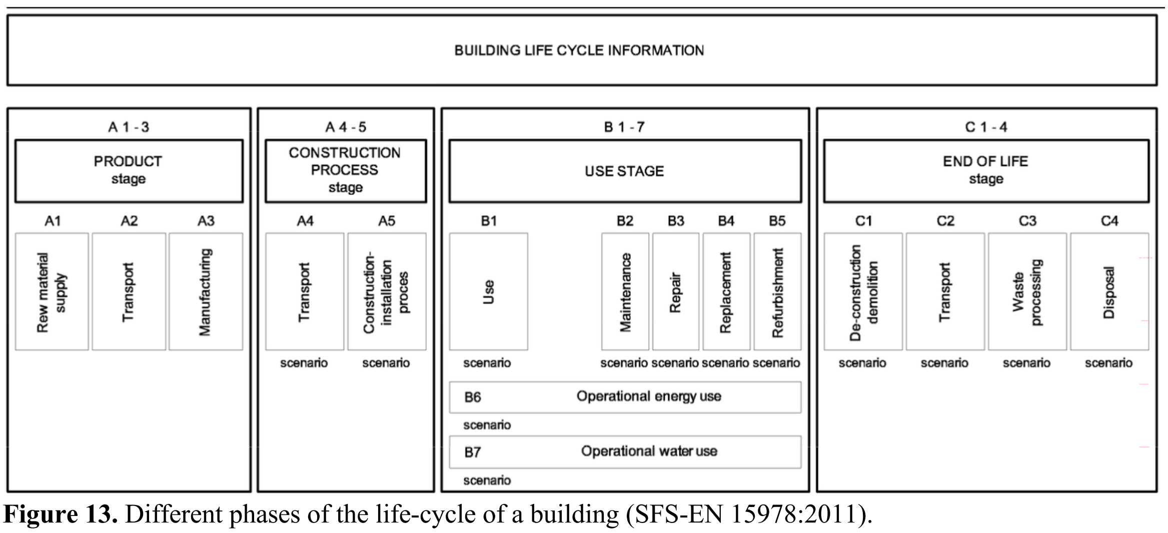

**Figure 13.** Different phases of the life-cycle of a building (SFS-EN 15978:2011).

Finland is planning to make carbon footprinting of new buildings mandatory by 2025. With time this practice is will be extended to include those refurbishment and renovation projects where either a building permission or energy declaration are required. There is not yet precise decisions from authorities regarding how this will be arranged, but all preliminary pathways revolve around the idea of assessing the greenhouse gas emissions resulted from the building. (VTT, 2018).

Energy consumption of buildings is significant part of the global energy consumption, making it key player in the clean energy transition as well. In 2018 construction and operations of buildings answered for over third of the final energy consumption (36 %) and nearly 40 % of carbon dioxide emissions regarding energy use. (IEA & UNEP, 2018). With large energy consumption comes lots of energy saving potential: IPCC has estimated that the scenarios for limiting the global warming to the 1.5 °C degrees requires 80–90 % cuts for the greenhouse gas emissions from buildings by the 2050. (IPCC, 2018).

Cutting the energy demand for the buildings decreases the emissions from the use phase of the building, as less polluting energy sources are used to meet the energy demand of the building to provide the needed service for its habitants. When considering from the energy efficiency point of view however, switching to cleaner energy sources does not decrease the actual energy demand, if it is simply produced by non-fossil fuels to eliminate emissions. The energy demand of the buildings can be decreased with the energy efficiency improvements, for example with low-carbon building architecture and choosing equipment, lighting and appliances with better energy efficiencies. (VTT, 2018).

In Table (1) are presented the estimated values for greenhouse gas emissions resulted from usual components of concrete buildings per floor area of an apartment building. Values come in quite large range, both when considering the minimum and maximum values as well as between the components. It is quite interesting to notice that even the smaller entities like windows, doors and glazing have their estimated basic value of 22 (range between 17,1–28,1) kg of CO2 equivalent per square meter, being quite similar to the basic value of roof structure 23,6 (range between 9,8-33,4) kg of CO2 equivalent per square meter, even though hot air goes upwards and making roof more likely for having extra thick materials for reducing heat losses.

**Table 1.** Estimated greenhouse gas emissions of a construction carpentry components used in typical residential multistorey apartment building. Building is made of concrete and the amount of emissions is calculated by CO2 equivalents per floor area [kg of CO2 eqv. / square meter] (VTT, 2018).

| | $CO_2$–equivalent $[\frac{kg}{m^2_{floor}}]$ | | |
|---|---|---|---|
| | Basic value | Estimated minimum value | Estimated maximum value |
| Soil | 0,4 | 0,0 | 2,9 |
| Piles | 8,6 | 0,0 | 30,6 |
| Foundation | 13,9 | 7,7 | 22,0 |
| Base floors | 9,4 | 8,6 | 18,3 |
| Separate, load-bearing building frame | 0,0 | 8,6 | 0,0 |
| Exterior walls | 75,4 | 33,8 | 108,8 |
| Partition walls | 51,3 | 20,4 | 51,3 |
| Middle base | 86,4 | 49,3 | 104,3 |
| Roof | 23,6 | 9,8 | 33,4 |
| Balconies | 37,9 | 14,3 | 37,9 |
| Flues | 6,5 | 1,6 | 18,7 |
| Stairs | 0,4 | 0,0 | 0,4 |
| Non-bearing dividing walls | 6,9 | 5,7 | 12,2 |
| Windows, doors, glazing | 22,0 | 17,1 | 28,1 |
| built-in furnishing, equipment, surface materials | 26,5 | 20,0 | 33,4 |
| Detached materials | 7,3 | 5,3 | 9,0 |
| Technical building systems | 12,6 | 9,4 | 15,5 |
| Materials for repair construction, 50 a | 114 | 86 | 144 |
| Construction | 67,2 | 36,7 | 97,8 |
| Repair construction | 5,1 | 4,1 | 6,1 |
| Demolition work | 26,5 | 16,3 | 36,7 |
| In total | 602 | 355 | 812 |
| In total without soil, piles, renovation, repair construction and demolition work | 447 | 248 | 591 |

Solely focusing on decreasing the energy consumption during the use phase of the building is not however sufficient when optimizing the environmental impact of buildings, as operational energy consumption does not make up for all of the energy consumption nor the environmental impact of building. When considering the whole life-cycle of buildings, there are other life-cycle phases to include to the optimizing of the environmental impact. Thus, the environmental impact should be reduced also regarding the embodied impact from the manufacturing processes of building materials, construction and end-of-life, in addition to the operational impacts. Due to this, in order to decrease the embodied GHG emissions, following aspects should be considered, as presented in Figure (14). (Lupíšek et al., 2015):

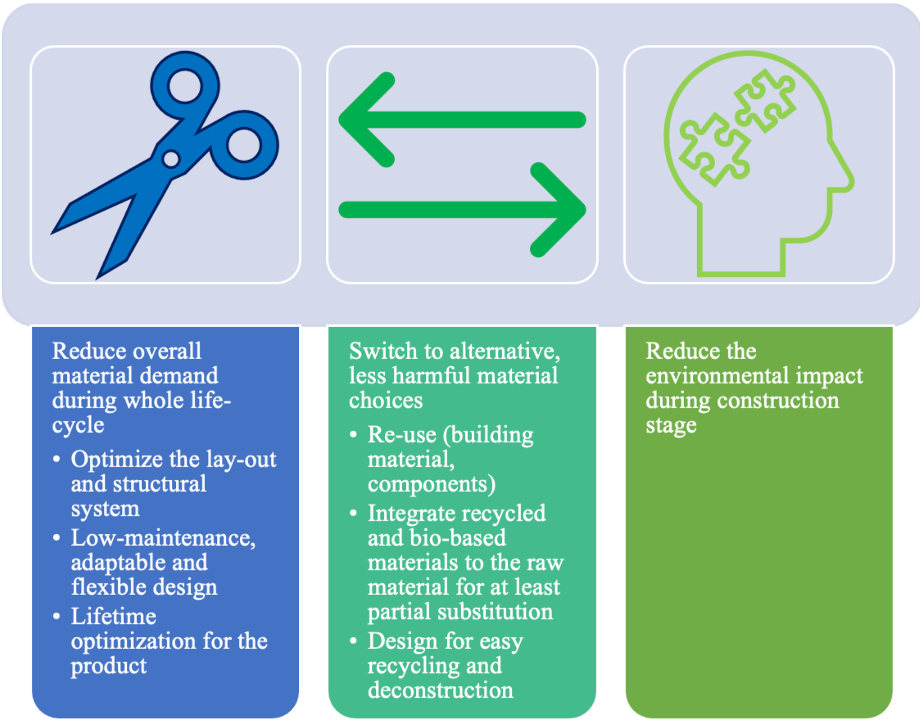


**Figure 14**. Decreasing the embodied energy and greenhouse gas emissions in the product and construction stage (Lupíšek et al., 2015).

By minimizing the use of materials within carbon-intensive supply chains, like construction, is popular way of decreasing greenhouse gas emissions from the early stages of the life-cycle. In practice these include for example optimizing structures and minimizing material by "lightweighting" and decreasing waste generated at the production site. Another approach is to maximize the useful lifetime for the materials, both in terms of fixing existing structures and making new ones flexible for change and easily fit for taking components for re-use or recycling. Third method is to substitute, at least partially, the material and construction products with alternative materials from lower carbon supply chains, e.g., integrating waste, repurposed or recycled material that allow the already once made material to enter into the use phase again. (Giesekam et al., 2016). The initial embodied energy is tied to the materials chosen to be used to produce building material and the processes that are applied to manufacture the components, from cradle-to-gate. This scope of initial embodied energy includes also the logistics and the energy that is needed to move the material from the factory to the construction site, but not the energy demand of the demolition phase, including logistics. (Koezjakov et al., 2018).

Use of timber in construction materials offer a way to sequestrate carbon. Especially softwood is attracting wood material for these purposes as while it has great strength-to-weight ratio, Figure (15), and is abundant and inexpensive resource with multiple engineered timber applications, it is also less energy- and carbon intense to work with than steel or reinforced concrete. The growth in demand for wooden building material should be controlled and ensure that the wood is produced by sustainable forestry, which can be recognized from Forest Stewardship Council (FSC) and Programme for Endorsement of Forest Certification (PEFC) labels for the wood. (Ramage et al., 2017).

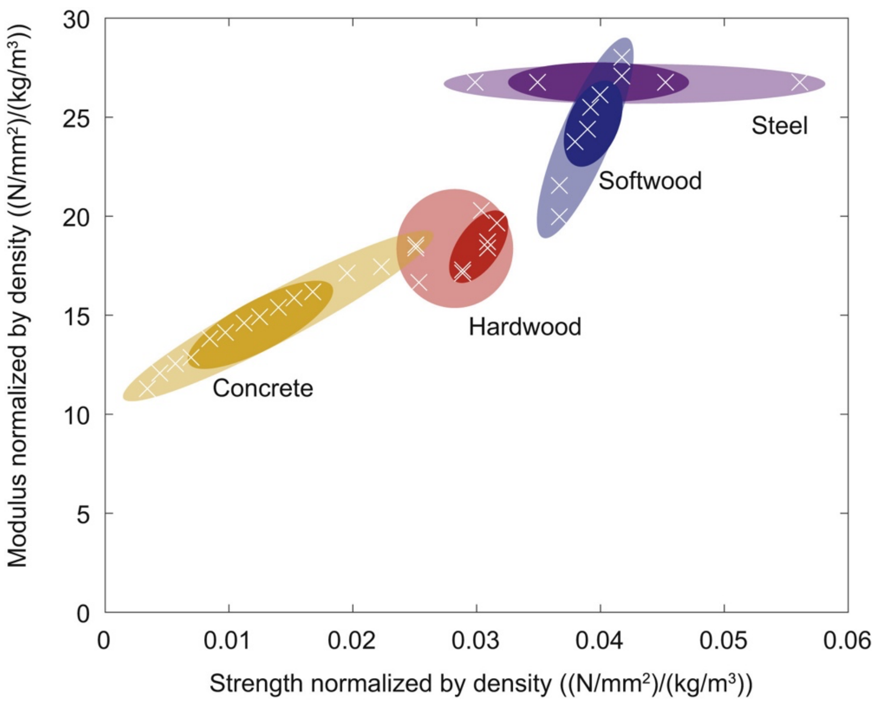


**Figure 15.** Compression strength and elasticity by density for popular building materials. (Ramage et al. 2017).

Energy efficiency improvements in the earlier phases of the life-cycle (supply chain, manufacturing of building components) have to be included when aiming for a building with lower environmental impact. Upon optimizing the energy efficiency in the operational phase, the impact load partially shifts to the embodied carbon, that is formed during producing the building materials. Enhancing the energy efficiency in the operational phase has resulted in growing the share of embodied GHG emissions from the manufacturing phase, yet the cumulative GHG emissions for the whole life-cycle do get smaller by better energy performance of a building, as Figure (16) shows. For example, value for a building meeting current energy performance requirements varies between 20–25 % of the embodied GHG emissions for the whole life-cycle of a building, while in case of highly energy efficient buildings this value becomes 45–50 %. (Röck et al., 2020).

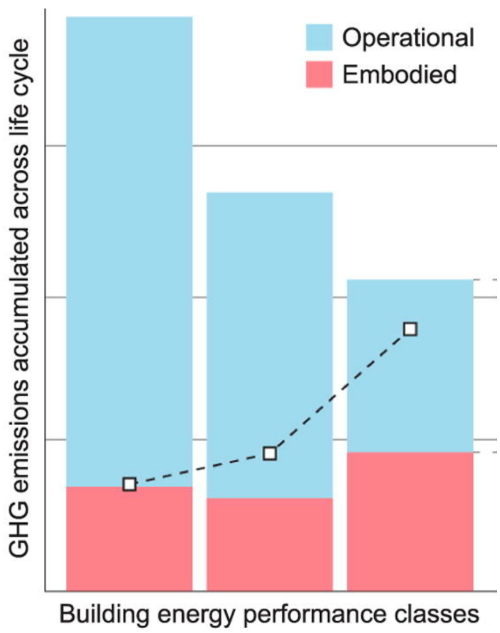


**Figure 16.** Relationship between energy performance of a building and growing share of the embodied GHG emissions (Röck et al., 2020).

Carbon architecture is needed to complement the emission cuts from operation phase of the life-cycle of the buildings. With carbon architecture buildings are able to lock in carbon from the atmosphere with walls, roof, foundation and insulation solutions made with for example from wood, low-carbon concrete or even with new innovations from plastic waste, that decrease the need for traditional, virgin materials used in these applications. (King, 2017).

One example of these low-carbon buildings are nearly zero energy buildings (nZEB). They are characterized by substantial energy performance that is achieved by installing heavy insulation that decreases energy losses through building envelope, and passive systems that cut the need for sourcing energy (e.g., reduces heating demand by keeping the warmth from the sun inside during winter time) and complementing the energy system of the building with renewable energy. This investing in early stages of the life-cycle results in lower carbon emissions regardless, since buildings do have long operational phase and larger amount of emissions can be avoided by having higher energy performance and utilizing renewable energy. (Kayaçetin and Tanyer, 2020).

Smart buildings are another innovation regarding energy efficiency improvements of buildings. they are characterized by technologies that enable adjustability and monitoring of the energy consumption, while improving user experience same time. Smart buildings have building systems where IoT technologies are applied and thus allowing more control over the energy demand and behavioural connections to energy consumption, for example identifying consumption patterns and for example shifting the consumption away from the consumption spikes that are expensive both to the producer and the consumer. IoT technologies provide also automatic solutions to cut unnecessary energy consumption related to activities related to buildings, for example with them unnecessary devices can be scheduled to shut down to eliminate energy consumption from stand-by or idling of the appliances.  (Karlsson et al., 2020).

# 4 SUSTAINABLE BUSINESS STRATEGY

There exists fundamental ethical dilemma within corporate social responsibility (CSR), regarding what motivates the corporation to engage in CSR. There are two main drivers for the corporations' engagement in CSR: ethical obligations towards society (moral approach) and the duty to maximize profits (business approach). Motivation and their agenda affect the quality of how they will perform regarding CSR. Until recently the trend has been more on dealing with negative impacts, when businesses should be changing their way towards sustainable business strategies and widening the value creation beyond economic profit to include social and ecological value as well. (Loorbach & Wijsman., 2013).

Organizational learning and its processes are significant to apply for analyzing and understanding the principles behind shaping operative actions, when transforming business towards sustainable business. These principles explain the basis for learning processes and include sustainability transformation facilitating processes like douple-loop learning, understanding societal scope and complementing the co-operation with learning to outperform competitors in sustainability-related learning (Hermelingmeier & Wirth, 2021).

Adopting Sustainable Business Models (SBM), gives businesses opportunity to gain competitive advantage and challenge their competitors to meet their sustainable performance, as they integrate the sustainability to their purposes and processes, which then stakeholders like customers, societies, suppliers, policymakers etc. respond positively. (Brennan et al. 2018). The core of Sustainable Business Models (SBMs) is to address the demands of all stakeholders instead following the traditional way of prioritizing the expectations of the shareholders. There is lack of comprehensive view of how exactly businesses should do this and how to integrate sustainability into their business models. (Gong et al., 2019)

## 4.1 Embedded sustainability

There is no exact way for businesses to integrate sustainability throughout their whole supply chain partners, as usually businesses are able to incorporate sustainability inside their own operations, which they have direct power to influence. Organizations hold however indirect power to their supply chain partners, as they are able to set demands that they have to fulfill in order to collaborate and therefore put the pressure and transform whole supply chain according to their sustainability values. (Amini & Bienstock, 2014). One way to enforce this can be using binding contracts like Code of Conducts, guidelines, and standards such as ISO 9000, ISO14001 or SA 8000, that are applied for ensuring that the other organizations they are in relationship with meet their demands and standards. For example, Code of Conduct limits the selection of usable suppliers in their operations, if the sustainability of the raw materials that supplier uses does not meet the criteria set by the sourcing company in the Code of Conduct. Sustainable Supply Chain Management (SSCM) should be paired with good level of transparency and effective communication, so that value is captured, and stakeholders are able to reward the sustainability efforts. (Gong et al., 2019).

United Nations presented the 17 common sustainable development goals (SDGs) in global sustainability vision of 2030 that businesses are able to use as lens to assess their impact and opportunities to act on, set targets accordingly for their sustainable development. These identified sustainability challenges, presented in the Figure (17), support the implementation of Paris Agreement in practice, and they help not only the nations, but the businesses that are contributing to the state of these sustainability issues, to engage as an active actor and to carry their responsibilities in solving the global sustainability challenges. Adopting the SDGs in the business strategy, vision and values shapes the business model towards sustainability, and drives the change in the whole market through mainstreaming the responsible business. (UN 2015, 16-28).


**Figure 17.** 17 Sustainable Development Goals. (UNEP 2015).

Sustainable value created does not necessarily translate directly into profit, which makes the benefits of implementing SBM's difficult to identify. Regardless, businesses benefit from good reputation in sustainability as stakeholders answer to it through investment, consumption, productivity and eased regulatory pressure, which all give advantage for better performance in the competitive market. Stakeholders hold power as well over available resources and public opinions affect who gets the access to it, where sustainability performance plays significant role. Here it is essential to practice proper sustainability communication and reporting, as the stakeholders are not able to react to performance they are not informed about. (Gong et al., 2019).

Businesses need to embed sustainability throughout the organization, including strategies and operations, governance and management processes, organizational structures and culture, as well as auditing and reporting systems. (Dyllick and Muff, 2016). ISO 26000 emphasizes that in theory, the sustainability management should be built around the day-today business and reach all the levels of organization from strategic to operative level. To do this, there is demand for proper level of governance and structures to answer for both establishing and implementing sustainability throughout the organization.

Bringing sustainability from strategic level to operative level is presented in Figure (18). Organization integrates sustainability into their strategies to design and maintain the needed organizational structures and tactics that lead the way for implementing sustainability on the operational level according to their vision. Sustainable strategy needs a tactic to set up governance and management processes and procedures, but also supporting culture that answer for executing the actions in practice level, making and following the work towards the strategic goals. Roadmap for working towards the vision is created in the tactical level of an organization. They need to find the places for improvement and ways to manage them, as well as follow the progress and analyze gained insight of the performance that is created during completing the planned actions. Tactics include for example identifying the risks and benefits for the roadmap by which then they are responsible for choosing the suitable tools and programs to combine to achieve the wanted change, while avoiding the risks and identifying remaining, hidden opportunities.

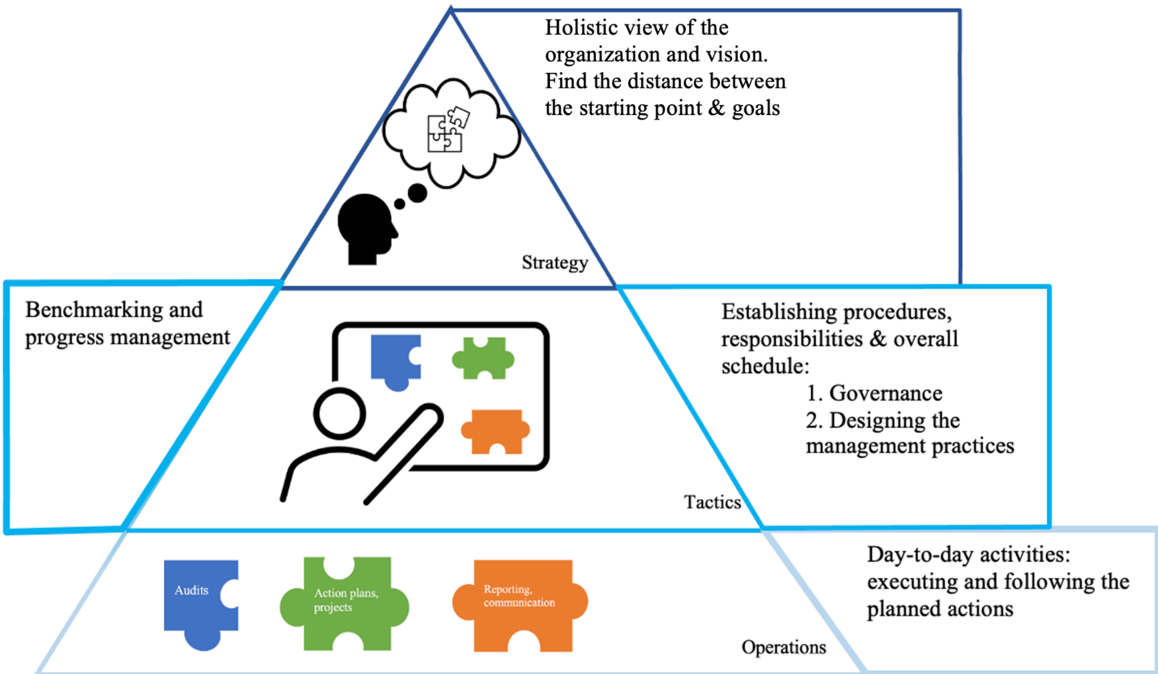


**Figure 18.** Embedding sustainability management into the day-to-day business through organizational structures. Interpreted from ISO 26000.

There are management models that organizations can adapt, and this way create systematic and gain level of permanence of sustainability management for their organization. Green Lean Six Sigma (GLSS) and its practical tools, like environmental value stream mapping (E-VSM) and continuous improvement principle embodied in Kaizen processes, has been found to provide good and agile strategic approach both in improving short-term and long-term sustainability performance. GLSS provides way to do more with less, while generating less harmful impacts and boosting positive effects. For example, applying GLSS in manufacturing processes energy consumption, emissions and waste can be reduced, while productivity and social benefits are improved. (Gholami et al. 2021).

## 4.2 Energy management systems

While establishing sustainability management businesses can choose to divide it to smaller pieces between different subsystems of sustainability related responsibilities, that complement each other. There are options for international standardized management systems, which can also be certified for proofing that the business is implementing the management of chosen theme in a certain way. For example, in terms of environmental sphere of sustainability, organizations can choose to apply ISO 14000 for overall environmental management system, and then complement it with the ISO 50001:2018 for establishing energy management system, as the first one does not include the framework for establishing energy management system. (SFS-EN 14001:2015, 7–8). This is benefitting also in the sense of meeting the legal requirements, as since 2015 due to Energy Efficiency Directive (2012/27/EU) 8 § companies that are not SMEs have to carry out energy audits at least every fourth year. However, if the company has European or International Standard certified energy or environmental management system these audits are not mandatory.

For energy audit to fulfill the description set in Energy Efficiency Directive (2012/27/EU) 2§ energy auditing has to be systematic procedure in order to provide sufficient description of the energy consumption profile of the target. With accurate energy consumption profile potential for cost-effective energy savings can be charted and measured. In order to have realistic and accurate energy consumption profile, standardized methods upon energy auditing should be used. For example, standards from SFS-EN 16247-1 to SFS-EN 16247-5 provide guidance regarding energy auditing of buildings, transport, processes, competence of auditors, in addition to general knowledge.

In Finland, the ISO 50001:2018 standard is the basis in the national Energy Efficiency Systems, EES and EES+, that have been created and applied specifically for improving energy efficiency in Finnish businesses. Both of these energy efficiency systems are rooted in the similar continuous improvement principle as the Energy Management System, EnMS, of the worldwide standard ISO 50001. (Motiva 2020). In Finnish Energy Efficiency Act (2014/1429) 7 § it is stated that management systems with the certified compliance to ISO 50001 is sufficient to meet the requirement for avoiding the four-year cycle of mandatory energy audits. Alternatively to the standardized SFS-EN ISO 50001 energy management systems, organization can choose to apply certifiable energy efficiency EES+ system to the environmental management SFS-ISO 14001 certified system, which together combined are enough to avoid the mandatory audits. The mandatory cycle for energy audits for large companies seize as well, if organization has signed the voluntary Energy Efficiency Agreement and implements the national Energy Efficiency System:2014 (EES+).

While ISO 50001 sets a framework for whole energy management system, EES and EES+ provide guidance for energy efficiency management precisely. The key in all three systems is to establish a cycle of continuous improvement through Plan-Do-Check-Act cycle. Main difference between systems is, that the EES and EES+ use this cycle as a tool for enhancing precisely energy efficiency, and the ISO 50001 contains more thorough view on energy management, as Figure (19) demonstrates. The ISO 50001 addresses the whole energy performance in more specific manner, including energy efficiency improving as one of the focus groups in addition to energy demand and consumption that together form the overall energy performance, while EES and EES+ are applicable for targeting energy efficiency, making it precise for supporting companies that have signed the National Energy Efficiency Agreement.

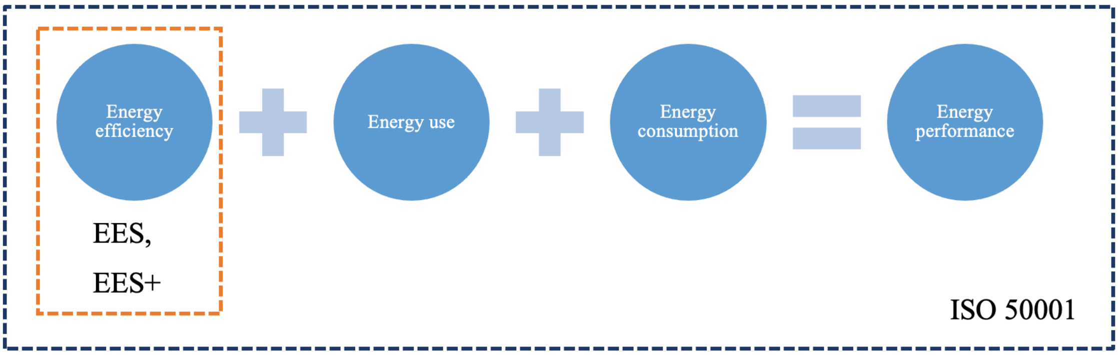


**Figure 19.** Suitability of energy management systems by theme.

Energy management systems are connected to the energy efficiency agreements, as they support implementing the energy savings needed to achieve in the agreement. Keeping energy efficiency actions voluntary by these arrangements has been found to be flexible and functional way to engage different sectors to improve their energy efficiency, while still providing significant energy consumption reductions. (Motiva 2020). Energy savings also bring economic benefits instead of only reducing the climate load, and it is no wonder why investing in energy efficiency has the interest of many companies. In Finland for supporting companies to achieve better energy efficiency, the voluntary Energy Efficiency Agreements between the government and industrial associations have been done since 1990. In the end of year 2020 the number of total agreed parties were 590 companies with their 6089 facilities, and 110 municipalities. Agreements help to ensure company involvement to the energy efficiency actions taken towards the EU energy efficiency targets, without the government having to result forcing by law, and the agreements have been decided to remain voluntary for the period 2017-2025 as well since they have been found to be sufficient in order to get businesses to invest in energy efficiency. The involved businesses are able to get guidance and financial subsidies, which helps them to improve their energy efficiency. (Energy Efficiency agreements 2016, 1).

The barrier between energy efficiency actions and companies is not question of the interest, but the resources. Governmental subsidies can be applied for encouraging organizations to make the needed energy efficiency investments. It would be necessary to however widen the acceptable criteria for subsidies to the preliminary investigation regarding energy efficiency investments as well, since it would lower the accessibility to plan investing in energy efficiency. Energy efficiency investments compete at the company level with other important investments, such as productive investments, which makes it harder to prioritize the energy efficiency related actions as side-effect through budgeting. (Työ- ja elinkeinoministeriö 2019, 19).

## 4.3 Establishing cycle of continuous energy efficiency improvement

Energy management includes more than just collecting data and setting targets. Organizations should have holistic energy efficiency strategies that support their energy efficiency management on long-term, as integral part of their business management. Organizations can obtain knowledge about their energy flows by making energy audits. In the energy audits organizations assess their energy consumption and energy demand of buildings, processes, or people. Significant energy demands regarding electrical, thermal, chemical or mechanical energy have to be identified and the consumption has to be followed and analysed to recognize energy saving potential without hurting productivity. (Vikhorev et al., 2013).

EES+ embeds energy efficiency management throughout the organization and continuously as part of the day-to-day business, as shown in Figure (20). Once the EES+ system is established and running, the organization is on the path of continuous improvement. In order to stay on the loop, organization has to integrate the energy and energy efficiency themes into their everyday activities, identify possible places for improvement and barriers that could prevent reaching them, or risks that could affect the energy consumption. This means that in practice to identify and plan proper actions, there is also need for communication and sharing knowledge about energy efficiency actions and tips, both inside and outside the organization, and gain knowledge and train personnel and managers working at the site. For training managers about recognizing significant uses of energy and calculating the gained improvements to the annual report, the Energy Efficiency Agreement provides platform for training and communication.  (Motiva 2015).

Continuous energy efficiency improvement in EES+ is based on Plan-Do-Check-Act cycle. Before taking energy efficiency improving actions, thorough plan must be made. Plan should be based on established Energy Policy of the organization and include all the energy use taking place inside the system boundary, factors that affect such energy use and choose suitable indicators and data sources that can be used in the operational level for monitoring and analysing the impact of executed energy efficiency action plan. For making effective plan, the most significant energy uses regarding the overall energy consumption have to be identified. A significant energy use (SEU) is defined as energy demand, which heavily contributes to the energy consumption of the target system, or otherwise having large potential for energy efficiency improvement. Typical significant energy uses can be for example space heating, hot water supply production, ventilation, or lighting in terms of energy demand of buildings, or in industrial setting also energy demand arising from the manufacturing processes, like large machinery and equipment, ovens etc. other appliances characterized for the production. (Energy Efficiency System:2014 (EES+), 9–15).

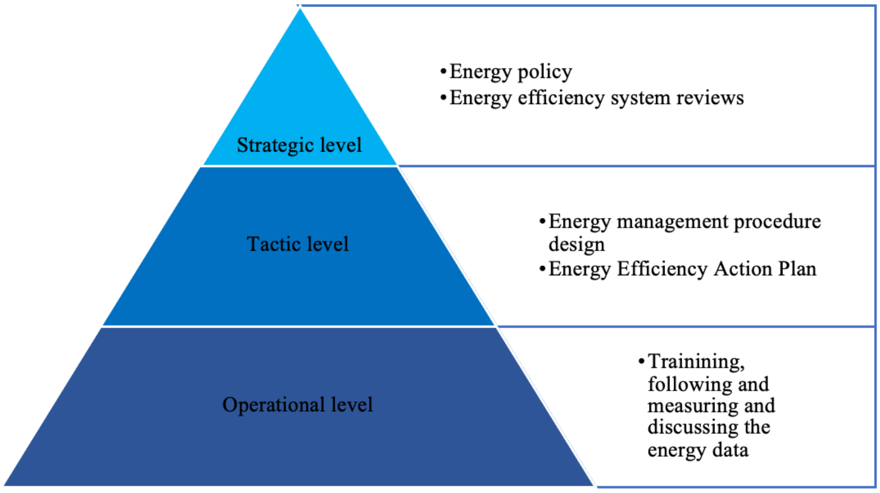


**Figure 20.** Reaching the organizational levels with Energy Efficiency System+.

EES+ does not focus only on the progress and managing the energy efficiency but it includes the review of the management system itself, which purpose is to audit the functionality of the management system and set up future targets. The audit consists of three main parts that each hold subcategories to be assessed:

1. Energy policy
   b. New targets and updates regarding targets
   c. Checking updates regarding arrangements and agreements that affect the Energy Policy

2. Energy Efficiency Action Plan
   a. Identified Energy Efficiency improvement possibilities
      i. Energy performance review during the year, e.g., on monthly basis
   b. Status of Energy Efficiency Improvements in progress
   c. progress in the target by achieved energy savings during the year
   d. Charting New Projects
      i. Yet unidentified places of improvement, prioritizing new targets
      ii. Revisiting yet unutilized places of improvement that could be possible now due to new technology etc. that would enable crossing old barrier.

3. Management review from the previous year
   a. Identifying organizational changes that affect the energy use and consumption at the site
   b. Operational, business related changes e.g., economical changes
   c. Comparing the energy policy and targets for the year and incoming year, checking if there is need to adjust

## 4.4 Quantifying improvement in energy performance

Measuring of performance can be defined as an accomplishment of a task measured against a certain standard, by indicators with suitable dimensions for assessing the performance. The focus of the indicators for the process can be operational, for example speed, quality, cost or accuracy (Franceschini et al. 2007). After measuring, performance can be improved. The on-going cycle of correcting the development of an improvement process and correct measuring is the key for any continuous improvement process.  As the goal is to establish constantly ongoing improvement processes, lean methodologies and tools are found especially applicable, as their core is on continuous improvement as well (Weinert et al., 2011).

Manufacturing sector, such as mining or construction, are answering for over 30 % of the energy consumption and CO2 emissions in the global scale. It is important for the organizations in the field of manufacturing to understand their resource flow and measure their performance as basis for recognizing places of improvement in the industry scale as well. Thus, the potential for energy savings is instead of just improving energy efficiency and decreasing energy demand of the manufacturing processes, but also the energy efficiency of the life-cycle of a product, creating and improving energy monitoring and management systems. (Can et al., 2019)

The core of the production system are the needed production processes and the technologies that are available and applicable to create them. Each process inside the chain has their own energy demand, and their own limitations and connections inside the chain that affect the energy consumption of the whole chain. Thus, the effect this has on energy consumption regarding the production should be acknowledged when energy efficiency objectives or management regarding energy consumption are established. For improving energy efficiency of production, the energy demand of process chain should be identified as a whole, instead of optimizing parts inside the process chain separately. Energy consumption should be followed at the factory level to improve energy visibility and awareness, as they provide insight of the current performance and then applied for finding the energy profile for the process chain. This means that the data regarding the made progress and consumption needs to be gathered, hence Key Performance Indicators (KPIs) should be chosen for measuring the improvement. (Uluer et al., 2016)

Some practice level criteria and parameters that affect the whole system are for example peak shaving, automatic kill-switches that shut down idling or stand-by energy consuming appliances, when set timeframe for non-use energy consumption is exceeded, or accommodations made to external aspects like energy price or renewable energy application. To include energy efficiency to strategic planning level, there has to be realistic description of the baseline, which explains the energy consumption in the current situation with details. Details include for example energy demand of machines and the energy needed for manufacturing of the product, with considering also the temporal influences, like varying intensity of the production and operating states of the appliances. (Weinert et al., 2011). Sufficient amount and quality information about the energy demand and consumption patterns representing the real-time situation are key components in improving the energy performance of manufacturing. This makes energy metering important facilitator for sustainable manufacturing and proper measuring equipment essentialities for creating holistic energy efficiency management approach. (O’Driscoll et al., 2015).

Measuring and calculating the energy consumed in all processes present when producing one unit of each product gives value for the embodied energy for each product. As different production tasks cause different energy consumption patterns, due to required changes in the processes, e.g. use of different tools, machines or required conditions in the production area, the embodied energy value can guide the organization to identify places of optimization or scheduling the production that benefit both the energy efficiency and the productivity. (Uluer et al., 2016)

In industrial environment, underutilized or idling energy consuming appliances are responsible for large amount of unnecessary energy consumption, which could be eliminated by shutting them down or to a lower setting in these situations. (Mouzon et al. 2007). It is possible to even split each manufacturing phase of a product is to smaller parts to assess the energy consumption in different states of operation, which then can be used to design and schedule production from the energy consumption and manufacturing phase duration point of view. (Weinert et al., 2011)

Data and different parameters related to energy demand and consumption should be chosen in a way that provide realistic picture and be gathered all the way from the manufacturing processes to the organizational level for steering the business in improving their energy performance. Designing energy metering system for the whole organization or facility is complicated as selecting the right equipment, location and number of measuring points, and interpretation of the data bring inconsistencies that affect the accuracy of the measuring. (O'Driscoll et al., 2015)

Energy awareness in organization is built on continuous and real-time measuring of energy consumption and infrastructure that provide insight via KPIs for reducing energy use and managing energy demand. Industrial energy use is heavily influenced by the context and variables like product design, processes that are applied in manufacturing them, fuel mix that is nationally available for use etc. local aspects, which make energy management challenging to compare and replicate the management procedures and best practices between industries. Flexible approach in energy management is needed, where establishing the Plan-Do-Check-Act cycle is found applicable, similar to standardized quality management ISO 9001. (Vikhorev et al., 2013)

# 5 METHODOLOGY

The aim is to establish cycle of continuous improvement, and to do this the data about the current starting point and the future target has to be found. Energy data is needed to identify the hidden energy efficiency improving potential, as well as measuring and monitoring systems in the three case-sites to find the path to the long-term improvement and proving the progress what will be made along the way. Both in the standards of EES+ and ISO 50001 it is mentioned that is not sufficient to only list the causes of the energy demand, but also to understand the variables affecting the energy data.

Figure (21) presents the phases applied to charting the SEUs and planning corresponding energy efficiency improving actions. Without considering the impacts that SEUs are affected by, there is a risk of getting a distorted picture of the current situation, which ultimately affects effectiveness of the energy efficiency improving actions too. The progress and impact of changes that will be made during the long-term energy efficiency improvement should be made observable. Data of the made progress can be difficult to observe, if the unidentified variables cause the measured values to shift, leading to false improvement, or seemingly worse performance.

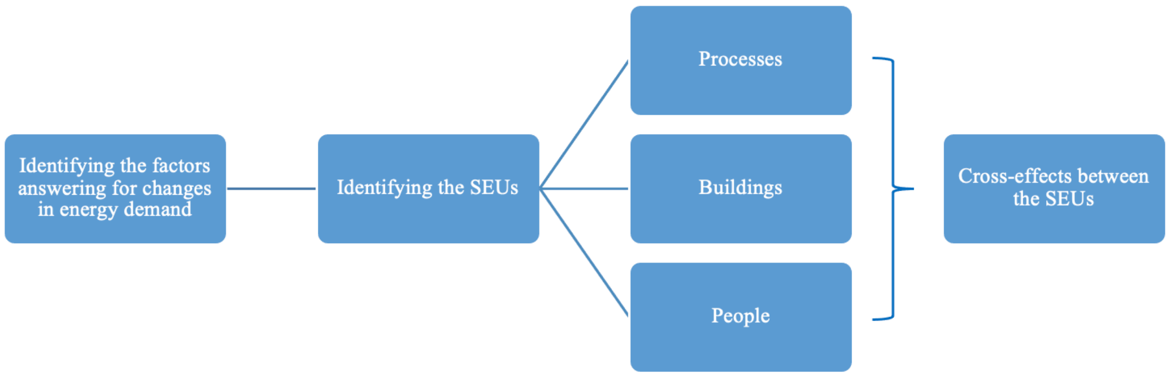


**Figure 21**. Identifying sources for significant energy uses and steps needed to make before taking energy efficiency improving actions for the SEUs.

In this case energy consumption is highly affected by the production, so its development and changes are likely to shape the energy consumption as well, for example by new manufacturing processes, products or procedures. This impact that production has to the energy demand and the energy consumption has to be identified, when analyzing the effectiveness of the energy efficiency management and needed improving measures. The changes in the production side provide both energy efficiency potential, as well as might cause unexpected variation to the energy efficiency data and cause misinterpretations.

The research methods should be chosen in way that they provide both sufficient amount and quality of energy data. Energy data should give insight to recognizing the real, numeric energy efficiency improvement potential, as well as include realistic, qualitative data about the current energy performance, and estimated changes arising from the current characteristics of the production and expected development of it. Energy data should be gathered in reliable way that provides comparability between the sites, as there are three of them co-operating.

## 5.1 Qualitative energy data from workshops

The energy demand is highly connected to the context where the energy consumption takes place, which makes it difficult to find all-inclusive auditing agenda to use as basis for energy efficiency action plan. Energy data is needed to give insight to both the current situation and to estimate the possible development, which both affect the sizing of the energy efficiency actions being planned to reach the current targets of each period.

To begin with collecting the qualitative energy data, workshops were arranged to connect the energy demand from significant energy uses to the energy consumption in the action plan. First right people to participate in the workshop were needed to find. As the energy consumption is highly connected to many areas inside the factory, people should be chosen with expertise from the different areas. Having multiple people and voices in the energy efficiency charting phase combines views and provides place of common understanding for the limitations and opportunities regarding energy consumption through discussion from multiple angles. Members to energy efficiency teams were then gathered from maintenance, production, and environmental management at the local sites for combining their expertise.

The basic structure and items of the checklist was obtained from literature, which then during workshops was extended to more detail. Since both the EES+ standard and the ISO 50001 recognize processes, buildings and people as separate categories behind energy demand, these three were chosen as main categories for also the agenda of the workshop. The agenda of the workshops was divided into three sections, reserved with free discussion in the end, as shown in Figure (22).

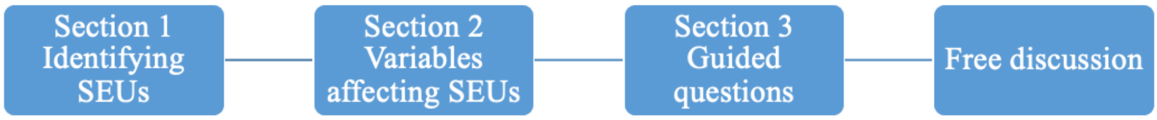


**Figure 22**. Structure of the workshops.

The aspects affecting the energy demand and characteristics of usual, significant energy demands were charted with checklist-method. Checklists are common way to go through the inspected theme and its characteristics in a systematic way, which is why it was chosen as a tool for gathering qualitative data to create comprehensive and realistic picture of the energy demand, energy consumption and identifying energy efficiency improvement potential and corresponding actions. Figure (8) was used as basis for charting the SEUs from buildings in first section of the workshop, while the items on the other two were based on the observations made during walkthrough of the factory site before workshop. Here the Vääksy site is the exception as due to COVID-19 pandemic we had to resort to keeping remote workshop and thus I used the checklist from Kuopio and Alavus as basis for the remote workshop for Vääksy.

The items obtained from literature on section two were then used as basis for identifying the variables for the energy consumption of the SEUs in the factories in the next section of the workshop, where the list was then updated to more detailed for each site upon discussion. Lastly, there was the third section reserved for free discussion, where the possible root-causes for unnecessary energy consumption and cross-effects between the three categories were charted.  In the third section I presented three starting topics, which I chose for testing my own hypothesis about the connections I had found from the quantitative data sources. Manuscript of the workshops with the checklist and guided questions can be found in the Attachment (1).

## 5.2 Quantitative energy data

In both EES+ and ISO 50001 it is stated that the organization must observe and analyze the development of their energy performance in planned periods of time. In this case the quantitative energy data is reviewed monthly, and the review contains the energy consumption by type and nominal energy consumption needed per finished product, which represent the overall energy consumption from usual day-to-day activities.

As Weinert et al. (2018) and Karlsson et al. (2020) found that idling state of the machines and appliances results in unnecessary energy consumption, decreasing that kind of energy consumption would decrease the energy consumption of production. Even though this kind of action does happen in day-to-day life on machine level, it can also appear in larger scale, precenting which should also decrease unnecessary energy consumption. For example, if one whole phase of the production would stop unexpectedly, it could result in avoidable energy use from the following phases that might keep running empty, while waiting for the halt to be over. There were no energy related procedures established to do in case of malfunction situations, even though they result in avoidable energy consumption, which is why the connection between malfunction situations is needed to be investigated.

Data for these are retrieved from the billing data and daily quality reports of production where number of finished products are kept track of. Partially the SEUs and the variables affecting SEUs I was able to retrieve from secondary sources, billed energy consumption and internal digital production effectivity monitoring systems beforehand of the workshops. In this case the energy consumption data was not traceable to each identified SEU, as it is billed only as whole total electricity or district heat consumed inside the factories during the billing periods. The production data of the process chain is retrieved from digitalized production monitoring system, Evocon, which is installed to a few of their key manufacturing appliances in their production phases at all case-sites.

As the production data contained multiple KPI values, correct values needed to be chosen for analysis. OEE indicates the degree of how successful the operation hours are, based on whether equipment is doing what it is supposed to do. OEE is calculated by the rates of availability, performance, and quality, and it is useful tool for identifying losses taking place in either one of these categories.  These include downtime losses, speed losses and quality losses that arise due to disturbances in manufacturing. (Muchiri and Pintelon, 2008).

Occurring of these losses have impact on energy consumption, which is why improving OEE can be expected to decrease unnecessary energy consumption, that currently is used in operations that create no value. To assess the impact of production to the energy consumption I then proceeded to cross-compare the electricity consumption, and OEE key values on daily basis with the Tableau software. The timeframe for this however was rather narrow, 10 months, as the OEE data was available only since August 2020, when the OEE monitoring system was installed and May 2021, moment of this study. Regardless of shorter period there was variance between the days, with planned maintenance weeks and days with unplanned need of maintenance and abrupt stops, so the data does include cases suitable for planning the possible unnecessary and unexpected energy consumption avoiding procedures.

The number of measuring devices attached to the workstations are currently located only for the earlier production phases, like pressing, edge machining and edge banding. Pressing is currently the only common measuring point for all the factories for the OEE, which is why the OEE data measured in other phases was excluded from quantitative analysis to identify the hidden energy efficiency improving potential. Availability represents the percentage of the planned running time which is truly used for production. The time lost is downtime, which is formed from both planned and unplanned stops. Availability in the OEE data does not consider if some share of the downtime is due to planned technical stops, as shown in Figure (23). Therefore, for analyzing the energy data about the impact of maintenance and the abrupt maintenance needs the changes of technical availability is checked in addition to OEE values.

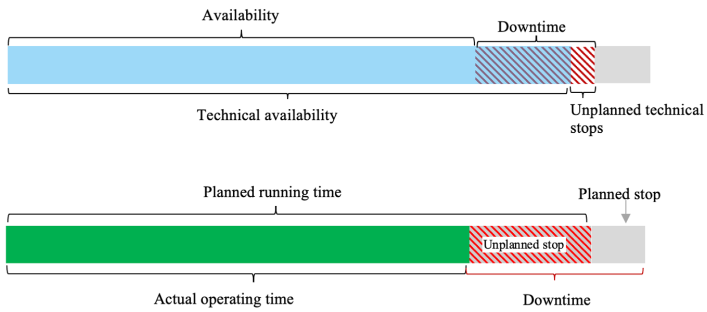


**Figure 23.** Differences between Availability and Technical Availability.

# 6 DESCRIPTION OF THE CASE COMPANY AND THE SITES

The case-company has committed to the Energy Efficiency Agreement of Wood Product Industry. Due to this they have to decrease the overall energy consumption with 7,5 % by the end of the year 2025. The comparison year is 2018, when the overall consumption was 37 290 MWh, which means that the amount of decrease equals to 2 791 MWh. This however is simply just the first step as the company is committing to improve their whole sustainability internally already in the long-term, which includes energy consumption as one and very significant category, since energy consumption has direct connection to emissions resulting from fossil fuels consumed. The needs of the case-company were charted with interviewing representatives from the upper management of each site and the head of EHS department in Finland level.

Case-company is large, global company with multiple locations, where currently already some areas implement certified, standardized (ISO 50001) energy management systems as part of their management system, while others do not yet have certified systems. As the network of the organization is global, different factories face different local policies and regulations, yet at the same time the pressure to be more sustainable and decrease the negative environmental impact from the business activities is the same. Pressure is present throughout the global organization due to similar products and manufacturing facilities inside the global level of the organization. This means that the minimum requirements set in law can vary, but the organization’s need to be better does not.

Since the EU has on social level very prominent role in addressing climate change and is activating businesses to contribute, as discussed in the theory part, the local upper management saw this as an opportunity to set an example for the whole organization. Widening the application of same agile management principles from the already existing management structures and culture of the organization to energy management is useful for integrating and driving the energy efficiency management inside the whole global organization. Adopting the model set by the case company would be especially benefitting in the areas, where requirements from the obligations differ from the level inside EU.

To make energy efficiency management systematic throughout the organization in Finland level, establishing energy efficiency management system was needed. The case-company implements already Lean management systems, and the chosen system was desired to be both as agile and built for continuous improvement for managing the energy efficiency as well, since these characteristics were seen to provide great benefits upon interviewing the upper management of the factories. Even though three factories have similarities, they have their own unique differences that were considered to be easier to address with similar flexible management system as with other themes already addressed (quality, safety, waste etc.) that can be customized for each site. Three alternatives were considered for energy management: ISO 50001, EES+ and ISO 14001 accompanied by EES. After discussion the EES+ was chosen to fit best to the criteria, as it was seen the most compatible to complement the already existing structures, and it also focuses directly to the energy efficiency, yet does not close any doors from widening the scope in the future to the whole energy performance addressed in ISO 90001. Establishing the EES+ was also seen as opportunity to pre-chart the emissions from the energy consumption from the manufacturing phase, as case-company is preparing for carbon footprinting and adopting environmental management system as well.

The case company has three sites in Finland, all of them producing doors (indoors, sauna and front) as their main product. The basic components for the unit is shown in Figure (24). Production of the other optional products such as top- or side-windows and their sills or doorframes for the door package is tied to the production of the doors, hence considered as side-products. Thus, the allocation of energy consumption between the products is not considered necessary, as production of side-products is essential for the whole main-product. Functional unit for calculating the nominal energy consumption is chosen to be energy needed for one produced door. Usually all sites run for 235 days a year, which does not include occasional overtime during weekends or holidays.

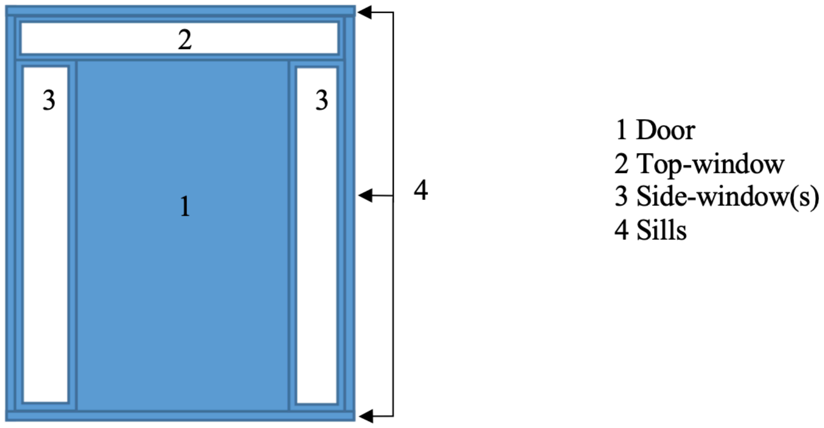


**Figure 24**.Basic components of the functional unit, 1 produced door package. The assembly varies depending on the product design.

All three sites have similar production line for interior doors, but each has as well their own different special door types, which affects to the energy consumption of production, as the share between the special products and general indoor production includes some variation due to differences between from a bit different manufacturing processes, as shown in Table (2). For example, some special doors may require two pressing phases instead of the one needed by the general interior doors, which rises the nominal energy consumption for the product.

**Table 2.** Product categories by site along the total energy consumption in the reference year 2018.

| Site | Interior door | Splash-proof door | Fire resistant door | Sliding, fire resistant door | Front door | Sauna door | Special Project Doors (hospitals, hotels etc.) | Annual energy consumption [MWh/a] | Nominal energy consumption in 2018 [kWh/unit] |
|---|---|---|---|---|---|---|---|---|---|
| Kuopio | x | x | x | x | | | x | 11 530,32 | 33,76 |
| Alavus | x | | x | | x | | x | 6 856,26 | 58,26 |
| Vääksy | x | | x | | | x | | 11 254,18 | 59,49 |

Manufacturing processes include use of chemicals for example during pressing and painting as well as upon installing edge-bands, where heat is needed either for polymerization or drying purposes. The main elements for the overall manufacturing process after the door press consist of machining, where the door takes it shape by milling (edges, designs, etc.), surface finishing processes, like sanding and painting, and furnishing where the components are installed to the product, like the locks, kick plates, glass-elements and hinges etc.

As products have either painted, veneer or laminated surfaces, they require different conditions in different phases of production. Generally, the main needs for ventilation are for ensuring quantity of fresh air and removal of used air to maintain the breathing quality of the indoor air for people inside the factory. In this case however the indoor air is affected by multiple demands arising from the processes. Air quality, pressure, moisture, and temperature are the most significant characteristics of the indoor climate that have to be maintained in suitable levels that vary between the production areas.

Not meeting the demands or having unstable conditions would cause safety and quality risks in the sites. Proper ventilation is needed to maintain the quantity and quality of air in most of the areas, either regarding paint fumes or saw dust, while maintaining the proper humidity is needed in the veneer and laminate processing areas. Technical solutions for ventilation are applied for managing the direction of the airflow and removing the contaminated air, which are complemented by the motorized breathing PPEs for the personnel in some high-exposure workstations, like at the manual spraying or sanding, where relying on technical systems alone are not sufficient for eliminating the health risks from the process.

Too dry indoor air in the area where veneer or laminated doors are manufactured causes the thin sheet material to dry up, leading quickly to large amounts of unusable materials as the dried sheets crumble. While producing painted doors, the risks regarding the state of indoor air are connected to the people working at the painting lines. Even though personal protective equipment can be used to decrease the respiratory risks related to the presence of chemicals in the breathing air, first way to lower the risk should be to provide structures that ensure good quality and amount of air for the operators in the painting process. Saw dust is another harmful substance present in the indoor air needed to be managed by the technical indoor air management systems, which follows similar principles as the removal of contaminated air at the painting lines. These air removal systems however generate as a side-effect at the same time significant pressure drop inside the factories, which affects for example the energy consumption through space heating and challenges maintaining the humidity in the other areas. Temperature and draft control due to difference between the indoor air and the outside is needed at all sites, especially during winter, when the accidentally sucked in outdoor air is colder.

Altogether the energy consumption was approximately 37 290 MWh in the baseline year 2018, which also includes some energy consumption from sites not anymore in use. The shares of old sites for the promised decrease in the Energy efficiency agreement are included to the improvement target to the current sites, so the energy efficiency actions planned for the consumption are not adjusted too small, as it would appear otherwise that the energy consumption has decreased significantly before actions are even taken.

Figure (25) presents the energy consumption of the case-company in the reference year 2018. All three sites share the use of district heating and electricity, which are sourced from local providers. Please note, that the energy from woodchips in Alavus and Vääksy are included in the corresponding district heat consumption values of the sites, and are shown as a reference for how much it decreases the need for district heat generated with other fuels. Approximately 80 % of the district heat demand of the case company can be met with utilizing the woodchips. Sites in Alavus and Vääksy supply partially their district heat themselves through collaborating with their neighboring district heating providers.

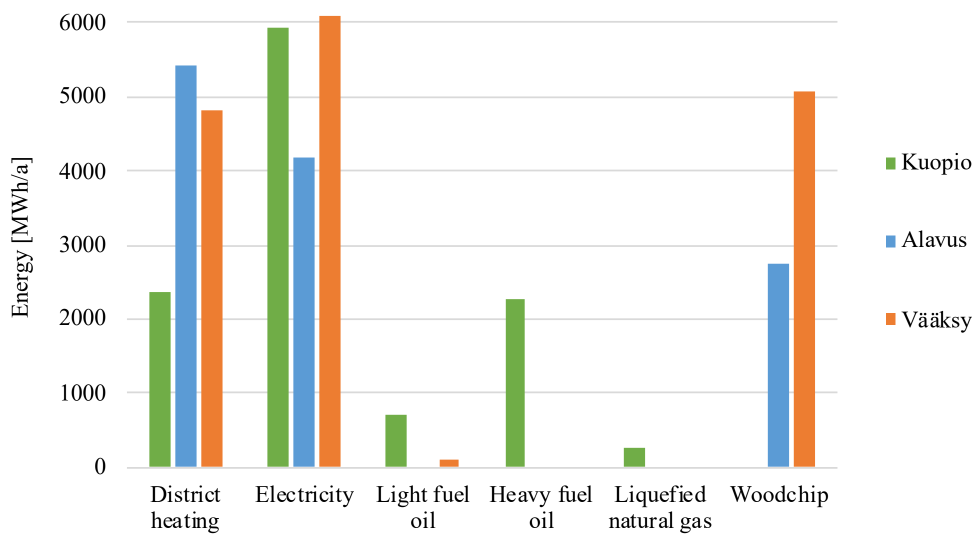


**Figure 25**. Annual energy consumption of the sites by the energy form in the reference year 2018.

The excess woodchips from the sites are used in the district heat generating process, along which the sites purchase occasionally some extra district heat in case the amount of heat from the woodchips is not sufficient for meeting the energy demand of the site. This usually occurs only during colder periods in winter, so regardless most of the district heat is generated by the woodchips. This collaboration is beneficial also economically, as it decreases the costs from purchasing district heat due to lower price and gives the possibility to sell excess heat from the woodchips, as by comparing the woodchips and district heat at the Vääksy site shows.

The shares regarding each type of energy are presented in the Figure (26). The direct use of fossil fuels, heavy fuel oil, light fuel oil and LNG forms approximately 10 % of the total energy consumption. When comparing to the Figure (25), most of this consumption can be traced to the Kuopio site. The site in Kuopio uses both light and heavy fuel oil in the processes, and some liquified natural gas for the forklifts inside the factory. If alternative methods were to be applied in the Kuopio site, there would be significantly less direct use of fossil fuels for the whole case company, while resulting to smaller greenhouse gas emissions to the atmosphere as well.

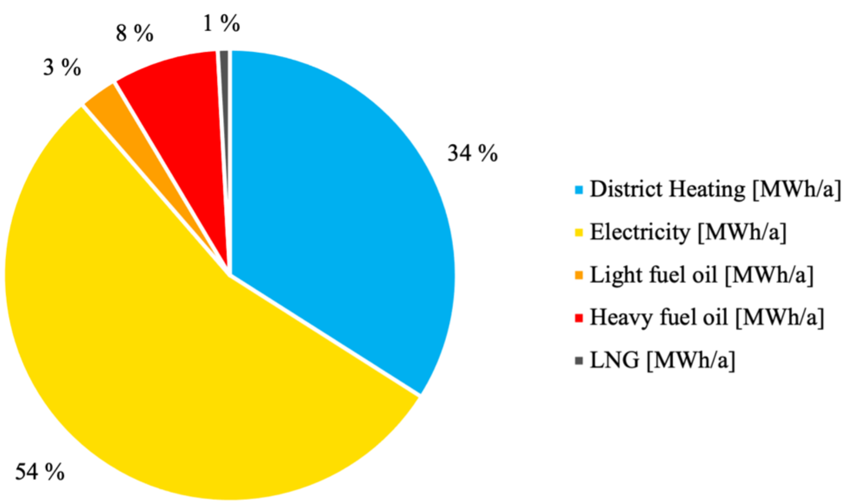


**Figure 26**. Energy consumption by type in the reference year 2018.

The significant uses of energy and variables affecting them at the sites were charted during the arranged workshops, and the key-findings are presented in the Table (3). There was level of resemblance between the findings, which can be explained by the similarities in their operations and products, as well as dealing with similar quality demands arising from the production environment inside the factories, e.g., systems regarding maintaining the desired conditions for indoor climate (sawdust removal, air pressure, humidity), space heating, painting lines, drying ovens, door-pressing, and machinery like CNC machines.

In addition to the technical production and building related energy demands, also the behaviour and actions regarding the people affecting energy demands were considered, and for example overtime and scrap generation were found to cause avoidable energy consumption. Alavus and Vääksy factories have possibilities to recover some of the energy consumed during manufacturing a product that during some point of the production happens to become unqualified to be delivered to customer with their on-going collaboration with neighboring district heat companies. Kuopio factory has no collaboration with district heating providers, and currently all scrap materials are going into waste treatment processes. Regardless of the partial recovery, reducing scrap would provide a way to decrease both the material loss and to avoid unnecessary energy consumption that is currently happening due to scrap generation in all sites.

Operations during overtime are problematic from the energy consumption point of view at sites in Kuopio and Vääksy, where the level of adjustability and automatization of the technical systems with high energy consumption like saw dust removal and pressurized air supply is lower than in Alavus. These systems are sized for higher level of production rate, so they are consuming too much energy when the planned production is lower, like in overtime when usually only a few people are working at smaller number of workstations. These systems are also vulnerable for common human errors, as they are not equipped to automatically switch off when no user is detected to use it, resulting in avoidable energy consumption. These situations were found to often happen during shift changes, if user assumes next shift will come soon and need it too, but when next shift does not arrive or does not need it, the energy is still consumed for no need.

**Table 3.** Common significant energy uses and cross-effects at the three case-sites.

| | Alavus | Kuopio | Vääksy |
|---|---|---|---|
| Area for space heating | 23 600 $m^2$ | 17 000 $m^2$ | 18 000 $m^2$ |
| Saw dust removal systems | 1448 MWh/a (385 kW, min. 3760 h/a) | 2256 MWh/a (600 kW, min. 3760 h/a) | 1692 MWh/a (300 kW, 5640 h/a) |
| Pressurized air supply system (compressors and the equipment like the air pistols, chords) | 818 – 1128 MWh/a<br>(145 – 200 kW, 5640 h/a) | 1128 MWh/a<br>(approx. 200 kW with 5640 h/a) | 1113 MWh/a<br>(180 kW, 6184 h/a) |
| Painting lines (both electricity and heat for drying) | 4512 MWh/a<br>(1200 kW, 3760 h/a) | 4715 MWh/a<br>(836 kW, 5640 h/a) | 5076 MWh/a<br>(900 kW, 5640 h/a) |
| Presses (both electricity and heat for pressing) | 2858 MWh/a<br>(760 kW, 3760 h/a | 4286 MWh/a<br>(760 kW, 5640 h/a | 4286 MWh/a<br>(760 kW, 5640 h/a) |
| Lighting | 1873 MWh/a (498 kW, 3760 h/a) | 376 MWh/a (100 kW, 3760 h/a) | 282 MWh/a (50 kW, 5640 h/a |
| Other machines | CNC machines (approx. 20 kW/unit) | CNC machines (approx. 20 kW/unit) except one larger responsible for 530 MWh/a | CNC machines (approx. 20 kW/unit) |
| People | Scrap generation, delivery date estimates (affects other sites too, if component is delivered between sites) | Overtime, scrap generation, warehouse management | Overtime, scrap generation |
| Cross-effects between Category 1 and 2 (Processes and buildings): | Overtime and lack of adjustability to technical building systems<br>Leaks in pressurized air supply chords<br>Cold air flow from negative air pressure rises the space heating demand, which affects the water consumption in the areas with specific humidity control | | |
| Cross-effects between Category 2 and 3 (Buildings and people): | User behaviour with technical building systems, e.g. Forgetting to shut down the technical building systems during weekends or holidays<br>Temperature rises indoors during summer, and cooling energy demand for the personnel rises to meet the requirements for safe working environment | | |
| Cross-effects between Category 3 and 1 (People and Processes): | Bottlenecks of production or abrupt needs of maintenance causes overtime and decreases OEE.<br>User behaviour in case of sudden maintenance needs.<br>Unpredictability of the delivery dates, miscommunications and scheduling problems causes overtime | | |

Beginning the cycle of long-term energy efficiency improvement starts by taking the first steps, which in this case is reaching the common target by 2025 set in the Energy Efficiency Agreement the organization is committed to. Since the three sites have their own characteristics regarding the energy consumption in the three main categories, it is recommended to start by sharing the focus areas for each sites, so they can then share their knowledge they have learned and aid each other through communicating about the best practices or identifying hidden improvement potentials.

## 6.1 Kuopio factory

District heating is used for space heating and hot water production, and all the other energy flows are used in the production processes. Hot water produced by district heating is however not process water in any of the sites, as it is only generated for meeting the demand of personnel and cafeterias. Electricity consumption is resulted both by the buildings e.g., lighting, air purification systems, and by processes, such as from the CNC machines and other appliances used in production. Liquified natural gas is used for transportation, as the forklifts used indoors consume it as a fuel. Light fuel oil is used both in the process for providing heat to the painting as well as some of it goes to the transportation as fuel to the outdoor forklifts. Heavy fuel oil is used for generating process steam in the door-presses and the higher capacity painting line. The annual operating hours regarding the energy consumption in the production is 3760 h for the 235 working days per year and 16 h per day due to two shifts a day, but without considering possible overtimes.

Share of the energy consumption reduction target for Kuopio site is 1 600 MWh, which should be achieved by the year 2025. Energy consumption however is directly connected to the production, which is controlled by the demand for the products. Thus, the nominal energy consumption chosen to represent the development of energy efficiency, should be calculated to take into account possible shifting in the production instead of aiming for one value, as it would limit the production to the state that it was in 2018. The nominal space heating demand can be calculated to Kuopio site as it is only facility that does not use yet district heat in the manufacturing processes. The nominal space heating value for Kuopio is approx.. 138 $\frac{\mathrm{kWh}}{\mathrm{m}^2}$, with the area of 17 000 $\mathrm{m}^2$, and district heat consumption of 2 353 MWh in 2018.

The consumption of fossil fuels in the process heat are taking place in the pressing and painting lines at Kuopio site, where heavy fuel oil and light fuel oil are currently used. The factory is interested in changing the process heating source for these phases to district heat in Kuopio site, like it already is in the other sites. This change would mean that the steam circulating in current processes would be done with liquid water instead and replacing the steam radiators with radiators using liquid water. This causes need to change the lay-out as these take more space. It is likely that the technical systems for the building could be optimized at the same time, as for example the excess heat that is removed when feeding the flow back to the grid has to have low enough temperature. This excess heat could be usable for lowering the space heating demand in wintertime. With including the heating pump to the process there is also opportunity for heat recovery for the compressor pressing the circulating refrigerant steam. After the change the heating capacity would be 1 017 kW and cooling power for returning district heat 722 kW. The minimum temperature for the input flow to meet the requirements of the manufacturing processes would be 95°C, and desired temperature for the returning stream would be 40°C. (Etteplan Oy/Hiltunen 2019, ordered investigation)

The data for significant energy uses was gathered by auditing the case sites with the local upper management representatives from production and maintenance. There was multiple SEUs for each site, but the key findings that were common for all three factories are gathered in the Table (3). Even if the scale is different between sites, it was obvious that improving these even by smaller actions would not only provide large improvements but is such a repetitive theme that it can be used as a starting point to ask around and share best practices inside the whole organization, starting from the other Northern and Baltic factories that share the similar environment and/or production processes, as all of these are connected directly to both or either of them.

During the audits significant cross-effects were charted as well, including for example, the findings related to the pressurized air supply system and saw dust removal was coming up from all three sites, and also listed in the focus points for efficiency improvement plan in all three sites due to the high power demand for them. It was found out also however that the pressurized air supply and saw dust removal also increases remarkably the heating demand, because system increases air pressure difference between the indoor air and outdoor air, creating suction (especially during winter) for the cold outside air to enter and lower the temperature inside, which leads to a higher space heating demand as well.

## 6.2 Alavus factory

Site in Alavus uses district heat and electricity in their manufacturing processes. Some amount of diesel oil is consumed in material transportation vehicles, but there are no LNG forklifts inside the factory like in Kuopio. Most of the district heat is sourced from the neighboring district heat provider, who reciprocally utilizes the excess wood chips from the factory that are resulting from the manufacturing processes. Woodchip load is usually enough for meeting the district heating demand of the site. The capacity of the boiler in the district heating process is known to be 5 MW, and it supplies energy for the whole industrial area, as this site is not the only customer in the neighborhood. The woodchips decrease the environmental impacts that otherwise would be due to district heating consumption in the area, as they are used by the district heat provider for serving all of their customers in the area, thus decreasing the need of fossil fuels in their processes.

Alavus factory has the largest area and space heating demand, which shows in their District Heating consumption. The output from the factory was smallest of the three in the comparison year, but the district heating consumption was the largest of all three. The share of the decrease for Alavus site was chosen to be 1000 MWh, as it was expected that by improving their building envelope the heat losses eliminated would be so significant. The site has large area of the roof covered in windows, that are very likely to answer for high share of the space heating losses. Alavus factory has large outside warehouse areas as well, which are restricted outside of the scope of this study. These warehouses are not inside the manufacturing facilities and do not have continuous staff presence, but they could be addressed for example upon assessing the energy use of logistics and transportation at the site.

During the audits it was clearly noted that Alavus site has quite different layout and flow of production when compared to Kuopio, while they do have similarities in their final products they manufacture. Alavus site has currently three painting lines and three door presses, while Kuopio site has two presses and four different painting lines. The manufacturing processes have similar steps, but they are in different scale and some cases also done bit differently, for example with different level of automatization. Upon the audits it was found out that with the streamlining of the production flow at the Alavus factory would likely to have positive cross-effect on the energy efficiency of the site. This would also have positive impact on predictability of the production, which would decrease the occurrence of sudden overtimes, where the manufacturing disadvantageous from the energy consumption point of view as the systems are oversized for the smaller output hours. Improving predictability was seen useful also from the customer service point view, as it would enable giving more precise information e.g., delivery-dates etc. and improve the customer experience.

## 6.3 Vääksy factory

Vääksy factory resembles lot of Kuopio factory, but they have very different products when compared to the other two that work mainly with project customers. The Vääksy factory produces most of the hardware-store-products that are directly purchased by the end-user. Like the Alavus site, Vääksy factory collaborates with their neighboring energy provider. Currently the Vääksy site has their own smaller boiler, where they produce district heat with excess woodchips, and sell the amount they don’t need in their own process to the neighboring district heat energy company.

The boiler is approximately 22 years old, and as it was scheduled to be replaced right in the ending of this first period of Energy Efficiency agreement that ends already in 2025, the share for Vääksy site was deliberately chosen smaller than the for the others, with approximately 200 MWh, as they will have large investment for the boiler coming to the following agreement period. There are already preliminary plans made for the future boiler, as they intend to deepen the collaboration with the neighboring energy company. To do this, the new boiler is estimated to be a bit larger than the current one, which has been fitted originally only for the factory. The new boiler is planned to grow by approximately third of the current one but remain under 5 MW.

## 6.4 Examples of Energy Efficiency improvement calculations

After identifying the significant areas of energy consumption, the next phase for planning energy-efficiency improvements can begin with identifying the variables, as well as the restricting factors affecting the energy demand and monitoring the changes in energy consumption regarding each area of energy efficiency potential. Acknowledging the external actors enables more reliable revision of the progress, as the reasons behind changes in the energy consumption can be traced more precisely to the actual measures taken when the effects of other actors is known, for example weather or variation in demand.

The development of energy performance can be followed with nominal energy consumption, which provides insight to seasonal and inter-annual changes in energy consumption, as well as to fluctuations of demand. Nominal energy consumption represents the amount of needed energy per one produced unit, meaning that lower the nominal energy consumption value, the more units can be produced with the same energy. With the known values from the baseline year 2018 and ideal energy consumption and production, the optimal nominal energy consumption can be calculated, which then can be used to guide the sizing of the energy efficiency actions.

As there are multiple factors that affect the wanted annual output of the units, fixed target for energy consumption is problematic measure for planning proper energy efficiency actions to achieve the wanted energy savings. Since the energy consumption varies according to the production that is not fixed, also the target should follow the fluctuation of production, instead of setting fixed target for the energy consumption, as shown in Figure (27). This keeps the amount of difference equal regardless of the number of produced units. With using fixed target, the difference would grow quickly larger than anticipated, if the production is not the same as it was during the baseline year, making sizing the energy efficiency improving actions difficult.

For the Kuopio site the amount of planned energy savings is 1 600 MWh/a from the level of year 2018 consumption, while the amount of output units was 338 526. This means in practice that the energy efficiency actions should be applied in a way that in year 2025 same number of doors could be produced with only 9930 MWh/a. Production however should not be restricted to the number of produced units in 2018, as it should be allowed to be varying according to supply and demand, rather than energy consumption.  As energy consumption naturally grows when the number of output units grows, the interest is to achieve savings by decreasing the steepness rather than restricting the output units. The nominal energy consumption can be applied as defining the slope of the graph.

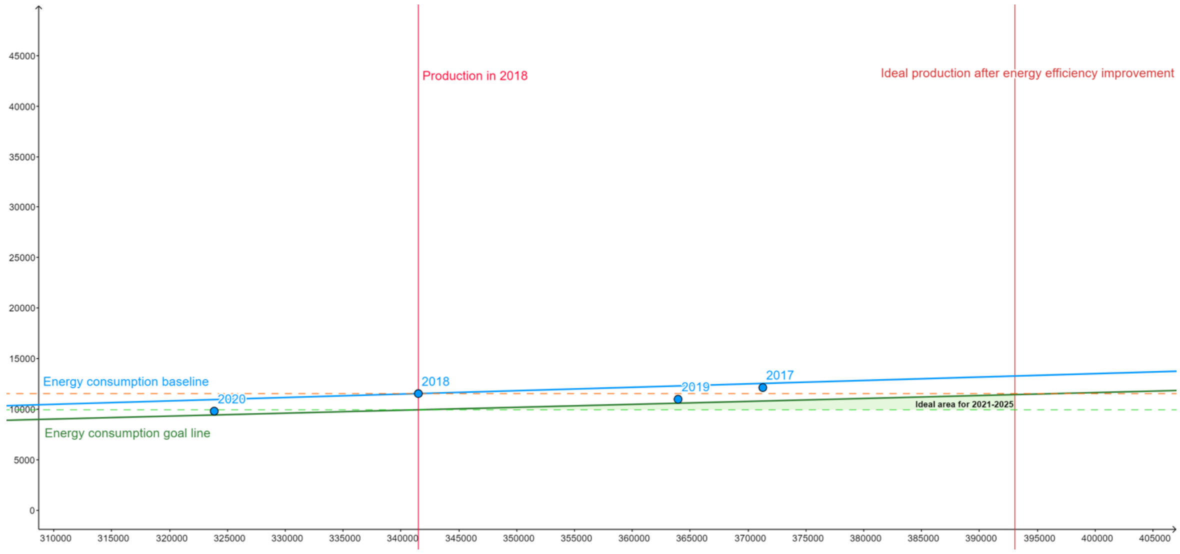

**Figure 27**. Calculating the ideal area for the annual energy consumption as function of produced doors in Kuopio site.

The calculated ideal value for the produced amount is simply considered to be reached, when the number of produced doors with the achieved better nominal energy efficiency value meets the energy consumed in 2018. This ideal situation means that the factory has been able to produce more doors with the same energy that was earlier needed for smaller output. It should not be considered as a limit, but rather as a post to aim for with the planned energy efficiency actions. Calculating the target nominal energy consumption with the reduction targets of energy consumption is done with the Equation (2) for all the sites:

$$E_{consumption,_{i,\ 2025,\ i}} = E_{consumption,_{i,\ 2018,\ i}} - \Delta(E_{consumption,\ i}) = \frac{E_{2018,\ i}}{Volume_{2018,\ i}} - \frac{E_{savings,\ i}}{Volume_{2018,\ i}} \quad (2)$$

where:

$E_{consumption,\ i}$ is the nominal energy consumption in $[\frac{kWh}{unit}]$

$E_{2018,\ i}$ is the measured energy consumption in the baseline year in [MWh]

$Volume_{2018,\ i}$ is the number of produced units in the baseline year for each site

$E_{savings,\ i}$ is the amount of wanted decrease in the energy consumption to reach during the time period in [MWh]

The target nominal energy consumption for Kuopio site, when the reduction target is 1 600 MWh:

$$E_{consumption,_{i,\ 2025,\ Kuopio}} = \frac{11\ 530{,}32\ \text{MWh}}{338\ 526\ \text{units}} - \frac{1\ 600\ \text{MWh}}{338\ 526\ \text{units}} = 0{,}02933\ \frac{\text{MWh}}{\text{unit}} \approx 29{,}33\ \frac{\text{kWh}}{\text{unit}} \qquad (2)$$

The target nominal energy consumption for Alavus site, when the reduction target is 1 000 MWh:

$$E_{consumption,_{i,\ 2025,\ Alavus}} = \frac{6\ 856{,}23\ \text{MWh}}{117\ 680\ \text{units}} - \frac{1\ 000\ \text{MWh}}{117\ 680\ \text{units}} = 0{,}049407\ \frac{\text{MWh}}{\text{unit}} \approx 49{,}41\ \frac{\text{kWh}}{\text{unit}} \qquad (2)$$

The estimated development for the energy consumption for Alavus is presented in the Figure (28). It can be seen that during the latest years the progress is steeper, when comparing the distance of the 2019 and 2020 to the baseline. It is likely that this is due to the growing production rate and high capacity available for production, and as the interest is to grow it even more, the energy efficiency actions should be applied to support the growing production, and idealistically decouple the growth rate of energy consumption from the growth of production, by decreasing the nominal energy consumption.

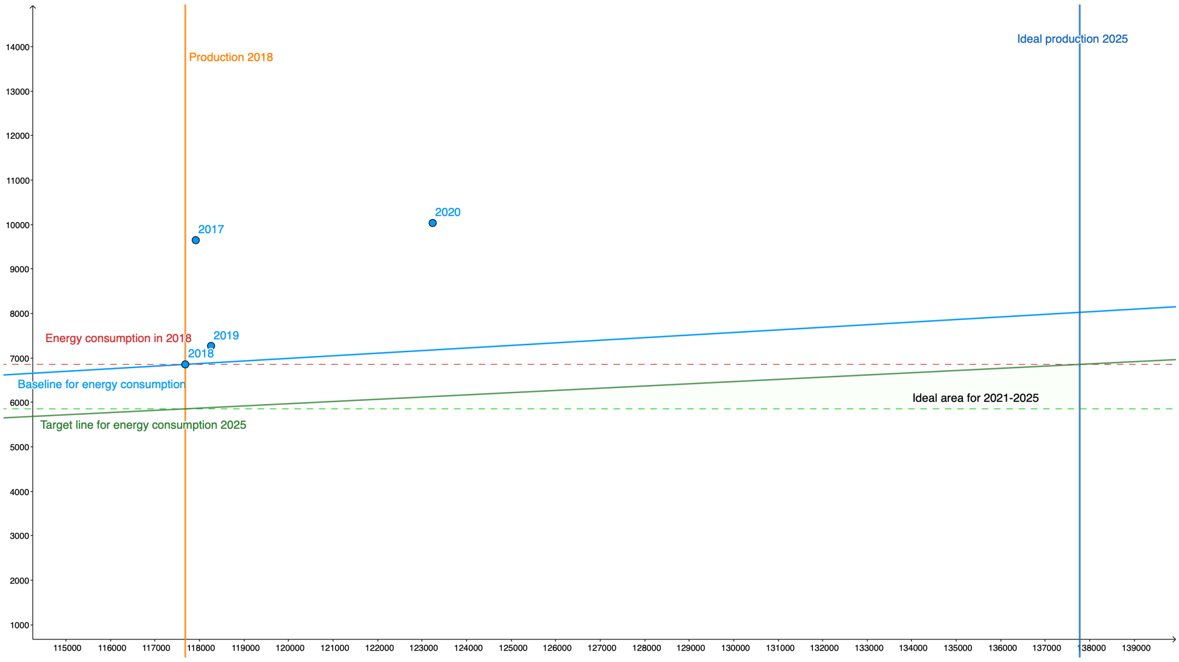


**Figure 28.** Target for energy consumption development in Alavus factory.

The target nominal energy consumption for Vääksy site, when the reduction target is 200 MWh:

$$E_{consumption,_{i,\ 2025\ Vääksy}} = \frac{11\ 254{,}176}{189176\ units} - \frac{200\ MWh}{189\ 176\ units} = 0{,}005848\frac{MWh}{unit} = 58{,}48\frac{kWh}{unit} \qquad (2)$$

The energy consumption target line for Vääksy site has two ideal areas for energy efficiency improvement, as this site is expecting to have significant changes later on. If these actions were to be conducted during the first agreement period, for example at the end of it, the estimation would clearly go over the first reduction line. If these actions were taken, the ideal area would be anywhere below the target line, yet likely somewhere over the original consumption, as highlighted in blue in the Figure (29).

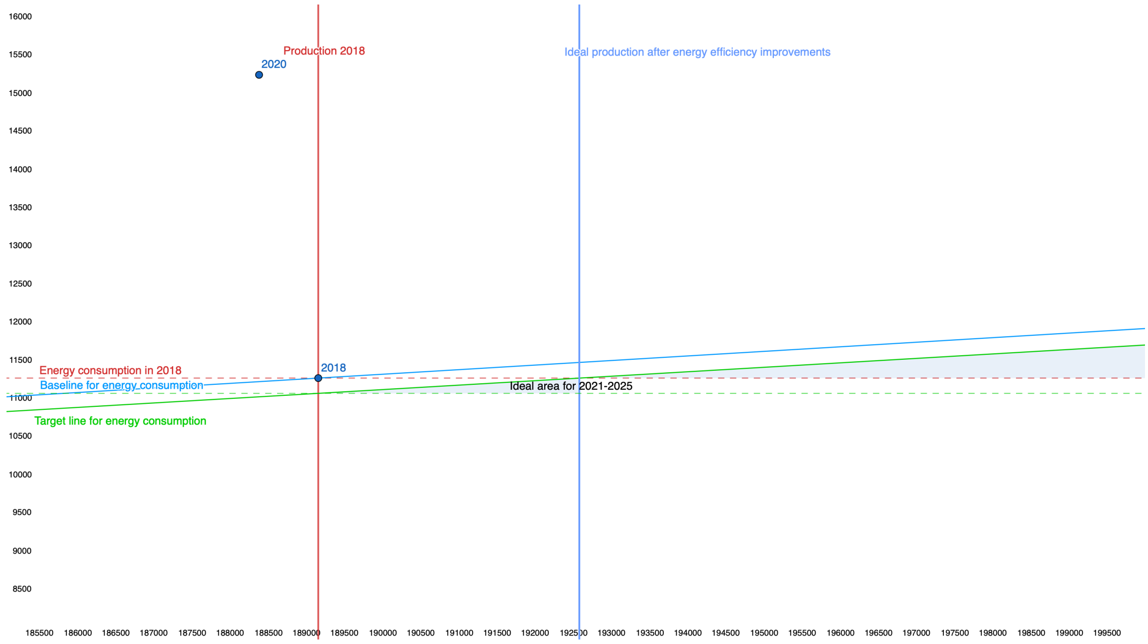


**Figure 29.** Energy consumption target line for Vääksy site in 2025.

Table (4) presents the results for the overall targets for the nominal energy consumption in the target year that upon reaching are expected to fulfill the wanted energy consumption decrease from the baseline year.

**Table 4.** Nominal energy consumptions and energy savings used to size energy efficiency measures.

| Site | $E_{consumption,2018} [\frac{kWh}{unit}]$ | $E_{savings} [\frac{MWh}{a}]$ | $E_{consumption,2025} [\frac{kWh}{unit}]$ |
|---|---|---|---|
| Alavus | 57,91 | 1 000 | 49,41 |
| Kuopio | 34,06 | 1 600 | 29,33 |
| Vääksy | 59,49 | 191 | 58,50 |

# 7 ENERGY DATA ANALYSIS FOR EFFICIENCY ACTION PLAN

As a result of energy data analysis, the energy efficiency action plans for each site are created. Energy action plans are first and foremost are for bringing together the strategic and operational level of established cycle of continuous improvement for long-term energy efficiency management. Comparability of the action plans is necessary also for sizing the energy efficiency actions correctly to see, whether or not the sites are fulfilling their part on reaching the target for each energy efficiency agreement period they are committed to.

Establishing and upkeeping energy efficiency action plan answers to the implementation of the energy efficiency management on the operative level of the business management, and it is highly connected to the context to identify the items to include to the action plan and to consider the possible cross-effects that changes can cause throughout the chain of processes inside the factory, as earlier mentioned: the energy efficiency improvement should be optimized holistically for whole processes, as partial optimizing for sub-parts of the process can cause problems arising elsewhere in the factory. During the executing phase of the energy efficiency plan, the progress is monitored and analyzed to see if the taken actions are leading towards desired outcome. Gained knowledge is shared between the energy efficiency teams in other sites, where they can by following this same order identify new energy efficiency improvement potential they possibly missed.

After the energy data about the characteristics was gathered, the next phase of the workshop was to identify actions for each SEU to the energy efficiency action plan, which was followed by dividing the responsibilities between the energy efficiency team member and prioritizing the actions. The responsibilities regarding the actions were shared according to the area of SEU in question of the action, and the expertise of the responsible person, as shown in Figure (30) which is a sample from the Energy Efficiency Action plan made in the Kuopio site.

| NO | MEETING | SEU | ACTION | SAVING POTENTIAL [MWh/a] |
|---|---|---|---|---|
| 1 | 20.2.2021 | Heating in pressing & painting lines | Change to district heat from oil | -814,68 |
| 2 | 20.2.2021 | Pressurized air supply (3 x ≈100 kW compressors) | New compressor room, heat revocery possible | -233,33 |
| 3 | 20.2.2021 | Saw dust removal system, multiple units together ≈ 600 kW | More adjustability to the system | 2160 |
| 4 | 20.2.2021 | Painting line: UV, 60 kW | Automatic paint feeding and new pumping system for the production. Pump chosen should be energy efficient and correct size | N/A, energy efficiency and sizing will be considered upon investment again and saving potential |
| 5 | 20.2.2021 | Space heating, large area | New roof to avoid thermal energy loss. Heat recovery after changing the process heat. Not yet applicable | Saving potential and possibility for solar energy should be charted |
| 6 | 20.2.2021 | Lighting | Changing the old high pressure Na-lamps to LED | 24 |
| 7 | 20.2.2021 | Torwegge | Cutting use hours when possible, directing production to smaller CNC machines. After renovating upstrairs (layout changes in summer 2023, changing the machine altogether to smaller or removing it altogether | 450 |
| 8 | 20.2.2021 | CNC machines (Homag), ≈ 100 kW total | No actions yet required | Not yet actions considered, annual energy consumption 376 |
| 9 | 20.2.2021 | Heating Pump, 300 kW | No actions yet required, will come along the process heat change | N/A, energy efficiency and sizing will be considered upon investment again and saving potential |
| 10 | 20.2.2021 | IR-oven, 65 kW | No actions yet required, will come along the process heat change | N/A, energy efficiency and sizing will be considered upon investment again and saving potential |
| 11 | 20.2.2021 | Forklifts | Use of electrical transport measures indoors always when possible (roller conveyors, transfer sleds etc.) for minimizing the need of forklift transport indoors. Indoor forklifts consume LNG currently. | No yet actions considered, annual energy consumption 240,77 |
| 12 | 20.20.2021 | Heating posts for cars, 100 x 400 W | Each post is on from November to March, 4h/day (2h for each shift). Possibility to decrease the posts now with growing remote work? | 17,6 |

**Figure 30.** Example of the Energy efficiency action list made as result of the energy data analysis.

After comparing the action plans between the sites, some of the cross-effects seemed to appear on all of the sites, for example the connection between the OEE indicators and the electricity consumption and overtime and excessive energy consumption. For better understanding of these phenomena were studied more in Kuopio site, as it seemed to share most of its characteristics with both of the other two factories, when considering the similarities in the products with Alavus, and having similar size with Vääksy site.

While addressing the energy efficiency for each whole line at a time upon planning energy efficiency improving action, the risk of cross-effects and shifting the energy consumption inside the line is decreased, but still not affects the possible impact the production lines can have between each other. Likewise the cross-impacts between the categories of energy efficiency should be considered when planning energy efficiency improving action. I believe that these cross-impacts are necessary to be investigate further, as they could be taken advantage of or cause risk for action to fail, which both are valuable information for ensuring the effectivity of the action plan.

After investigating the data from the production few suitable days to compare energy consumption were found to estimate the significance of key production phase (press) malfunction to the electricity consumption. Both presses use heavy fuel oil for the steam, so cutting either one of these out of use due to malfunction should decrease the electricity consumption by the amount they consume and likely to cause even the whole production line to stop, with some delay. The scenario in the first case is the malfunction of the press from the standard line, while the project door line has just usual day of production, the second scenario was same but the other way around.

It appeared that naturally the amount of good production hours had large impact on the electricity consumption, as those are the hours when the output is highest, and most material is processed. It would also appear that the hour of disturbed production can be decreased significantly with applying precautionary maintenance, as the audits already suggested. For example, in Kuopio, precautionary maintenance was done in March during the holidays when production was not running, see Figure (31). The good production time increased in both presses after the maintenance, as well as the availability became steadier, meaning that the need for sudden maintenance decreased as well.

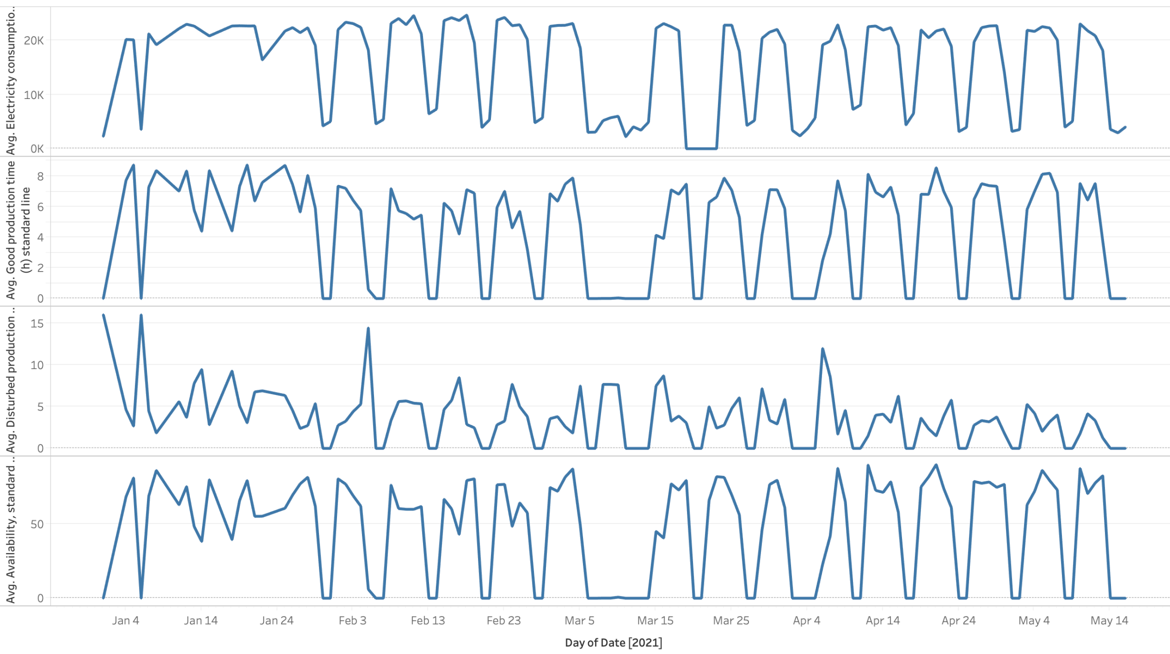


**Figure 31.** Effect of precautionary maintenance on interruptions in the production.

As a result in the first scenario, it was seen that usually when the disturbed time in the standard press was decreased by 10 hours, the electricity consumption increased approximately 4 MWh.  As a result of the second scenario, the disturbance was decreased by 12 hours, and the increase in electricity consumption was approx. 5 MWh, when the production was balanced during the week. However, when only the project press is put to work on weekend, the electricity consumption due to this activity itself varied between 3 – 8 MWh, which especially compared to the number of production output is rather large.

Technical availability represents the relationship between the planned production hours and the time for production available after considering scheduled maintenance hours. Abrupt needs for maintenance in malfunction situations decrease the operating time, causing lower level of availability. Availability is one of the key values in calculating the Overall Equipment Efficiency, OEE. OEE consists of availability, performance, and quality. Figure (32) represents usual pattern found in the data. It can be seen that both as the availability and the time of good production grow, it naturally has increasing impact to the electricity consumption. In addition, when the OEE for the production can be increased when the technical availability increases, since it decreases the disturbed time and increases the performance and availability of the production.

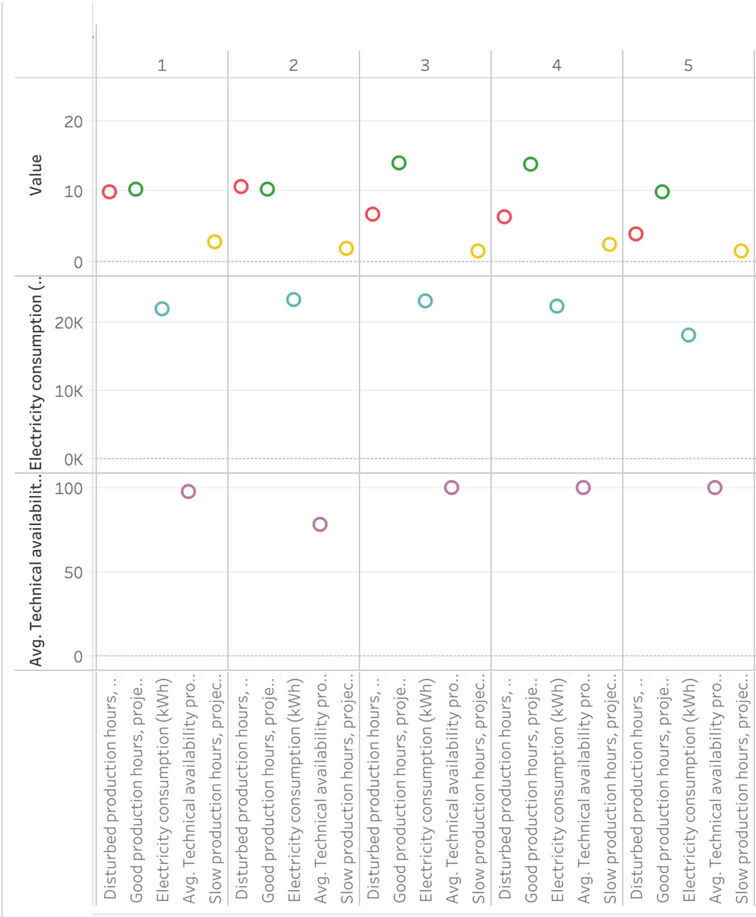

**Figure 32**. Example of the production week in the data.

Due to these findings, the energy efficiency plan should consider also the actions supporting the efficiency of the production, as more steady production decreases the sudden situations that are not favourable for energy consumption, like for example for reducing the overtime, where the manufacturing processes are often over-sized in the sites. Also what seems to be present in the data as well is that the products made in project line consume more energy than the standard product line, as the number of standard products made is still larger even if the effect on electricity consumption from malfunction situations are quite close to each other. Another interesting cross-effect would be to investigate how much of the originally consumed energy needed for producing one unit could be recovered by utilizing the scrap products in district heat generating process.

Currently some of the non-usable products that have gone at least partially through the manufacturing processes are utilized in Alavus and Vääksy as woodchips that enters as fuel in the district heating processes. This could not be yet investigated however as there was no data available for the amount of scrap doors re-entering the production processes as fuel. It should also be noted that decreasing the sudden maintenance at sites is important especially when considering situations where malfunction occurrence causes interruptions in the energy generating processes, like heavy fuel oil power plant or woodchip district heating boiler, because starting again boilers requires lot of energy and is usually causing spike in emission release from the burning process.

The energy balance of buildings is especially acute target of interest for improving energy efficiency at the Alavus factory, where large share of district heat is lost through the ceiling windows. Alavus factory has large floor area, as well as large ceiling area, making changing the roof to a solid, windowless ceiling a significant energy efficiency investment. The ceiling-windows do not currently significantly increase the lighting inside the factory, as they are partially covered with veneer sheets etc. material to block escaping heat. Regardless as a preparing action, the old lighting solution has been changed to LED, decreasing the original 1873 MWh/a to half, while gaining improved efficiency in the light since these provide also better level of illumination.

# 8 CYCLE OF LONG TERM ENERGY EFFICIENCY IMPROVEMENT

The EES+ system revolves around the principle of continuous improvement, similar to already existing management practices in the case-company, and throughout the whole global organization. The cycle of long-term energy efficiency improvement is built on having routines for reviewing the state of energy consumption and identifying places of improvement. By actively and systematically searching, new improvement potential is likely to be found. Thus, the energy efficiency has been included to the already existing agenda of the operations reviewing process that is done on monthly basis.

The continuous improvement requires also continuous measuring of the energy consumption and monitoring the progress of the energy efficiency improvement made over time. In addition to the monthly monitoring and analysis, the first review of the year concludes the earlier year and updates the agenda for the next, as well as assesses the need to develop also the management system itself and set new actions to be followed through and identify new opportunities and risks present at the current time. This energy consumption monitoring and regular analysis is happening as part of the cycle for maintaining the energy efficiency action plan, as presented in the Figure (33). The loop should be supported with effective communication between the sites inside the case company, even between the sites of the whole global organization, upon knowledge is created during the first period and learning results are analyzed during annual reviews.

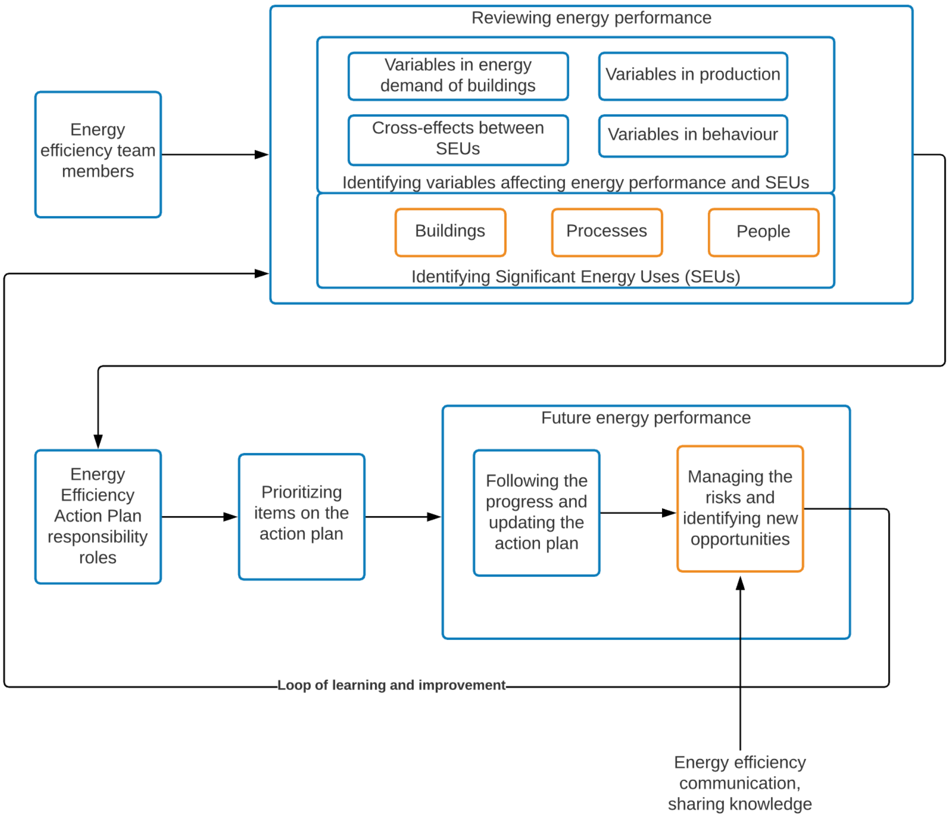


**Figure 33.** Schematic for the Energy Efficiency Action plan reviewing loop.

The Energy Efficiency Action plans are set to work as a map for reaching the targets, but new targets are needed to be set after reaching the first targets in order to keep the loop going. The target is set on the Energy policy, which naturally means that the Energy policy itself needs to be reviewed regularly too. In this case the target in the Energy policy is set to be updated in the same cycle as the Energy Efficiency Agreement period, and additionally always if there comes external changes from regulators, or internal changes in management procedures, like adopting new energy or environmental management standards.

It was found that Energy efficiency investments are prone to lose the competition at the company level against other important investments, such as productive investments, which makes it harder to prioritize the energy efficiency related actions. (Työ- ja elinkeinoministeriö 2019, 19). This means, that likely partially energy efficiency improvements are generally not prioritized high enough, as not enough people making the investment decision value it over the other items on the investment list. Reviewing the energy performance creates knowledge and educates the management about the energy performance. Cultivating the energy perspective in the day-to-day management can be beneficial to driving the energy efficiency investments and identifying places of investments that can be multi-benefitting. For example, decreasing downtime, increasing OEE and optimizing the good performance of the operating hours has been and will remain as one of the key-interests of the plant management. It however should interest them now on also for the energy benefits they can gain at the same time, which can change the order of the list when prioritizing investments.

By dividing the review throughout the year, management is engaged into the energy aspects in the everyday life. This supports actively considering energy efficiency aspects and see the hidden potential when they might appear in the day-to-day level, also regarding how the energy policy is implemented and how effective it is. The networking should be extended to reach other factories on wider scale. To do this, one part of the energy efficiency communication is the best practice sharing and sharing also the criticism about the content of the efficiency program, as if some risk occurs and one place notices it, others can take their advice on how to prevent the risk to hinder the energy efficiency action to work.

Governance and power structures need supporting environment inside the organization that fosters sustainability culture. Achieving the goals and implementing energy efficiency strategy, all people that contribute to the activities that consume energy should be engaged. To do this communication and training are needed, as well as the management should be eager to listen the operators that for example use the machines every day to find any operative change related energy savings, like for decreasing the energy consumption from the idle or stand-by time in the production.

The communication should also go across the organization to engage all factories to co-operate or become even motivated to actively work for improving the energy efficiency. If energy efficiency investments are put under competition through budgeting or regarding allowed investments, it is at risk to be seen as nuisance that limits the existing way of working, cutting their budget. Energy efficiency improvement is in this case not desired to translate into limiting production, as it should be seen as quite the opposite and as an asset to make more with the same resources, like the organization already has implemented in its Kaizen methodologies with waste.

For gathering the qualitative data about the characteristics of the energy demand and the possible development regarding it, it was clear that the information is partially tacit, behind different departments of the organization. To gather this information together workshops were arranged for representatives from maintenance department, production planning and management as well as the environmental management. Agenda for the workshops included the three main categories: processes, building and people.

The loop of continuous improvement for energy efficiency should be paired with loop of learning about not only the content energy data but ensuring quality and quantity, which are essential for relying to the energy knowledge that is generated along the way. The best practices should be shared between the case-sites to both benefit from the findings and to avoid possible risks and facing same problems. Open energy communication is needed to complement the data gathering process, as otherwise the source of energy data and the energy efficiency improving potential could be missed by the energy efficiency team responsible for energy efficiency management.

# 9 CONCLUSIONS

Shared, global issue in the field of CSR lies between the actual changes and communicated strategies of businesses. Business model connects the company to the societal context, bridging the company level to the system level. There has been recognized however disconnection between the company level actions and the sustainable development, slowing the progress. (Koistinen et al., 2018).

Aware stakeholders, like customers expect the businesses to think beyond making money and to pay attention to social and environmental issues, before they are making buying decision. The level of skepticism is increasing among stakeholder groups, and people are becoming more cautious towards businesses, as with time they have experienced widely the phenomenon of businesses greenwashing their brand. As nearly 70 % consumers think that advertising is often untruthful, the task for business management to convince the public that their practice meets the promises is challenging. For gaining the trust businesses should show that instead of leaving CSR to the level of occasional initiatives and projects labeled as promoting sustainability, all of the spheres of sustainability are really embedded in the core of their business models, and then carried out into their day-to-day practices. (Schons and Steinmeier, 2016).

Rebound effect takes place between the reduced costs of energy service, which occur due to better efficiency and new consumption that is now able to do with the same cost as before, resulting in more consumption with lower price, as the new amount was before undesirable due to costs. This Jevons Paradox, describes a phenomenon where the better efficiency causes the consumption to rise, both through direct and indirect pathways (York and McGee, 2016). This can be explained by the fact that with the improved efficiency the production is able to grow as well. However, this causation between energy efficiency and growing energy consumption is debatable, as while higher energy efficiency makes it possible to accelerate productivity, it does not make it mandatory. If the energy efficiency investment is not based on the meaning to increase production, the energy consumption will decrease.

Regardless whether or not achieving the higher energy efficiency decreases energy consumption, ultimately the production is done with less energy it would have taken before. If production is allowed to grow upon better energy efficiency, it also enables meeting the demand of larger number of customers with products made with less energy than for example competitor, who do not invest in their energy efficiency.

The sustainable transition of energy system shapes all industries, including construction. Regional carbon neutrality targets shift the pressure to all parties that are responsible for greenhouse gas emissions, and when considering the huge share of emissions that result both from the energy consumption of buildings during the use phase of buildings and the emissions from the actual construction process and the supply chain from the stages A1-A3 in Figure (13), from raw material production and reaching the manufacturing the building components. Identifying energy efficiency improving potential lays good foundations for also carbon footprinting, as significant shares of the emissions resulted from manufacturing processes are resulted from energy use.

Governance and power structures need supporting environment inside the organization that fosters sustainability culture, making it essential for fostering energy efficiency promoting culture as well, since energy and energy efficiency are significant part of sustainability management of businesses. As a building envelope component manufacturer, the case-company has to recognize their role as larger, global actor and supplier to the construction industry and be prepared to adjust to the pressure that is already given due to demands of legislation and expectations of the end-users, as carbon neutral housing will require carbon neutral supply chain too. These developments of the construction industry are expected to shape the product design and requirements, which already shows in the current, energy efficient product lines in the selection. This impact of the global sustainable transition can be expected to become even more significant in the coming years, which will require also the sales and R&D department to engage in energy efficiency improvement of the product for the purpose of the customer.

Upon aiming for carbon neutrality, the greenhouse gas sources and sinks should be in balance. Sustainable forestry is already essential part of the carbon sinks, including also the embodied carbon in the wood products – like the construction carpentry. Manufacturing doors with wood provides a way of sequestrating carbon, which can be something new to consider in the product development along the already common energy efficiency related themes, like U-values and sealing performance. It is good to keep in mind that one of the main motives behind the energy efficiency and sustainability movement is the societal change to carbon neutral countries. Even if not all countries yet are not committed to carbon neutrality, the demand for better sustainability performance is everywhere. The case company is large actor in their field of business and engaging in this gives them opportunity to drive the change throughout their massive organization, affecting the whole branch and activate their competitors too, resulting in the co-evolving between technology and user environment that is needed for driving the whole global sustainable energy transition.

For embedding energy efficiency management to Lean management organization, EES+ was found applicable. The key to establishing flexible and curated EES+ starts with charting the current energy consumption, and finding out the significant energy uses, SEUs. SEUs are specific appliances or systems that have high energy demand regarding the overall energy consumption or have high potential for energy efficiency improvement. In addition to energy efficiency improving potential and amount of the energy consumption, the items on energy efficiency action plans should be prioritized by considering the possible cross-effects they have on the energy consumption and energy efficiency.

The energy consumption under investigation should include the day-to-day energy demand. However, for eliminating unnecessary energy consumption that is generated as result of sudden changes or abnormal situations should be investigated as well, like occurrence of downtime due to malfunction. In these situations there is energy consumption that can be averted, which in annual level can cumulate to significant decreases of energy consumption. To get control over these situations, precautionary maintenance seems to have good impact, and it is likely that investing even more in maintenance and providing more automatic systems to observe the production would prevent occurrence of large and sudden breakdowns, if for example the early signs of weariness could be noted and precautionary maintenance actions predicted more accurately. There is need to chart possibilities and establish procedures for the machine operators to both inform about possible early signs of maintenance need, and energy saving behaviour, that they are able do and prevent unnecessary energy consumption during malfunction situations.

When considering that one of the main reasons for improving energy efficiency is to reduce the negative environmental impact, energy efficiency actions related to energy demand answering for consuming largest shares of fuel or energy systems that have the highest environmental impact should be taken into account upon prioritizing the changes. All energy efficiency improving actions are meant to improve energy efficiency, but not all will decrease the use of fossil fuel and the emissions the normal consumption would generate.

Trigger for new opportunities can appear through the energy communication and mutual learning, as even though the three factories are not identical, they share similarities and it is expectable that sites are able to share lots of best practices they learn along the way. Also there can appear sudden changes over time, e.g., due to changes in operating loads, equipment degradation and improvements in available technologies and techniques. Opportunities and risks regarding these have to be regularly reviewed and keep track of how equipment and systems are operated and maintained.

Recommendations for the organization to meet their first target and accelerate exploring their energy performance is to focus on three main categories: process, buildings and people on different case-sites, since there are three of them too. After starting from different focuses, sites can share their best practices with each other, and streamline this way also the practice level implementation of the all categories, since it is expected that even after the first SEU charting, there still exists significant, hidden potential in all of these areas of improvement.

Kuopio site should start with the process, by changing their process heating source and applying heat recovery from the heat pump coming along the change. In addition to these, the pressurized air supply systems and saw dust removals are significant for all of the sites. Kuopio site should include improving the leak-eliminating procedures or systems to the pressurized air supply system, and piloting for more flexible saw dust removal system, that could be adjusted by the level of production running, decreasing the excess use of energy in abnormal production situations like overtime and weekend work.

Root cause for the overtime work however is usually connected to bottlenecks in the production chain, which cause delays in the process flow. Kuopio could also investigate the effect of reducing bottlenecks to the energy consumption. During the energy audits made it became quite clear that also using woodchips from the by-product streams of production is a good resource not yet advantaged in Kuopio site. There has been earlier attempts for collaboration, but as the nearest district heat provider is not as close as in the other cases, the collaboration has not gone further. Re-attempting this should be considered, as it would provide a way to promote circular economy locally and enhance the resource use, as well as give opportunity to recover some of the energy used in scrap doors that currently just go to waste.

Alavus site should start with the energy efficiency of the building structure, as they are the most prominent of the sites both in terms of space heating demand and the heat losses through their building envelope. Changing the ceiling would decrease significantly the energy consumption for the space heating, and likely result to even lower the nominal energy consumption even more than needed. This would be very beneficial as their production is most likely to grow due to future investments like the new painting line and door press coming that increase the production. As the importance of reducing heating and cooling energy demand are prominent in the energy consumption of all buildings, Alavus site could also consider the optimization of heating and cooling fluids, and their system control as part of their energy efficiency program.

Vääksy has the smallest target currently, and for making it more challenging would be to try to get the improvement just by implementing operational changes. It would however provide great insight to the other two to implement on top of their technical changes. One operational change Vääksy could start investigating would be to establish guidelines to act on malfunction situation for decreasing energy consumption generated from the idling machines when something needs maintenance and other machines after the machine being operated on are waiting to be running again.

Workshops were arranged for each location for collecting energy data about the energy demand and variables affecting the energy consumption. There are for example technical aspects from the machines and facilities, business aspects from level of current and estimated production, as well as environmental aspects to consider, which is why it is recommended to gather multiple people from at least of these areas of expertise for the energy efficiency team members in any other site this case-company is part of.

# 10 SUMMARY

Due to the connected nature of the systems and natural, already existing differences in the climate, climate change manifests differently in different areas. It will not only boost the already existing risks but create new risks for humans as well. Additionally, the risks of climate change are not equally distributed. The most disadvantaged people with smaller resources to mitigate to the new conditions, living in communities already in difficult areas, e.g., suffering from food or water scarcity, are in danger for amplified issues. For example, those places that are already warm and water-scarce are in danger to have less rainfall, even drought, while those areas with heavy raining will get even more precipitation and even flooding.

As large portion of the excess greenhouse gases are formed in consumption of fossil fuels, it is in great interest to minimize the need for these polluting processes that are fueled by fossil fuels. If the energy conversion processes have higher efficiency, more can be made from less, which naturally reduces the energy consumption as with lower efficiency, more fuel would be needed to get to the same outcome. Energy efficiency can then be improved by decreasing the amount of unnecessary energy consumption, or decreasing the energy demand with making changes in the process that is consuming energy e.g. switching to newer, more efficient technologies or increasing level of automatization and adjustability to gain more control over the systems using energy.

Global sustainable energy transition pressures industrial actors to disengage from the fossil fuel consumption to limit the climate change their business-as-usual actions otherwise boost. This includes structural changes to the management and business strategies, as organizing projects or other separate events on the operative level of the business is not sufficient for company to actively control and steer their performance regarding sustainability performance, which energy efficiency management is part of. Sustainable energy transition forces businesses to adjust their processes and business-as-usual actions to less carbon intensive. Switching to the clean energy however does not necessarily decrease the consumption as it changes the source, which is naturally good for decreasing the emissions from the operational phase, but the consumed energy will not however necessarily get lower, if energy demand cannot be decreased, or even eliminated simultaneously. Hence, the sustainable energy transition and climate change mitigation needs to pair the clean energy sources with improved energy efficiency of businesses.

The energy efficiency management should be integrated as one of the core values and given equal interest as other values of any business. There needs to be established role of responsibilities, e.g., energy efficiency teams, who have wide enough expertise together to combine their views and educate each other to ensure that the actions aimed to improve energy efficiency are not causing shifting the load to other phase. Changes in the industrial processes are tightly connected between each other, and there is a risk that the action does not bring the benefits it was expected to do.

The energy data chosen to monitor the effectivity of the management should be representable and reliable. The energy data monitored should be reviewed regularly and. include not only the consumed energy data, but also the nominal energy consumption to prove the made progress in terms of energy efficiency. Part of the energy consumption is avoidable, as there are energy losses in all sites, whether they are from building, processes or people. To prevent unnecessary energy consumption, precautionary maintenance and to catch the early signs of possible malfunctions technical management systems are needed. Making these more precise require further investigation in the case company, as well as establishing procedure for the operators to follow in case of malfunction situations.

Identification of significant energy uses is based on energy data analysis, after which alternative actions can be proposed. Identifying the energy efficiency improvement potential should be done by multiple people and with discussion, to consider the cross-effects that might be present in addition to direct energy consumption sources. Energy consumption is highly connected to the context of the use and it can be difficult to find the right actions, or prioritize them especially in competition situations upon deciding the schedule for investments. As the main motive behind the energy efficiency is to improve sustainability, the sustainability of each alternative should be considered throughout the life-cycle of each option, and base the decision with the smallest environmental impact while being cost- and energy effective.

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## Manuscript of the energy efficiency workshops

Energy efficiency team members present:
Date:

General information:

- Location:
- Size:
- Energy sources:
- Operation hours (annual):

Section 1: Why are you using energy?

Identifying significant energy uses:

- Processes
    a. Pressing
    b. Painting (as a whole process lines)
    c. Pressurized air supply (for appliances used in production and removing negative air pressure from inside the factory)
    d. CNC-machines

- Buildings, see Figure (8)
    a. Space Heating
    b. Lighting
    c. Ventilation (saw dust removal system)

- People:
    a. Unnecessary idling of the machines in need of abrupt maintenance or stand-by energy consumption from the plugged-in chargers that are not in use (Weinert et al. 2018).

Section 2: What variables affect the current SEUs?

Identifying the factors that can cause the energy demand to change (Energywise, 2012):

- Production levels
- Scrap levels
- Downtime, lack of maintenance
- Quality of raw materials
- Product palette
- Weather

Section 3. If there are any known cross-effects, how they affect energy consumption?

1. “How would you describe the relationship between category 1 (Processes) to category 2 (Buildings) from energy point of view? Tell me about the restrictions and qualities demanded by processes for the building and indoor climate, and if there are some positive impacts, they have on each other on some area.”

2. “How would you describe the relationship between category 2 (Buildings) to category 3 (People) from energy point of view? Tell me about the safety and health requirements of working environment and their impact to the energy consumption of category 2 (Buildings).”

3. “How would you describe the relationship between category 3 (People) and category 1 (Processes) from energy point of view? Tell me about the behavioural aspects and energy consumption resulted from day-to-day actions.”

Free discussion:

4.” What kind of known restrictive aspects there exists related to SEUs? For example, quality demands from the production side, that affect the behaviour of the operator, which affects the energy performance. If there is, can they be arranged differently to minimize impact or averted to improve energy efficiency e.g. with new technologies?”