Laura Mettinen

Sustainable manufacturing in Finnish industrial SMEs from the LCA perspective

Development of energy efficiency, resource-efficiency, and CE measures

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TIIVISTELMÄ:
Tänä päivänä monet ympäristöön liittyvät huolenaiheet vaikuttavat liiketoimintaan. Teollisen valmistuksen sektori myötävaikuttaa vahvasti ympäristöhaasteisiin, kuten ilmastonmuutokseen ja resurssien ehtymiseen. Konkreettiset toimenpiteet vastuullisuuden edistämiksesi ovat kuitenkin riittämättömät ja alalta löytyy hyödyntämätöntä potentiaalia. Edellinen akateeminen tutkimus on korostanut suuria yrityksiä, vaikka teollisen valmistuksen sektori koostuu enimmäkseen pk-yrityksistä. Tämän vuoksi teollisilla pk-yrityksillä on yleensä rajallinen asiantuntemus ja resurssien puute kehittää vastuullisia toimintatapoja. Tämän tutkielman tavoitteena on tutkia vastuullisuutta suomalaisissa teollisissa pk-yrityksissä, ja esittää kattava määritelmä vastuullisuuden käsitteelle. Lisäksi tämä tutkielma osoittaa ajurit ja esteet vastuullisten toimintatapojen implementointiin, nykyiset toimintatavat, ja tulevaisuuden näkyvät. Tutkielman läpi korostetaan elinkaarianalyysi -näkökulmaa. Empiirinen tutkimus koostuu kuudesta suomalaisesta teollisen valmistuksen yrityksestä, ja tulokset on kerätty yksittäisistä haastatteluista toimitusjohtajien kanssa ja yhdestä työpajasta kaikkien haastateltavien kesken. Kirjallisuuskatsaus esittää akateemisen yleiskatsauksen vastuullisen valmistuksen määrittelemiseksi, sisältäen energiatehokkuuden, kiertotalouden, ja resurssitehokkuuden näkökulmat. Lisäksi kirjallisuuskatsauksessa käydään läpi keinoja tunnistaa ja integroida vastuullisia toimintatapoja yritykseen. Tulokset osoittavat, että haastateltavien käsitykset ovat suhteellisen yhtenäisiä vallitsevan kirjallisuuden kanssa, mutta implementoidut toimintatavat ovat rajallisemmat. Tämän lisäksi tulokset liittyen vastuullisen liiketoiminnan haasteisiin pk-yrityksissä vastaavat akateemista tutkimusta, mutta eroja ilmenee ajureissa, mikä johtuu oletetusti Suomen olosuhteista. Haastateltavat esimerkiksi toteavat, että lainsäädäntö ei tue tarpeeksi modernien ja vastuullisten toimintatapojen adoptoimista ja asiakkaiden halukkuus maksaa lisää ekologisista vaihtoehdoista on vielä melko alhainen. Tämä tutkielma voi avustaa pk-yritysten johtohenkilöitä uudelleenarvioimaan prosessit ja tuotteet ja tunnistaa uusia ympäristölle suotuisampia toimintatapoja, jotka eivät vaaranna kilpailukykyä. Lopuksi voidaan todeta, että 3D-printtaaminen, kierrätettyjen tuotteiden ja komponenttien kaupallistaminen, ja kollektiiviset alustat ja verkostot tulevat todennäköisesti yleistymään tulevaisuudessa teollisen valmistuksen toimialalla. Näillä strategioilla on lisäksi potentiaalia edistää vastuullisen ekosysteemin kehittymistä.

AVAINSANAT: vastuullisuus, teollinen valmistus, pk-yritykset, kiertotalous, energiatehokkuus, resurssitehokkuus, elinkaarianalyysi

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Abbreviations

CE = Circular economy
CEAP = The new circular economy action plan
CP = Cleaner production
C2C = Cradle-to-cradle
EEM = Energy-efficient measure
EoL = End-of-Life
GHG = Greenhouse gas
HVAC = Heating, ventilating, and air conditioning
LCA = Life cycle analysis
PSS = Product-service system
SME = Small and medium-sized enterprise

1 Introduction

Environmental concerns have realized in recent years and sustainability should be a fundamental part of business. It is urgent to address environmental threats such as fossil fuel usage and resource depletion, and actively pursue in developing environmental systems and sustainability. (Ludin, Mustafa, Hanafiah, Ibrahim, Teridi, Se-peai, Zaharim, & Sopian 2018). Consequently, environmental challenges are irrevocably changing the nature of business and competition. In global scale, manufacturing industry has a crucial role in producing emissions, and particularly industrial manufacturing which dominates it (Dawal, Tahriri, Jen, Case, Tho, Zuhdi, Mousavi, Amindoust, & Sakundarini 2015).

Organizational development for eco-friendly initiatives and practices should be a continuous process which leads to active implementation of the measures. Altogether, decreasing the negative environmental impacts of manufacturing companies requires a significant change towards sustainable business ecosystems. Primarily, long product life cycles and circularity of resources are substituting short-term planning, limited usage purposes for resources, and linear business models. (Choi S. & Lee J.Y. 2017).

Sustainability is quickly becoming a necessary part of manufacturing due to insufficiency of traditional practices and growing amount of regulations and requirements from governments (Singh S., Olugu E.U., Fallahpour A. 2014). In addition to governments, demands for sustainability are coming increasingly from non-governmental organizations and consumers (Altmann 2015). As a result, manufacturing industry faces various challenges regarding operating with less material consumption, resource waste and minimum environmental harm. (Singh S. et al. 2014).

The concerns among societies are partly from the UNEP Emissions Gap Report which has estimated that global resources are extracted at the rate of 47-59 billion metric tons per year, which is highly alarming (Olhoff, Christensen, Burgon, Bakkegaard, Larsen & Schletz 2015). Thus, raising awareness within societies is crucial to ensure resource adequacy and stop climate change. Sustainability should be embedded into the core structures of business in every industry. (König W., Löbbe S., Büttner S., Schneider C. 2020).

1.1 Problem statement

Industrial manufacturing sector is largely responsible of the global resource consumption, especially considering coal, natural gas and oil (Thollander, Danestig & Rohdin 2007). Additionally, it has been stated that industrial manufacturing sector covers approximately 50 percent of the total energy consumed globally (Trianni, Cagno, Worrell & Pugliese 2013). As a consequence, their impact on environment is undeniable. European Commission's SBA Fact Sheet (2019) estimates that in EU region 99,8 percentage of companies are SMEs which indicates that industrial manufacturing sector is mostly composed of them too. Already in 2012, it was stated that over 95 percent of industrial manufacturing sector is small and medium-sized enterprises (SMEs) whereas large enterprises form only a small percent (Trianni & Cagno 2012). It is established that SMEs' contribution to environmental problems is severe (Dey, Malesios, De, Budhwar, Chowdhury, & Cheffi 2020). However, the previous literature and research about environmental sustainability in manufacturing industry has focused heavily on large enterprises, and neglected SMEs. This has had an effect on the limitations for technical and organizational capacities among SMEs. (Ibrahim, Hami & Abdulameer 2020).

Fortunately, at 2010s the interest towards SMEs and sustainability has grown a lot in academia but practical approaches remain to be insufficient. In fact, it has been estimated that only four percent of SMEs in EU region have a comprehensive environmental management system. (Trianni et al. 2013). Furthermore, it has been argued that within industrial manufacturing sector, SMEs consume most of the resources, but almost 60 percent of them do not have suitable guidelines or equipment for attaining energy savings (Cagno & Trianni 2012). This implies the need to develop sustainability measures which are applicable for SMEs.

There is an imbalance between global resource adequacy and resource consumption in manufacturing. In order to reduce this imbalance, environmental principles and measures should be more coherent and correspond to existing conditions. (Bi, Liu, Baumgartner, Culver, Sorokin, Peters, Cox, Hunnicutt, Yurek & O'Shaughnessey 2015). However, this requires applicating modern sustainable manufacturing practices, even though research in this area is limited. (Ibrahim, Hami & Abdulameer 2020).

Life cycle analysis (LCA) is not emphasized in the literature, but it could provide support in developing sustainability within industrial manufacturing companies. LCA is seen as a helpful tool for successfully implementing sustainable manufacturing practices and reducing environmental footprint. Although, adopting LCA requires investments which companies are more unlikely to make if they do not have adequate technical support, knowledge, or expertise. (Dawal, Tahriri, Jen, Case, Tho, Zuhdi, Mousavi, Amindoust, Sakundarini 2015). Feasibility of the academic research is highly essential for SMEs that may have resource limitations. For eliminating the research gap, this thesis will seek to identify sustainable manufacturing practices among SMEs while considering the LCA aspect, and provide practical implications for industrial manufacturers to explore.

1.2 Research objective and question

The purpose of this work is to explore sustainability in industrial manufacturing SMEs. The objective is to clarify the concept of sustainability in manufacturing context thoroughly, and address sustainable practices. Furthermore, it is investigated how various internal and external factors influence on the application of sustainable practices in small and medium sized manufacturers. This work focuses on the LCA aspect in sustainable development. In this context, LCA process refers to the stages of product planning and design, raw material acquisition, production, logistics, use, and end-of-life (EoL). (Ludin et al. 2018).

The various areas of sustainable manufacturing are explored individually and instances of related practices are presented. The explored areas are energy efficiency, circular economy and resource-efficiency. This work aims in providing a holistic understanding of sustainable manufacturing in the SME context and to identify improvement potentials and challenges among Finnish industrial SMEs. The objective is approached with the following research question.

RQ: How can sustainable manufacturing be clarified and how different factors affect the sustainable development and the integration of practices in the stages of the LCA process in Finnish industrial SMEs?

The research question presents a vision of the desirable outcomes and brings forward the SME and LCA perspectives regarding sustainable manufacturing. The definition of sustainability, practices in the LCA process, and drivers and barriers are at the center of attention. Furthermore, this work will seek to establish projections for developing a new sustainable ecosystem. Current literature has not researched this context extensively which influenced on the emergence of the topic. Moreover, this work seeks to extend the knowledge among manufacturing SMEs regarding environmental sustainability and its measures, and contribute to the existing literature.

1.3 Delimitation of the thesis

The delimitation of this work is made based on the academic literature which suggests that sustainability is much neglected in the industrial manufacturing sector and particularly among manufacturing SMEs (Mitchell, O'Dowd & Dimache 2019; Ünal, Urbinati, & Chiaroni 2019). Consequently, this work focuses on SMEs and excludes large enterprises because they have been focused more in the previous research regarding environmental sustainability. Furthermore, industrial manufacturing sector is chosen as the research topic since within this sector the sustainability measures are limited and there is a shortage of practical methods for a successful implementation of these measures (Garza-

Reyes, Salomé Valls, Peter Nadeem, Anosike, Kumar 2018; Millar & Russell 2011). The manufacturing industry is not being explored as a whole due to inherent and significant differences between the organizational characteristics, for instance textile and forestry compared to industrial organizations. Applicability for industrial manufacturing companies is the priority.

Sustainability can refer to various factors, but most frequently it refers to economic, ethical and environmental aspects. Economic sustainability ensures the continuity and competitiveness of a company and it is generally the main strategic objective that guides the business decisions. (Kuzmin, Vinogradova, & Guseva 2019.) Economic sustainability has been largely explored in the academic field, thus, it is not in the core focus in this work.

Ethical sustainability is a wide concept which refers to the behavior of a company that can be expected by the society. It includes moral, legal and social aspects which a company’s behavior should reflect in the ethical manner. Social responsibility is critical in determining the ethicality of a company, and its attributes vary depending on prevailing global and national issues. Since ethical sustainability has a lot more aspects than solely environment, it is delimited. (Richardson 2009).

Climate change mitigation and resource scarcity are significant issues affecting sustainability principles of a company. Environmental sustainability can be incorporated to ethical sustainability, but here it is separated for a more specific emphasis. This work will investigate environmental sustainability due to growing global interest and requirements for industries during recent years (Choi & Lee 2017; Dayaratne & Gunawardana 2015). Economic and ethical impact are regarded only as additional effects from environmental sustainability measures.

1.4 Structure of the thesis

This work contains five chapters which are introduction, literature review, methodology, findings, and discussion and conclusion. The current chapter has introduced the subject and provided reasoning and motivation for the study. Following introduction, is the literature review which presents the theoretical data and creates a framework for sustainable manufacturing context. The sustainability areas of energy efficiency, circular economy and resource-efficiency are analyzed from the LCA perspective. The literature review ends with establishing factors for identification and implementation of sustainable practices.

Following the literature review is the methodology of the work. It presents the research approach and design, and the method used for data selection, collection and analysis. There are also few words said about the research quality. After, findings are presented, including the results of the empirical research. The last chapter includes discussion of the results from the theoretical perspective and the conclusion. The conclusion presents a conceptual contribution, managerial implications, limitations, and suggestions for future research. This will summarize the main findings of the work and provide answer to the research question.

2 Literature review: understanding sustainable manufacturing

Millar & Russell (2011) define sustainable manufacturing as *"the creation of manufactured products that minimize negative environmental impact, conserve energy and natural resources, are safe, and naturally sound"*. Regarding this, sustainable manufacturing considers also decreasing carbon footprint and waste generation. In order to achieve the sustainability objectives, it is beneficial to integrate active life cycle assessment as part of the business. In particular, assessing the circularity of energy and material flows is desirable for manufacturing companies. (Epping & Zhang 2018).

The primary objective of sustainable manufacturing is to protect the environment while pursuing competitive and economic development. This is challenging for companies due to deficient knowledge of what *sustainability* truly signifies, and the versatility of available data and research. However, the legislation and awareness of people is going to the right direction to make changes happen. (Yamin, Hami, Mohd Shafie, Muhamad, Abdul-Aziz 2020).

Based on this, sustainable manufacturing is divided into energy efficiency, CE, resource-efficiency, and green supply chain in this work. These concepts comply to the sustainability definition, and therefore, are justified choices for the review. Moreover, the empirical data emphasizes the aspects of energy and raw materials, resource flows, and sustainable supply chain which corroborates the framework of the literature review.

2.1 Energy efficiency

Energy efficiency has become more significant during previous decade which has led to companies seeking opportunities to develop their energy systems in manufacturing operations and processes. Energy efficiency has been defined with various ways in research but in summary, it signifies implementing activities which reduce energy consumption and utilize renewable energy. (Wang, Li, Gan, Cameron 2019; Trianni, Cagno, Farné 2016). Generally fossil fuels are the core of energy efficiency discussion, due to their injurious impact on the environment, and they are referred to a lot in academic research.

Energy efficiency means optimizing energy consuming processes and minimizing the use of energy (Robinson, Sanders, Mazharsolook 2015). Furthermore, it is increasing the energy produced with renewable sources in order to decrease GHG (greenhouse gas) emissions. GHG emissions are contributing to the climate warming, and reducing their formation is an important topic in manufacturing. (Cagno & Trianni 2013). Considering organizational point of view, energy efficient measures must be economically wise for companies to adopt them. Önüt & Soner (2007) state that energy efficiency in business is decreasing energy consumption while maintaining the same performance and productivity. Although this definition is fairly old, the statement that environmental sustainability should be profitable is perpetual.

Energy efficiency has several drivers which can be classified to political, economic, social, technological, environmental and legal categories. This classification addresses the external factors which positively influence on the implementation of energy-efficient measures. This thesis analyzes industrial manufacturing SMEs so the presented drivers are applicable to them. The results gathered from the literature are presented in Table 1.

Table 1 Drivers for energy efficiency

Category	Drivers
Political	Public incentives, Inputs from European Commission, Concern from governments (financial support & energy guidelines)
Economic	Cost reduction & competitive advantage, Increasing market share
Social (organizational)	Managerial commitment, Long-term energy strategies, Employee engagement, Benefits for society, Appreciation from consumers
Technological	Appeal of modern and innovative technology, Decrease in technology prices, Enhanced productivity, quality & delivery speed
Environmental	Growing emissions and fast depletion of natural resources
Legal	EU directive 20-20-20, Environmental regulations, Increasing energy taxes

Table 1 addresses the most common drivers acknowledged by various scholars. **Political drivers** are public incentives, inputs from European Commission, and support and energy guidelines from government. Providing incentives for SMEs based on their energy-efficient behavior would increase the probability of EEM *(energy-efficient measure)* implementation. Lack of financial incentives is a part of the problem affecting the low implementation rate of EEMs. (Trianni, Cagno, et al. 2016). Thus, developing a proper system for rewarding energy efficiency would gradually affect competition and reduce energy consumption. Inputs from European Commission influence on companies operating in Europe. European Commission has set objectives for energy-efficiency which emphasize the reduction of GHG emissions and replacement of fossil fuels with more environmentally sound alternatives such as biogas and solar power. (Cagno & Trianni 2012). In conclusion, establishing clear and practical guidelines and providing financial incentives could support the application of EEMs. Political drivers are significant particularly if companies have uncertainty due to lack of knowledge and experience.

Increased market share and competitive advantage are **economic drivers** from profitable and cost-effective energy management. Customers are becoming more conscious of environmental sustainability which can affect their purchase decisions. For this reason, energy efficiency may provide a competitive advantage when customers are comparing companies. In long-term, this can result in growth of market share and turnover. (Dayaratne & Gunawardana 2015).

Another **economic driver** is attaining monetary savings from reduced costs due to advanced energy-efficient technologies and machinery. Utilizing less energy throughout the value chain will decrease costs, and release capital for other operations. (Ünal, Urbinati, Chiaroni 2019). Besides, innovative approach in developing energy efficiency can help to differentiate from competitors and obtain competitive advantage. Companies are more likely to adopt energy-efficient practices if competitive advantage can be achieved by doing so. (Millar & Russell 2011).

Social and organizational drivers that can contribute to energy-efficient practice implementation are managerial commitment, long-term planning, employee engagement, and gaining societal benefits and appreciation. The probability to implement practices is higher in companies whose managers are committed to sustainable manufacturing (Ünal, Urbinati et al. 2019). However, it has also been argued that general managers who do not have operational role have only little if any influence in increasing EEM implementation (Blass, Corbett, Delmas, Muthulingam 2019). This indicates that the effect is relevant from the managerial commitment in operational positions. Managerial commitment can determine sustainability awareness inside a company which further affects employee engagement. When employees are motivated and receiving to sustainable changes, it is very much easier to implement new practices successfully. (Aboelmaged 2018).

Methods for enhancing employee engagement are company-specific, but generally different reward systems have worked expectedly. Additionally, the existence of a long-term energy strategy eases the application of energy-efficient practices since a company has a better ability to resourcing and capacity planning. Therefore, they are more likely to implement new practices compared to companies who do not have a similar ability.

Finally, attaining economic benefits is more probable when energy efficiency is incorporated into business permanently. (Thollander, Danestig, Rohdin 2007.)

Technological drivers originate mainly from the technology revolution. Significant development in technological innovations appeal to companies due to enhanced features that can improve manufacturing processes and support energy efficiency. Modern and innovative technology has advantages because it can enable better quality and delivery speed which furthermore, leads to energy savings and better competitiveness. When companies have sufficient knowledge and skills to implement new technologies, it has potential to improve productivity. This has an effect to the social drivers, especially managerial commitment, since improved productivity has economic benefits. Secondly, purchasing modern production technology requires capital investments, which are more likely made when managers are concerned of energy efficiency. (Trianni, Cagno, Worrell 2013; Millar & Russell 2011).

Another **technological driver** is the estimated decrease in technology prices. Modern technology provides a possibility to improve operations with fewer costs than traditional machinery. Considering organization types, innovative companies seem to be more proactive with respect to energy efficiency, and will therefore, adopt innovative technologies as well. Strongly hierarchical and old-established organizations are inherently more doubtful and transition reluctant but technological advancement will gradually affect this through competition. (Cagno E & Trianni 2013).

Environmental drivers are ambition to decrease emissions and stop the fast depletion of natural resources. Companies that are sustainability conscious seek to find ways to reduce their carbon footprint. Environmental sustainability should be an important objective within industrial manufacturing companies because they are responsible of a significant amount of energy consumption and fossil fuel utilization. (Millar & Russell 2011). Improving energy efficiency is recognized as one of the most vital factors for the mitigation of climate change (Andersson, Karlsson, Thollander, Paramonova 2018), and industrial manufacturing sector covers approximately 50 percent of global energy consumption (Trianni, Cagno, Worrell, Pugliese 2013).

Awareness of these issues among manufacturing companies has risen during previous years, and environmental sustainability influences decision-making more. However, in many cases, it is still not a priority due to several barriers which are later discussed in this chapter. Moreover, limited availability of non-renewable energy sources motivates companies to find sustainable ways to manufacture. Besides, the fast depletion of energy sources is a threat for industrial sector which will influence on the value chains. A proper understanding of the problem is assumed to increase actions regarding energy efficiency. (Garza-Reyes et al. 2019).

Legal drivers such as environmental regulations are becoming more common globally. At the moment, they are the most effective drivers in achieving rapid changes for energy-efficiency since companies will get penalties and fines for not operating as the regulations state. The energy regulations intend to restrict or enhance certain behavior which can be, for instance, decreasing the utilization of fossil fuels. (Choi & Lee 2017). Additionally, EU has set a directive which objective is to shift operations towards saving energy. The 20-20-20 directive includes 20 percent reduction in GHG emissions, 20 percent share of energy produced with renewable energy, and 20 percent improvement in energy efficiency. This directive is essential for SMEs which cover most of the energy consumption in industrial sector, but over half of them have hardly any measures for reducing GHG emissions. (Trianni, Cagno et al. 2016; Cagno & Trianni A. 2012). Increasing energy taxes is another legislative method which will put pressure on the development of energy-efficiency (Trianni, Cagno et al. 2016). It is argued, that application of EEMs is financially more beneficial in the absence of the regulations than when legislation imposes the true cost of carbon (Millar & Russell 2011). Although, it is uncertain whether this argument has been verified.

While there are many drivers which can facilitate energy efficiency, there are also barriers for it. Considering SMEs in industrial manufacturing industry, it is noted that low implementation rate in EEMs is mainly due to limited knowledge and availability of information. Especially, a critical issue is the lack of practical tools which makes it more difficult to implement practices. Relying solely on academic data is inconvenient for businesses, and therefore, solutions for this are needed. (Robinson, Sanders et al. 2015).

Several studies emphasize that there is deficient literature focusing on SME perspective in energy efficiency even though their contribution within industrial manufacturing sector is significant compared to large enterprises. Academic research has previously focused a lot on large enterprises which has resulted in suggested implications not being applicable for SMEs. (Wang et al. 2019; Cagno & Trianni 2012; Önüt & Soner 2006). There is huge potential to save energy among companies which are typically seen as energy inefficient but the issue is they do not have suitable tools and management systems in use (Önüt & Soner 2006). It has been stated that non-energy intensive SMEs cumulatively consume more energy than large enterprises (Andersson, Karlsson et al. 2018) which addresses the vitality for R&D that supports energy efficiency among them.

Shortage in financial resources is another significant barrier for implementing energy-efficient practices. This can be due to limited access to capital or limited economic support from government. However, it is important to acknowledge the differences between organization types when analyzing energy efficiency; SMEs and large enterprises should not be bundled together. SMEs tend to have less available capital to make investments than large enterprises, so for instance, the financial barrier is not generically applicable. (Trianni & Cagno 2012).

Scholars have also identified various organizational barriers such as lack of awareness, time, interest and expertise. As a result, SMEs are not prioritizing energy efficiency which would be essential in increasing the application of practices. (Trianni, Cagno et al. 2013). Thollander, Danestig et al. (2007) have suggested providing low-cost energy auditing programs for companies which would be organized by local energy consultancies. According to their research, this seems to be an effective policy option in terms of achieving energy savings relative to money spent. Their original idea was to assign public funds for the audits which would mitigate the barriers regarding the accessibility of information and limited knowledge and capital. To conclude, they argue that energy auditing has a potential to increase the application rate of EEMs among SMEs.

2.1.1 Energy-efficient practices in the stages of the LCA process

There are many challenges related to enhancing energy utilization. The limited number of suitable practices complicate reaching energy efficiency targets. However, academic field has determined some practices which can be currently exploited in decreasing emissions and improving energy performance. The presented practices are linked to the LCA process which consists of these stages: product design and planning, raw material acquisition and internal logistics, production, logistics and delivery, use, and EoL (Ludin et al. 2018). According to the research, energy-efficient practices strongly focus on the first stages of the LCA process whereas logistics, use, and EoL are hardly considered. (Andersson et al. 2018; Cagno & Trianni 2012; Önüt & Soner 2006; Kannan & Boie 2003).

Regarding product design and planning, it is vital to carefully plan and optimize volumes, production process and internal logistics in advance. Operational planning of production will help to optimize energy usage in each process step and reduce energy waste. Product design and planning stage includes purchasing energy-efficient technology, a suitable method for increasing energy efficiency. Nowadays, technological advancement is significant in terms of achieving high performance with low costs, and this applies to the objectives of environmental and economic sustainability. (Özbilen, Rende, Kılıçaslan, Karal Önder, Önder, Töngür, Tosun, Durmuş, Atalay, Aytekin Keskin, Dönmez, Aras 2019).

To achieve energy efficiency benefits, companies must have thorough knowledge of their energy systems and usage. It is suggested that companies calculate the total monetary usage for each energy source in three different scenarios; business-as-usual scenario, realistic scenario, and ideal scenario. This exercise will provide a reference point of tangible energy savings and shift actions towards the realistic and ideal scenario. It is suitable to have the calculations at the beginning of product design and development, to avoid challenges throughout the manufacturing process. (Özbilen et al. 2019).

Raw material acquisition and internal logistics are not much emphasized in the literature regarding the energy-efficient practices. However, production and further processing stage has opportunities for implementing energy-efficient practices. Some scholars present specific platforms for optimizing energy-efficiency. AmI-MoSES platform is to be applied to heat treatment in manufacturing chains. AmI-MoSES bases on ambient intelligence that refers to a sensory-based system that is aware of its environment and is responsive to people. The platform emphasizes user-friendliness and more efficient service support, and is designed for improving energy efficiency while maintaining process performance. AmI-MoSES supports online detection of energy efficiency problems so it might not be suitable for less technologically advanced companies. (Robinson, Sanders et al. 2015).

Another platform for energy efficiency is the point energy platform. It is a system that gathers a granular picture of electricity usage and sends it to IoT cloud service to be analyzed. The point energy platform utilizes LoRa concentrators for the data transportation and stores it into a secure MySQL database. The platform enables companies to allocate machinery workloads and minimize voltage unbalance, which results in energy savings. (Wang, Li et al. 2019).

It is argued that the highest energy efficiency potential is in the support processes of manufacturing companies, including heating, ventilating, and air conditioning (HVAC) systems and lighting. The support processes concern the sustainability of buildings and facilities, which have unrecognized potential. Collective application of EEMs which focus on reducing energy consumption in the support areas, would help mitigate GHG emissions and provide financial gains for companies by decreasing HVAC costs. For instance, these practices include power regulation of processes that can reduce power output during non-production hours, elimination of standby losses, and installment of engine heat controllers. Companies can also convert to more energy-efficient sources, for example, switching lighting to LED bulbs. (Andersson et al. 2018). Other HVAC-related EEMs are to eliminate leaks in inert gas and compressed air lines, install compressor air intakes in coolest locations, utilize energy-efficient ballasts and belts, purchase modern electric motors, and bare insulate equipment. (Cagno & Trianni 2012).

After implementing the EEMs, it is crucial to monitor their execution. It is fundamental for energy efficiency to construct an evaluation criterion for analyzing the performance of EEMs. Evaluation criteria help companies to find bottle necks in their production and support development activities. It also enhances the appropriate execution since there is always a risk of employee neglect. (Trianni, Cagno et al. 2013). Organizing regular internal meetings which focus on evaluating EEM performance is a feasible method for avoiding deficiencies during production and maintaining organizational awareness towards these issues (Trianni & Cagno 2012).

In conclusion, it is unlikely for every company to have sufficient capabilities and knowledge about the practices and their implementation instantly. To overcome this obstacle, scholars suggest that contacting energy consultancies, hiring an energy manager, and participating in energy auditing programs are crucial actions towards incorporating EEMs into business. (Blass et al. 2014; Cagno & Trianni 2013).

2.1.2 Renewable energy trends in industrial manufacturing sector

Due to a large consumption of fossil fuels in manufacturing sector, CO2 emissions have increased significantly which is contributing to climate issues. Legislation is shifting actions towards more sustainable production through regulations related to fossil fuel usage. Although it is important to limit fossil fuel consumption, it is equally important to find new technologies for renewable energy utilization. Replacing fossil fuels with renewable energy is a desirable outcome for manufacturing industry, but profitability must be included. (Folk 2019). The prevailing challenge which decreases the implementation rate of renewable energy systems is that the economic benefits are unclear; companies need a lot of advanced data processing and evaluation techniques to succeed. (Pechmann, Schöler & Ernst 2016).

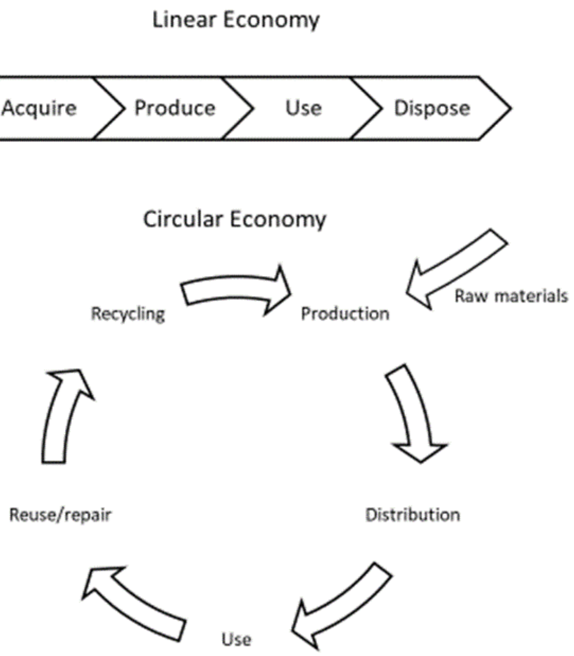
The current renewable energy trends in industrial manufacturing sector are wind, solar and bioenergy, hydrogen and battery technologies as well as energy storing and saving possibilities. Investments in wind turbines or solar panels is emphasized in academia for their long-term energy security and sustainable aspect. (Folk 2019). Additionally, the technologies for producing energy with wind and solar power are fairly advanced, especially compared to hydrogen and battery technologies, that still need research and development. Virtual power plants have grown interest in the research, due to the advantages in terms of finance, operational effectiveness and renewable energy sources. Virtual power plant is a cloud-based data center for controlling and managing energy production. It integrates different distributed energy sources from many locations into a network, which will provide energy continuously. (Pechmann et al. 2016).

Motiva Oy informs on their web page that in Finland, the most significant renewable energy source is bioenergy. Bioenergy is being produced and utilized extensively in various organizations, but forestry sector is the most common bioenergy user. Bioenergy has many possible origins but usually it comes from forests, agricultures and industrial side streams and wastes. At the moment, it is crucial to get other large sectors, such as manufacturing, to utilize and exploit bioenergy. (Aarni 2020).

2.2 Circular economy

Circular economy (CE) refers to the concept of changing business design from linear model to loop economy. Strategies of loop economies emphasize waste avoidance, resource-efficiency and resource dematerialization. CE creates restorative and regenerative industries in which long-term raw material cycles are at the center. (Bockholt, Hemdrup Kristensen, Colli, Meulengracht Jensen & Vejrum Wæhrens 2020). Figure 1 presents a simplified demonstration of the linear economy and circular economy.

Figure 1 Models of linear and circular economy



As Figure 1 shows, the most prominent distinction between the two models regards the EoL stage of product life cycle. The stages in linear economy are acquiring raw materials, production, customer usage, and disposal. At the end of the linear business design, products are simply considered as waste and disposed without exploring restorative potential. Recycling and reuse are not considered as a part of the life cycle which leads to massive waste generation, value losses, unexploited resource potential, and pollution. The distinction is significant compared to CE, which emphasizes circularity and closed loop of raw materials in business. The benefits of CE include the maintenance of material and product value, exploitation of full resource potential, waste minimization, and new business opportunities. In addition to environmental benefits, CE provides opportunities for financial growth. (Bockholt et al. 2020).

CE contains various eco-design methods, including improvement of recycling capabilities, utilization of renewable resources, elimination of wastes, and development of a forward-looking business model (Paletta, Leal Filho, Balogun, Foschi & Bonoli 2019). Some authors determine CE as a branch of the sustainability science, which focuses on cradle-to-cradle (C2C) approach and the replacement of traditional material flows with new circularity flows. It is argued that early stages of LCA are emphasized, because planning and design have a strong affect determining the whole material cycle of a product. (Ünal et al. 2019; Garza-Reyes et al. 2018). The objective of CE is to prolong product life cycles to respond environmental demands. At the core of CE are intense product usage, product upgrades, modularity, repair, remanufacturing, component reuse, and closed loop recycling. All these activities decrease resource consumption, which enhances sustainability. (Ingarao, Zaheer, Campanella & Fratini 2020.)

MacArthur (2013) determines CE as *"an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoring, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impede reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models"*. This definition addresses the comprehensiveness of CE, and how it should not be confused with a single environmentally sustainable action, such as having a waste management system (Ghisellini & Ulgiati 2020). CE attains to maintain the highest utility constantly for each product, material and component (Howard & Webster 2018) which is an ambitious goal that requires a significant shift in business modeling.

In recent years, the interest towards CE has been growing globally. It is mainly due to increasing environmental issues for which CE is seen as a solution. CE measures help decreasing the fast depletion of natural resources, which is a significant threat organizations are facing at the moment. (Garza-Reyes et al. 2018). Accelerating the circularity of resource flows, particularly plastic-based materials which release toxic chemicals to environment, is a desirable target contributing to carbon neutrality. New Plastics Economy -concept provides directives which guide business operations to more sustainable in manufacturing sector. Firstly, New Plastics Economy urges effectively to after-use plastics by enhancing the uptake of recycling, reuse and controlled biodegradation. Secondly, it pursues a major decrease in the leakage of plastics into natural systems and other externalities, and finally, decoupling plastics from manufacturing materials by exploring and adopting renewable alternatives. (Paletta et al. 2019).

Nowadays, increasing the functional, material and remaining *(=percentage that can be recovered)* value of products should be emphasized in a business model. This pursuit applies both to environmental and competitiveness related objectives of CE. Academic field considers that a service-based business model is a feasible measure for taking full advantage of the value dimensions and securing the profitability. Transferring to the service-based business minimizes purchasing new and losing resource value while providing opportunities for savings and new business ideas. (Bockholt et al. 2020; Ghisellini & Ulgiati 2020; Howard & Webster 2018). Technological innovation is a significant contributor to the service-based businesses, since it supports planning and executing practices with less resources and waste (Ingarao et al. 2020). The development of various online-based platforms and applications is an excellent instance of the technological benefits.

Drivers for CE are similar to energy efficiency. There are economic drivers, such as cost reduction, competitive advantage, and market growth. (Ünal et a. 2019). An additional economic driver is a product take-back activity, which is considered profitable for companies due to raw material savings and reuse and remanufacture potential. (Bockholt et al. 2020). However, the logistics cost and environmental impact for taking-back products was not regarded in the article.

There are also legislative and governmental drivers for CE. For instance, EU promotes practices related to recycling, reuse and recovery of products (Garza-Reyes et al. 2018). The new circular economy action plan (CEAP) is a part of the European Green Deal, and consists of a strategy for transitioning to CE. CEAP sets out new rules and directives for the EU's 2050 climate neutrality goal and to stop biodiversity loss. (European commission 2021).

Besides to legislation, social drivers affect CE adoption as well. Gaining positive marketing results and enhanced brand image thrives companies more likely to implement CE practices. This is especially typical in companies, which managerial commitment is high. (Ünal et al. 2019). At the moment, companies mainly adopt CE principles due to social and financial reasons, and not for environmental benefits. (Garza-Reyes 2018).

Academic field has identified several challenges that affect the implementation of CE practices. The lack of suitable measurement tools for performance evaluation is discouraging for companies. CE principles are seen less tempting and investments are made more reluctantly when companies are unable to measure tangible results. Furthermore, the manufacturing industry is currently influenced by prevailing uncertainty of actual financial benefits and profitability in implementing CE practices. (Garza-Reyes 2018; Millar & Russell 2011.)

There are challenges concerning informational and organizational capabilities. The capability to analyze CE-specific data is a significant weakness in many companies, which means that useful information might be available but knowledge for utilization is insufficient. This influences drastically on decision-making processes in various production stages. Regarding organizational capabilities, CE practices often affect the whole supply chain, and substantial development would require collective efforts and participation from stakeholders. However, manufacturing supply chains remain to be relatively weak and incoherent regarding CE progress. The reason for this is a lack of awareness and collaboration among stakeholders. (Garza-Reyes et al. 2018).

Lastly, CE has many core areas, which are difficult to integrate successfully without previous experience or references. Companies have to actively manage customer value proposition and interface, value network, and managerial commitment to maintain competitiveness while pursuing CE. However, the interdependency of these areas remains greatly underlined in academic research, even though it is a crucial factor among companies. Lack of research contributes to the growing threshold affecting the transition to CE business models. (Ünal et al. 2019).

2.2.1 CE practices in the stages of LCA process

Recycling and reuse of materials and components have a significant role in a CE business model. Several scholars are emphasizing the positive effect of recycling and reuse on waste reduction, resource-efficiency, and other circularity objectives. (Bockholt et al. 2020; Ingarao et al. 2020; Paletta et al. 2019). Considering the LCA process, most recycling opportunities are located in raw material acquisition, production and EoL stages. Companies often generate resource waste during raw material acquisition and production, and particularly within industrial manufacturing companies, waste of metals is typical. The capacities for utilization of these side streams and overflows are increasing in societies, and thus, recycling of raw materials should be strongly encouraged. Companies can recycle materials properly and take advantage of waste side stream possibilities if they have sufficient knowledge and technical capabilities. The managerial level can, for instance, enhance organizational commitment by providing instructions and organizing workshops for recycling and reuse. (Bockholt et al. 2020; Ingarao et al. 2020).

At the EoL stage, products' circularity can be increased through recycling, remanufacturing, and reusing. EoL components are often recyclable, but their users are not aware of it. This problem can be reduced by informing customers about the recycling capabilities at the purchase moment and when disposal is approaching. (Ingarao et al. 2020). This requires data of the length of a product life cycle. Besides, reusing EoL product has grown the interest among companies since it is economically and environmentally beneficial. It is suggested that taking-back products from customers is a suitable strategy for evaluating reuse possibilities. This method's core is that manufacturing companies take responsibility for EoL products and decide whether the products can be reused or remanufactured and, if not, dispose of them properly. However, identification of reuse and remanufacture purposes requires deep industry-related and technical knowledge from a sustainability perspective. Lack of this knowledge is a significant barrier in pursuing reuse and remanufacture strategies (Bockholt et a. 2020; Garza-Reyes et al. 2018).

Considering the use stage in the LCA process, the longevity of usage is affected by the decisions and actions made earlier in a manufacturing process. For instance, choosing high-quality materials prevents arising problems with a product during its usage, and companies can estimate a longer life cycle which is, resources considered, profitable. It is necessary to invest in product planning and design, including mapping suppliers and conducting LCA calculations of alternative propositions. Hiring a sustainability expert is, in some cases, crucial for conducting these analyses. (Garza-Reyes et al. 2018; Millar & Russell 2011).

Additionally, it has become quite typical for businesses to adopt PSS *(product-service system)* strategies, and during recent years, manufacturing industry is shifting towards this ecosystem. PSS strategy emphasizes service-orientation in business modeling: traditional selling of products is being replaced with providing comprehensive solutions. (Ünal et al. 2019). Servitized business model aims to increase customer attraction with additional services and benefits. Upgrading and repairing of products during different life cycle stages are an instance of such services. These services support CE’s objectives by extending product life cycles, saving resources, and reducing the need for purchasing new. (Ingarao et al. 2020). Besides, leasing of products is a general cost model in service-based business model. It has sustainable advantages because it enables the manufacturer’s return of products who can lease them to other customers, remanufacture them, or transfer materials to reuse. Moreover, research and development of commercialization strategies for remanufactured products would enhance their application and improve the circularity of products and raw materials. (Bockholt et al. 2020).

2.3 Resource-efficiency and green supply chain

The concept of a green supply chain has emerged as the shift from a linear model of production to a circular economy has become more common in the manufacturing industry. Resource-efficiency is at the core of the green supply chain. (MacArthur 2013). Manufacturing companies have many industrial processes running simultaneously, and these processes practically utilize a combination of the industry-specific resources, including raw materials, water, equipment, chemical agents, process scraps, and packaging. A green supply chain is designed for supporting the intentions of sustainable manufacturing and circularity of material and energy flows, and therefore, contributes to a closed loop economy. (Ghisellini et al. 2016).

The 6R approach is suggested for maximizing the utilization rate of resources, which further enables a change for the green supply chain. The definition of 6R generates from redesign, reuse, remanufacture, recover, recycle, and reduce. In practice, using recycled materials for product design, reducing water and energy usage during production, using more renewable energy sources, and recycling wastes, such as water, for other intended purpose, is resource-efficient. However, the implementation of the 6R practices is challenging since companies often have limited resources and capacities in the supply chain. (Bi et al. 2015).

Altmann (2014) states that green supply chains should be developed with a pursuit to meet *"the needs of the present without compromising the ability of future generations to meet their own needs".* However, it is demanding to change the structures of supply chains that have formulated during many decades. Thus, politics and legislation are seeking to accelerate the adoption of "green" measures. Although, manufacturing industry requires tangible solutions not just restrictions.

Partnerships are a suitable method for increasing sustainability in a supply chain, since they enable a mutual sustainable development and effectiveness. Partnerships enhance circularity of materials and products through “sharing economy” principles. Exploring and establishing collective networks with different companies help to redesign supply chains and discover new sustainability potentials. For instance, sharing equipment and energy is a resource-efficient measure, that benefits each party of a network through reduced maintenance or supply costs. (Birkin, Cashman, Koh & Liu 2009).

Careful planning and design are emphasized in a green supply chain. It is essential to adopt a long-term perspective in decision-making and plan in advance of process flows, logistics and volumes regarding resources. Considering logistic processes, the number of operators in a supply chain (e.g. suppliers, facilities, warehouses, distributors) and their distance affect greatly on the environmental impact. Moreover, using an environmental criterion for supplier selection enhances the sustainability throughout a supply chain. Production processes typically generate a lot of emissions, which reduction is one of the main objectives in a green supply chain. Of course, the nature of the manufactured products varies, which determines how much emissions are produced, and thus, the extend of needed actions. Companies can help decreasing the negative impacts with investing in eco-friendly production technologies and increasing the utilization rate of production facilities. To succeed, integration of investment planning, capacity planning and allocation of production processes is vital. (Altmann 2014).

Cleaner production (CP) method considers eco-friendly objectives throughout a supply chain while considering the LCA process. CP aims in conserving resource utilization, avoiding usage of environmentally toxic materials, and reducing the amount and toxicity of emissions generating from production process. Even though industrial manufacturing companies have a significant environmental footprint during production stage, CP emphasizes the need for decreasing emissions during use and disposal stages as well. (Dayaratne & Gunawardana 2015). A closed-loop supply chain applies to CP principles as it holistically pursues to improve resource-efficiency. In addition, it is critical to consider monetary objectives in a closed-loop supply chain, so company’s competitive ability is not compromised. Altmann (2014) suggests a double-objective optimization model for designing a closed-loop supply chain, which focuses on minimization of total costs and total emissions. Practically this means that all of the supply chain processes are evaluated from economic and environmental perspective. Companies will conduct calculations and evaluations between various options at the supply chain stages, that will provide a comprehensive overview of the environmental impact and financial benefits of different propositions. The desired outcome is to support analytical decision-making and feasible strategic planning. (Altmann 2014).

Resource-efficiency in manufacturing context is building production processes that do not add negative environmental consequences. The discrepancy is that while there is a huge potential for resource-efficiency, the required human capabilities and organizational awareness is limited. (Dobes, Fresner, Krenn, Růžička, Rinaldi, Cortesi, Chiavetta, Zilahy, Kochański, Grevenstette, de Graaf, Dorer 2017). Academic field has presented different tools and frameworks that increase organizational knowledge, and thus, would remove the discrepancy. Due to inadequacy of existing tools, modern inventions should deliver systematic and analytical support for identifying and quantifying resource saving opportunities. Previously, identification and quantification abilities have been deficient. (Choi, Thangamani & Kissock 2019).

Another challenge concerning current resource-efficiency tools is that they tend to be either tool-driven (focus is solely on a qualitative nature) or do not address all levels of business. Comprehensiveness is critical in modern tools due to demanding characteristics of the green supply chain and CE. For this reason, academic field has developed a criteria framework for resource-efficiency tools, which considers the complex nature of sustainability. This framework includes various criterion, a question related to the criterion, and an ideal state for this factor. For an example, a business complexity criterion should be evaluated with a question “does the reviewed tool provide a comprehensive view of all levels of business?”, and the ideal state is that the tool focuses on and develops each business level. The business levels in this context are derived from the

management pyramid -model, including product, production, management system, strategy, vision and goals, and interest of stakeholders. (Dobes et al. 2017).
A successful quantification of resource usage is essential to attain long-term and tangible results with sustainable practices. Resource-efficiency is a fundamental goal in sustainable manufacturing, and it has seven strategic principles, which can be further categorized based on the magnitude of the resource saving opportunities. In this thesis, resource saving opportunities are analyzed from energy, pollution and cost perspective. The ranking of the seven resource-efficiency principles has been developed by Choi et al. (2019).

1. *Reduce*
2. *Reuse*
3. *Remanufacture*
4. *Recycle*
5. *Redesign*
6. *By-product synergy*
7. *Waste to energy*

Choi et al. (2019) have built this ranking for an industrial manufacturing setting, and it considers many typical resource types used in industrial companies. The considered resources are raw material, water, chemical agents, process scrap, packaging waste, and equipment. Reducing is preferred over any of the other principles because it decreases and eliminates all related resource consumption and emissions throughout the LCA process. Reuse is the second highest principle because it extends the life cycle of a product without adding materials and energy during production.

Remanufacture means finding an alternative use purpose for a product which, however, does not exclude additional resource utilization. Remanufacture is preferred over recycle because recycling processes (e.g. collecting, separating, purifying) typically include more resource consumption. Redesign is a specific process or production system, that requires skilled expertise and techniques for achieving alternative use of resources. However, it is estimated to be more resource-efficient than By-product synergy and Waste to energy. By-product synergy means transforming waste into livestock, which requires more resources and effort compared to previous principles. Waste to energy is ranked as the last because during energy extraction processes, resources are completely lost. However, Waste to energy is a sustainable effort in a sense that waste is not merely disposed without any usefulness.

To conclude, there are many opportunities for improving resource-efficiency within an organization, but the challenge originates from high investment costs and poor level of knowledge. This is especially general among SMEs. A research has indicated that applicating environmental management standard -certificates contributes to the higher level of resource-efficiency. The certificates have become more common, and companies can find several globally recognized organizations admitting them. Environmental management standard -certificates help companies to grow their awareness on resource depletion issues and support the development of resource-efficiency practices. Finally, they provide a global recognition as a sustainable business, which can enhance competitiveness. (Fadly 2020).

2.3.1 Resource-efficient strategies and EDIT-value tool

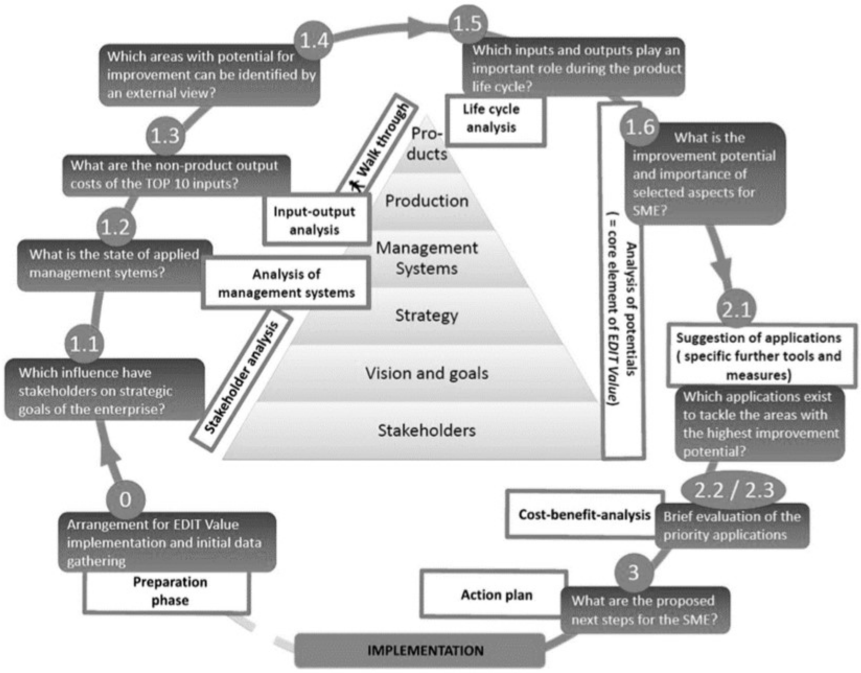
Academic literature has recognized few strategies that enhance resource-efficiency and decrease resource consumption, which are an additive manufacturing and remanufactured alternators. These strategies are acknowledged as suitable for industrial manufacturing companies. The limitations of these strategies are that they have been analyzed focusing mainly on large enterprises and thus, the applicability may differ with SMEs. The existing skills, technology, and resources of SMEs are necessarily not adequate, which means they need more consulting and support for the strategy application. (González-Varona, Poza, Acebes, Villafáñez, Pajares, López-Paredes 2020; Fatimah, Biswas, Mazhar, Islam 2013). In fact, governmental assistance, especially receiving consulting services and subsidies, correlates positively with higher level of resource-efficiency within companies (Fadly 2020).

A business model that focuses on a sustainable spare part logistics is a new method for extending product life cycles in an eco-friendly way. The sustainable spare part logistics is referred to as *additive manufacturing*, which derives from the invention of 3D printing. 3D printing of spare parts is the most significant factor in achieving sustainability benefits from additive manufacturing; it minimizes the need to transport materials and products and reduces logistics costs. The additive manufacturing business model requires either individual 3D printers for customers or the establishment of local 3D printing operators. 3D printing enables the development of a digital supply chain, which can be defined as a supply chain in which the manufacturing data can be transferred trough a digital network from one facility to another more effectively and without burdening the environment. Waste generation of additive manufacturing is mainly from unexpected defects or auxiliary materials. However, it has massive potential for more sustainable supply chain logistics and attaining energy and raw material savings, making it an environmentally benign practice for manufacturing companies. (González-Varona et al. 2020).

Another critical strategy for resource-efficiency is remanufacturing because it maximizes the use of components and avoids the excessive generation of landfill and energy usage. Advanced planning and budgeting are at the core of successful remanufacturing because extending EoL requires finding alternating objectives for components. Academia suggests exploring the business model potentials of remanufactured alternators. The alternator is a part of an automotive component that can be remanufactured for other purposes, and thus, improves resource circularity. However, the field of remanufacturing has been relatively unexplored, and practical suggestions are limited. From an organizational point of view, remanufactured alternators should provide viability in both economic and environmental sense to be beneficial. Utilizing recycled components for the remanufactured alternators supports sustainability since it causes less material consumption than new products. (Fatimah, Biswas, Mazhar & Islam 2013). However, the cost perspective for utilizing recycled components for remanufactured alternators is unclear in terms of financial advantages, and requires more data.

EDIT-value tool is a holistic and needs-driven method for conducting quantitative diagnosis of resource-efficiency processes throughout a supply chain. EDIT considers the LCA perspective and the application of EDIT has been tested in 18 manufacturing SMEs. The results indicate that EDIT supports employees in discovering weaknesses and opportunities for resource-efficiency improvements. The development and testing of EDIT have been executed at the levels of the management pyramid, which are product level (considering all life cycle stages), process level, management systems, strategy and strategic level, vision and goals, and stakeholders. These levels are influential regarding identification of resource-efficiency potentials and sustainability innovations. (Dobes et al. 2017). Due to the extensive nature of EDIT, the original framework of the tool is presented below in Figure 2.

Figure 2 The framework of EDIT-value tool



EDIT has several phases which result in the identification of resource-efficiency potentials and formulation of an improvement sustainable plan. The first phase is preparation which includes enabling the implementation of EDIT and gathering of initial data. Following this, is the identification phase, which consists of five analyses: stakeholder analysis, analysis of management systems, input-output analysis, life cycle analysis and finally, analysis of potentials which is the primary element of EDIT. After the potentials have been identified, the suggestions for practical solutions are made. This phase requires exploring and allocating alternative tools and applications, that are further analyzed from the cost-benefit perspective. In the third phase, the action plan is designed based on the most effective tools and applications. A successful implementation and execution of EDIT often requires support from consultants because of the fairly advanced technical, managerial, and practical skills. (Dobes et a. 2017).

2.4 Identification and evaluation of sustainable manufacturing potentials in SMEs

To increase the sustainability of manufacturing processes, it is essential to identify improvement potentials for which sustainable practices should be targeted at. Various scholars have developed tools and frameworks to ease the process but the practicality of many tools is not adequate which leads to insufficient results. (Favi, Germani, Mandolini & Marconi 2018; Burke & Gaughran 2005). There are four basic factors that prevent tools from becoming fully effective in identifying sustainability improvement potentials in SMEs. (Dobes et al. 2017).

1. *Attention is solely on a single business level*
2. *Limited quantification of losses in material and energy flows*
3. *A tool-driven approach which may overlook specific improvement potentials and needs of a SME*
4. *A requirement for external technical support and capacity creation*

Based on these restricting factors, the characteristics for an ideal tool and framework for identifying sustainability potentials has been developed. Firstly, with a proper tool, managers of SMEs should be able to explore their manufacturing processes throughout the life cycle of products. Secondly, the tool should provide a multi-criteria system to support managers' comprehensive decision-making processes concerning sustainability measures. A multi-criteria system considers different perspectives of a practice, process, or method that can help to identify and analyze hidden improvement possibilities in them. Additionally, all levels of a management pyramid should be assessed in a systematic way regarding sustainable actions that can enhance the value of a SME. An ideal tool will provide a holistic view while maintaining a clear, direct, and logical approach which is necessary for further applicating the identified improvement potentials. (Dobes et al. 2017).

Singh et al. (2014) argue that conducting a regular sustainability assessment helps more effectively to identify weak areas of performance that should be developed. To identify and improve the weak areas, organizations need specific indicators which measure the performance of sustainability activities in manufacturing SMEs. Singh et al. (2014) have compiled and categorized a list of key performance indicators for sustainability that consider the characteristics of SMEs. They have identified these indicators from various research for a holistic overview. Table 2 presents the most significant indicators in three separate categories (economic, environmental, social). The results are listed in an occasional order.

Table 2 Key performance indicators of sustainability for SMEs

Economic	**Environmental**	**Social**
Cost	Direct & indirect emissions	Training hours/employee
Quality	Water consumption	Community involvement
Flexibility	Energy & material intensity	Customers' satisfaction
Responsiveness	Recyclable & reused material ratio	
	Material intensity	
	Hazardous & waste material ratio	
	Renewable energy ratio	

The sustainable performance indicators are categorized to economic, environmental and social groups. The environmental indicators are emphasized, but economic and social indicators are significant as well in terms of achieving profitability with an eco-friendly business model. Some of the primary characteristics that distinct SMEs from large enterprises are lack of finances, resource and skill limitations, more flexible and horizontal structure, lack of sustainability knowledge, and smaller market shares. Regarding the economic performance, cost is the strongest driver affecting business, particularly in SMEs. Therefore, reducing manufacturing costs, and minimizing waste generation and resource utilization, increases profitability. Due to smaller market shares and customer segments, SMEs generally compete with the quality aspect, and due to less hierarchical structures, SMEs can find competitive advantage from more flexible and responsive business. (Singh et al. 2014; Joung, Carrell, Sarkar & Feng 2013).

From a social point of view, customer satisfaction and the efficiency of employee trainings are significant performance indicators, since SMEs' have smaller number of customers and limited market accessibility compared to large enterprises. Besides, organizational capacities and resources have more limitations regarding training and education. Maintaining a favorable brand image is important for SMEs to remain competitive against large competitors. Therefore, community involvement is an essential indicator, since it enhances the brand image. (Singh et al. 2014; Erol, Sencer & Sari 2011).

The list of environmental indicators focusses on the most significant factors affecting environment and defining sustainability, including resource and water reduction, renewable energy utilization, recycled material usage, and emission mitigation (Singh et al. 2014; Joung et al. 2013; Erol et al. 2011). Companies must research the estimations for the ratios of each environmental indicator in order to establish objectives and monitor their realization. SMEs may need support from consultants or sustainability specialized personnel to calculate and evaluate the environmental impacts correctly, but this depends on the organizational capabilities.

Conducting a credible LCA is a common and widely preferred method for identifying prevailing sustainability improvement potentials. LCA is becoming a more fundamental part of business. Rather than solely using intermittently, companies will continuously perform LCA to maintain emphasis on sustainability. The effectiveness of LCA is based on its methodology of gathering and analyzing data that is necessary for a comprehensive environmental sustainability assessment, as opposed to calculating, for instance, carbon footprints only. (Heidrich & Tiwary 2013). Integration of LCA with the key performance indicators is beneficial for both an effective identification of development areas and performance evaluation of the corresponding practices.

2.5 Implementation of sustainable manufacturing strategies in SMEs

Choi et al. (2019) have proposed a framework for implementing sustainable strategies to industrial manufacturing companies. The framework focuses on the assessment of the seven principles of sustainability (reduce, reuse, remanufacture, recycle, redesign, by-product synergy, waste to energy) in terms of resource-efficiency, and the process is divided into three stages. In the first stage, a company will identify the resource categories for saving and improvement opportunities. In the second stage, the applicable resource principle is determined regarding the selected resource category. The applicability of the resource principle depends on the capabilities and expertise of a company. In the third stage, a company will implement sustainability measures into their business and create a specific assessment recommendations of sustainability goals. The sustainability goals can be energy savings, resource minimization, cost minimization, reduction of life cycle emissions and wastes, but the ability to calculate the results is essential. It is suggested that the process for applicating the 3rd stage is following: conducting industrial audits, analyzing the obtained results in integrated resource and principle matrix, applying engineering knowledge (in-house/external consultant), and finally, establishing the assessment recommendations.

The LCA perspective is emphasized in each stage of this framework. For instance, to identify the resource categories for saving opportunities (1st stage), a company must analyze resource usage throughout a whole manufacturing process. The suggested method for this is illustrating the resource usage with a visual process of functions. Figure 3 presents a simplified example of the resource categories in a manufacturing process.

Figure 3 Identification of resource saving categories in manufacturing process

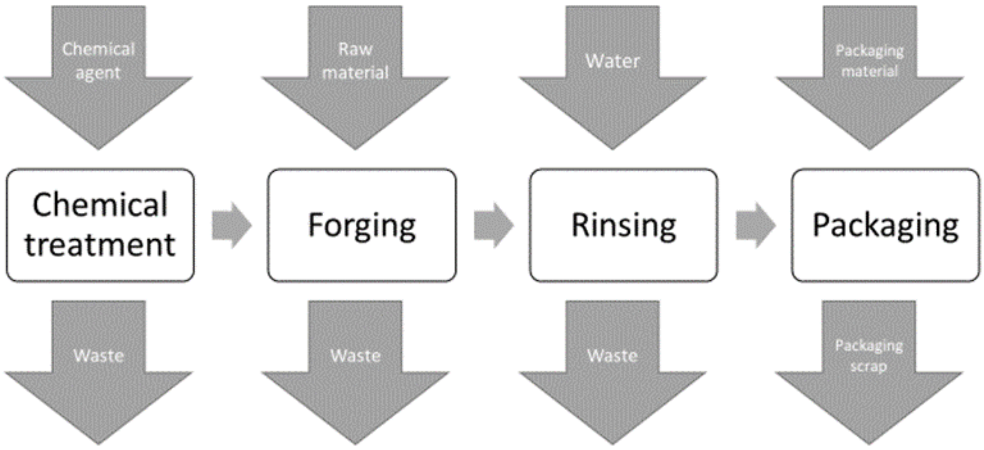


Figure 3 is an example of the industrial process of a bolt manufacturing company. It establishes how by illustrating the manufacturing process, a company will get a comprehensive overview of various resource categories and can make a logical, data-based decision of resource saving potentials. It is to be observed that Figure 3 does not have any detailed data of the resource categories that an actual company would.

Afterwards, the chosen resource category of which the resource principle is targeted at is analyzed and developed at all life cycle stages. Figure 3 presents only the resource categories of a production stage of the LCA process, and it is important to perform similar analysis at every other stage also. Previously, the sustainable efforts (e.g. energy audits) have focused solely on production, whereas the LCA perspective have been neglected from the operational management. Current research pursues to remedy that. (Choi et al. 2019).

Birkin et al. (2009) have argued that nowadays sustainability should be incorporated into the business model of every company. They have established a framework for the integration process, and even though it is not the most recent, it is reasonable and practical, and thus, seems appropriate to present here. This framework assumes that a company will integrate sustainable development into an existing business model, rather than having to redesign a new business model. The sample of the case study has been 20 companies, which means that the framework may not be applicable for everyone, and thus, should be critically reviewed. However, the core of it is relatively feasible, and a company-specific modification should be possible.

The framework of Birkin et al.'s (2009) for implementing sustainable development into business emphasizes three key areas in the process consisting of four steps. The key areas are capability & understanding, commitment, and partnerships. These areas of improvement correspond to the academically distinguished primary barriers for adopting sustainable practices within SMEs: the lack of expertise, resources and awareness (Mitchell et al. 2020; Dayaratne & Gunawardana 2015). Table 3 presents the suggested actions at each step of the implementation process for each key area. It is a capsulized version of Birkin et al.'s (2009) original framework.

Table 3 Framework for implementing sustainability into business model (Birkin et al. 2009)

	Investigating >	Internalizing >	Integrating >	Innovating
Capability & Understanding	Mapping sustainability development drivers (e.g. SWOT, Risk analysis, Impact assessment) + Managerial level discussions & delegation of responsibilities	Incorporating detailed understanding of sustainability impacts through supply chain + Estabslihing learning networks + Sustainability as part of leadership curriculum	Developing sustainable leadership traits for key staff + Completing 1st round of organizational education + Extractin value from learning networks (+ Integrating new ways of work)	Creation of sustainable culture (organizational culture worksheets / questionnaires, field trips, awareness boosting activities for maintaining sustainable culture)
Commitment	Gathering data of preferences internally (interviews, questionnaires, encouraging open communication)	Clear sustainability policies & goals + Determining value & performance indicators + Coordinating structure for sustainability agenda (who, what, when, how?)	Integration of value & performance indicators throughout supply chain + Building sustainability focused R&D strategy + Generating relevant information from all organizational levels	Sustainability indicators as part of organizational and personal goals + Demonstrating the credibility and benefits of sustainable development for personnel & consumers (transparency in actions & decisions)
Partnerships	Stakeholder analysis + Researching competence needs and demands +	Defining advisory boards + Building/exploring partnerships with "sustainable-orientated" companies + Conducting pilot projects	Establishing new partnerships & implementing partnership porfolio management system/policy + Evaluating mutual usefulness	Exchanging knowledge with key partners + Follow-up activities (if improvement ideas are revealed)

The emphasis of this framework is in incorporating sustainability into an existing business model through a systematic analysis and development of capabilities, organizational commitment, and partnerships. Since sustainability is typically not a priority among SMEs (Choi et al. 2019), this framework provides an assistance to including sustainable aspects into strategic decision-making. Achieving energy-efficiency and resource-efficiency have influenced the development of the framework. Moreover, feasibility of the steps is at the center of attention. (Birkin et al. 2009).

The 1st step, investigating, refers to comprehensive data gathering and conducting of various analyses for which the other steps will be based on. For instance, suggested analyses include SWOT, stakeholder, and risk analysis, as well as gathering personnel data. In the 2nd step, internalizing, the conclusions are made according to the gathered data. This step includes establishing learning networks, determining sustainability policies and objectives, and coordinating these for each organizational level. The 3rd step is integrating, in which the practical implications for sustainable development are performed. This step includes, for instance, the integration of value and performance indicators, completing the first round of conceptual education, and implementing partnership portfolio management systems. The 4th step, innovating, further enhances the sustainable development actions and regularizes them into the existing business model. Furthermore, this step consists of reflection and learning through knowledge exchange with partners. Designing follow-up activities, and organizational and personal goals, as well as boosting the creation of a sustainable culture is crucial for achieving a permanent change. (Birkin et al. 2009).

3 Methodology

The methodology presents the primary attributes of the empirical research and ensures why the results are credible and valid. The research strategy is presented, including the case selection and description. Following, an explanation of the data collection and analysis is provided. The objective is to address and justify the utilized research methods.

3.1 Research approach

Commonly, there are two methodological approaches for empirical research which are quantitative and qualitative. The approach is decided based on the objective and research question, because qualitative and quantitative methods emphasize different areas and have their own strengths. Qualitative approach aims in discovering subjective "meanings" rather than gathering information about objective "facts", which is usually the pursuit of quantitative research. (Silverman 2021). Another difference between quantitative and qualitative approach is that the previous one is more systematic and focuses on testing and confirmation, whereas the latter is more interpretative, aiming to find rationales through people's understandings (Ghauri & Gronhaug 2002). Quantitative data is usually presented with variables or other numerical objects while qualitative results are in a text form (Silverman 2021).

The objective of this research is to analyze sustainability in the context of industrial manufacturing SMEs. This thesis pursues to understand how sustainability can be defined and how different factors affect the integration of sustainable practices. Based on the nature of these questions, a qualitative approach is a more suitable research method since uncovering perceptions of people is at the core. The empirical data includes opinions and experiences of the interviewed CEO's of the case SMEs.

3.2 Case selection and description

The case description considers a sample of Finnish manufacturing SMEs from the Ostrobothnia region. The sampling was done in the Orbis database by searching active companies operating in the metal mechanics industry that fit to the description of a Finnish SME. A company can be described as SME if it has fewer than 250 employees and either an annual turnover under EUR 50 million or an annual balance-sheet total under EUR 43 million, and is based in Finland (Tilastokeskus 2020). Moreover, the metal industry was selected because it forms the largest portion of the industrial manufacturing sector, covering approximately 42 percent of it in Finland (Tilastokeskus 2019). Thus, this work can provide suitable data for many companies that are facing challenges related to sustainability.

The search resulted in fifteen potential companies which were all contacted. Contacting method was to send an informing email and after that to call the CEOs to inquire their interest to participate. Seven of the CEOs declined, three of them did not answer, and six agreed for the interview. The final case selection consists of five metal and component processing manufacturers.

The empirical research was conducted with interviewing the five industrial manufacturing SMEs and organizing a mutual workshop for the SMEs. The following primary data is gathered from the interviews with the CEOs and from companies' websites. The framework of the interview structure is found from APPENDIX 1. The primary data of the case SMEs is listed in Table 4.

Table 4 The primary data of the case SMEs

Company	Position	Business concept	Turnover (2019/20)	Personnel (2020)
A	CEO	Metal subcontracting: metal assembly products	~EUR 8 million	~65
B	CEO & owner	Metal processing: component manufacturer	~EUR 9 million	~75
C	CEO	Industrial engineering: component manufacturer	~EUR 8,5 million	~75
D	CEO	Industrial engineering: engine insulation solutions	~EUR 14 million	~60
E	CEO	Industrial engineering: metal pistons manufacturer	~EUR 8 million	~40

Company A is an industrial engineering company focusing on metal sub-contracting and was founded in 2014. The company operates in various industries and has approximately thirty customers. All of the customers do foreign exporting. Company A's primary products are integrated assembly solutions such as stators, engines and sheet metal products, and the most significant customer is a large Finnish industrial organization. Additionally, it has customers' customers but does not gather specific data about them. The most important suppliers are steel manufacturers. Company A aims to manufacture in own facilities as much as possible so the percentile of outsourcing is low. According to the latest financial information, the company has around EUR 8 million in annual turnover and 65 employees.

Company B is a metal processing company that focuses on metal component products and was founded in 2016. Its business idea is contract manufacturing, which the CEO, amplifies as "selling time for customers which includes all of our competence and professional knowledge". The main customer is a large Finnish industrial organization (50 percent of the production), and other significant customers are various industrial organizations. Smaller customers consist of energy and electricity suppliers. Customers'

customers are, for example, oil refineries and companies utilizing special engines. Company B's supply network is mainly various steel producers. Production is in own facilities, except for surface treatment which is currently outsourced. The company's annual turnover is EUR 9 million and the number of employees is around 75.

Company C was founded in 1993. It is a subsidiary, which operates in the field of industrial engineering. Company C's primary manufacturing products are components made out of pipes, and its customer base consists of global companies in the energy and marine industry. The core business is subcontracting for customers, and for instance, a large Finnish industrial organization has outsourced most of its pipe production to Company C. Other significant customers are large technology, industrial, and automotive organizations. According to the CEO, their annual turnover is EUR 8-9 million and they currently have about 75 employees.

Company D is also a subsidiary and was founded in 1989. It is an industrial engineering company which core products are engine insulation solutions from sheet metals. Company D's only direct customer is a significant Finnish industrial organization and it has customers' customers from power plant and cruiser businesses. Company D has a subcontracting company, that focuses on welding, as part of its business. It purchases assemblies from different suppliers depending on the customer's preferences. The CEO states, that most of its business is indirect exporting since only a small percent of the products stay in Finland. Regarding the personnel, approximately 30 percent are subcontracting employees and the rest are production workers. According to the most recent financial information, the annual turnover is around EUR 14 million and the number of employees is 60.

Company E is an industrial engineering company founded in 1997. It designs, produces, and markets large metal pistons for engine manufacturers. A large Finnish industrial organization is the most significant customer but it also exports products to Asia and Europe. According to the CEO, Company F constantly looks for new potential customers but at the moment the customer base is quite focused. Suppliers consists of steel factories and foundries, and customers' customers are mostly powerplants and shipping companies. The value of own processing is extremely high, and thus, Company F has outsourced only 5-10 percent of the production. The previous annual turnover is around EUR 8 million and it has personnel of 40 people.

3.3 Data collection

The data was collected using a semi-structured interview method. The aim was to acquire data of specific predefined topics from each company while simultaneously enabling free discussion. The interview questions were selected in advance but regarding the situation the order or content of the interviews could alter accordingly. The semi-structured method was chosen because it eases the discussion since there is a certain guideline to be followed, and the interviewee will not feel pressured if the subject is not familiar. Discovering and recognizing new insights can be enhanced with the semi-structured method because it provides some content surface for the interviewees. However, it was intended to have relatively interactive discussions for enabling interviewees to bring up topics which would not have been otherwise disclosed.

The interviews were held in an online platform and each interview lasted approximately 90 minutes. Five interviews were held in Finnish and one in English. The interviews followed a detailed but adjustable structure. The same primary questions were asked from all the interviewees to acquire useful and comparable data regarding the thesis objective. Depending on the insights of the interviewees the discussions focused on distinct areas which resulted in receiving versatile data and understanding of various topics and perspectives. The interviewees were asked for a permission to be recorded during the interview and everyone agreed to it.

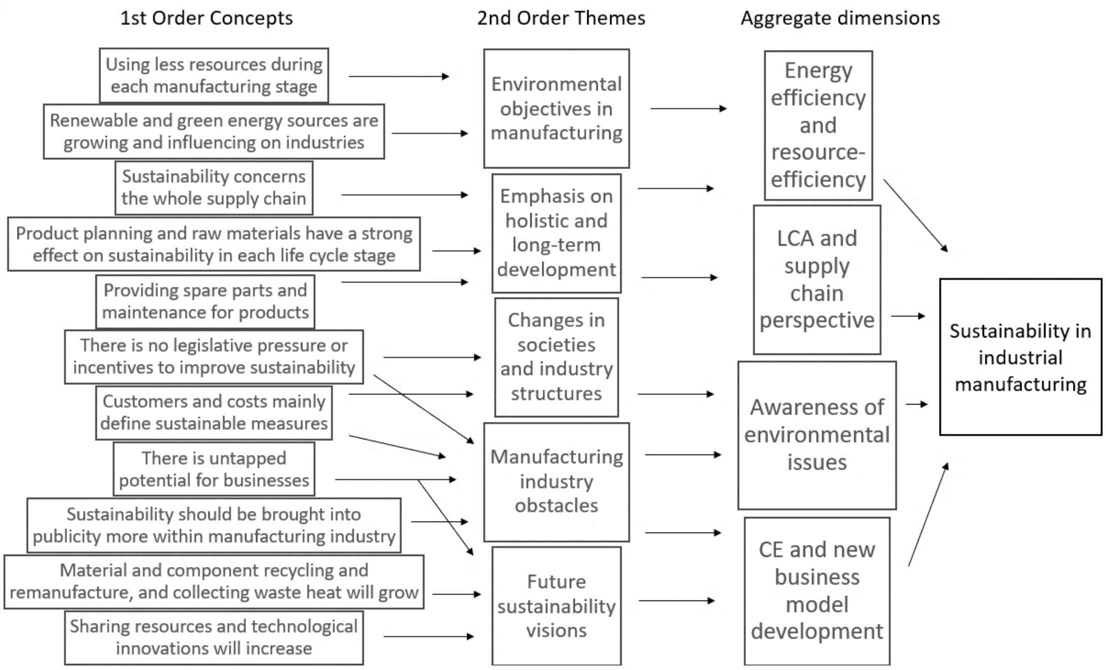
After the interviews, the recordings were listened to again and the discussions were transcribed. The transcriptions were approached with various methods. Firstly, the whole interviews were thoroughly transcribed to an individual document. Secondly, the primary topics regarding the thesis objective were identified and transferred to a specific document. These topics consisted of the practices in the LCA process, perceptions on sustainability in value chain, and industry and ecosystem, and finally, obstacles. Thirdly, some visualization figures of the overview were made. For instance, a figure addressing all the practices mentioned in the interviews throughout the LCA process.

In addition to the individual interviews, the data collection consists of a collective workshop in which each of the interviewees participated. The topic of the workshop was current sustainable practices and future insights of a sustainable ecosystem. More specifically, the interviewees were asked to state factors which can boost the development of a sustainable ecosystem and reasons why it is difficult to achieve both profitability and sustainability. The workshop was held in Howspace -platform, and its structure was predefined. The workshop was held in English, and its duration was two hours. The results were gathered during the workshop to a separate document and they supported the data from the previous interviews. However, the workshop provided more practical insights regarding the future of sustainable industrial manufacturing compared to the interviews.

3.4 Data analysis

The data has been analyzed following the qualitative approach by Gioia, Corley, and Hamilton (2013). The original framework for analyzing an interpretative research was introduced in 2004 by Gioia et al. The framework illustrates a data structure method in three categories which are 1st order concepts, 2nd order themes, and final dimensions. The 1st order concepts have been collected from the case interviews, and they address the common and topical insights regarding the thesis topic. The 2nd order themes have been grouped based on the data from the 1st order concepts. They present a theoretical realm for the research. Finally, the identified themes are aggregated to higher-level dimensions that correspond to the central topic of the thesis. Figure 4 presents the data structure. The data structure illustrates how the raw data has progressed to the specific themes while conducting the empirical study. It also establishes the accuracy of the qualitative research and the significance in this study.

Figure 4 Data structure based on Gioia et al.'s framework (2004)



As Figure 4 shows, the 1st order concepts are a various set of insights that were disclosed during the interviews. Sustainability in industrial manufacturing is considered from many perspectives, and the interviewed CEOs brought attention to several topics. The 1st order concepts explain mainly the role of sustainability and its demands, current sustainable principles, and future visions. Based on the results, the 2nd order themes have been recognized, and further derived to aggregate dimensions. This study suggests that the primary areas regarding sustainable industrial manufacturing are energy efficiency and resource-efficiency, LCA and supply chain, people's awareness, and CE and new business model development. The findings and discussion will proceed from this supposition.

3.5 Research quality

The credibility and reliability are significant factors ensuring the quality of the research. This research has been conducted from relevant sources concerning the objectives and the case companies correspond to the topic. This enables discussing the empirical results from the theoretical perspective in a valid manner.

Yin (2013) explains that validating qualitative research includes internal and external validity and reliability. Internal validity means using established analytic techniques as external validity refers to analytic generalization. Reliability is ensured through case study methods and utilized databases.

This research is credible since the chosen research methods are suitable for investigating the designed thesis topic. The purpose is to explore how sustainability is perceived, what practices have been implemented, and how LCA influences sustainable manufacturing in Finnish industrial SMEs. The interview and workshop content correlates to this purpose. The concepts that have been utilized in the empirical research are *sustainability, LCA, resource-efficiency, CE, and energy efficiency* which apply to the research problem. This research uses an established data analysis method by Gioia et al. (2004) and presents a data structure according to it, which ensures internal validity. From an external validity point of view, the empirical results can be generalized to SMEs with similar attributes. The findings can provide a directive of sustainable manufacturing among industrial manufacturing SMEs in Ostrobothnia since the original search resulted in fifteen similar companies in total, and this research includes five of them.

This work is reliable since the exploited database, Orbis, is academically distinguished and the case selection methods are sound and justified. The interpretative nature of the research objective explains the data collection through interviews. Additionally, a multiple case study method is suitable for this research since the aim is to shed a light on the current state of sustainability in Finnish manufacturing SMEs which requires exploring several companies.

4 Findings

This chapter includes the results from the empirical multiple case study. The results are presented by the topic in accordance with the structure they were discussed in the interviews. Consequently, they are discussed in the theoretical perspective and compared to the findings from the existing literature. Direct quotes from the translated interviews are presented to support the data.

4.1 The definitions of sustainability in manufacturing context and its current role in the SMEs

All of the case SMEs combine sustainability with resource-efficiency. Moreover, this refers to energy, raw materials, and natural resources, and to a business model that avoids waste generation and utilizes resources long and carefully. In addition to resource-efficiency, each company emphasizes other aspects which concern their business the most or they see potential in exploiting them.

Company C and D discuss the significance of LCA and CE in sustainable manufacturing. They acknowledge that the development of sustainable business models requires a holistic product life cycle approach and collaboration with a whole supply chain. It is considered, that CE principles guide actions towards sustainability.

Using less resources throughout the whole life cycle of a product. The problem is that people do not think sustainability concerns the whole supply chain. (Company C)

Maximizing the utilization of resources and minimizing wastes. Sustainability and CE are linked, and I think there are new business opportunities in the field. (Company D)

Company B focuses on the technical improvement possibilities in addition to resource-efficiency in achieving sustainability. Optimization of machinery and manufacturing equipment decreases unnecessary energy utilization which is beneficial regarding environment and costs. Recycling is also emphasized because it increases the reuse of materials.

Company A states that sustainability in manufacturing is also about finding new opportunities for resources which extends their life cycle. Renewable energy utilization is also discussed but it still remains too uncertain and unprofitable for them. Company A suggests that at first, large enterprises could make structural changes and develop renewable energy systems, which would present an example. This would be more convenient for SMEs, which have more limited financial resources.

Sustainability is about energy- and resource-efficiency. Sustainable companies can create new use potentials for resources. Renewable energy utilization is also related to sustainability, but at the moment, there are limited potentials and valuation for it. (Company A)

Company E considers logistics and packaging as a significant part of sustainable manufacturing. Optimization of logistics and deliveries, and using eco-friendly fuel enhance sustainability. Regarding packaging, it is essential to minimize the usage of packaging material and pay attention to the quality and environmental aspect of materials.

The discussions disclose a variety of insights regarding the role sustainability has in the business. All of the CEO's emphasize sustainability but their reasonings are different. Economic advantage, customer satisfaction, and environment are the greatest influencers. Companies C and A state that product planning can affect strongly on the sustainability. It is said that effective design in processes and product features enhances sustainability and is also beneficial for the SMEs.

Sustainability is mostly considered from the cost and customer perspective. For instance, we are trying to manufacture our products in a way that their implementation is easy and fast for customers, and this means utilizing less resources and components. Sustainability is a result from this. (Company C)

Sustainability has a big role in our business. It is considered in the planning of products and manufacturing processes. We also try to be innovative and make better and more effective suggestions for our customers. (Company A)

Companies C, A, and E mainly consider profitability in assessing the role of sustainability in their business. According to Company E, they have implemented an international EMS 1401, which was not mentioned by the other case SMEs. However, the number of companies using environmental management systems will presumably increase in near future.

The other perceptions indicate that environment is a part of the company values, and guides operations. The role of the environment is considered as an objective to minimize consumption and wastes. For instance, purchasing new products and materials is seen unsustainable, which supports resource circularity targets. Additionally, Company B discussed that not all sustainable actions are sound for every company, and economic reasons are compelling.

Our values consider environment as important. We do each sustainable action that is sensible for us. (Company B)

4.2 The significance of sustainability in manufacturing industry

The significance of sustainability in manufacturing industry was discussed in the interviews. The shared conception is that sustainability is important within the industry but there are other priorities as well. Besides, most of the case SMEs have a customer base of a few big organizations that they sell components or products to. Thus, they are strongly dependent on the customers' requirements for sustainability. Marketing regarding sustainability in industrial manufacturing is also emphasized with their customers, since the brands are more well-known than the case SMEs.

It is absolutely essential for companies to consider environment. Actions has to be made and brought to publicity. For instance, motors (which are critical in our business) are usually perceived as non-environmental, even though, their development towards more carbon neutral has taken big steps. It is important to let people know about this, so we do not transfer solely to wind turbines, batteries etc. (Company E)

A couple of the interviewees acknowledged the reality of continuous growth in sustainability related demands which are reforming the industry. Stakeholders are more aware of sustainability, but still financial gains have the strongest effect in business. Additionally, Companies B mentioned that sustainability should be approached holistically from an ecosystem level, and collective improvement with an attention to economic gains should be made.

Sustainability is a comprehensive issue which affects the whole supply chain. There are many practices that are already being done but requirements are also increasing from many stakeholders. (Company B)

The importance of sustainability grows constantly within the industry, but in business, the cost is still the main determining factor for customers which should be considered while developing sustainable practices. (Company E)

Similar to all industries, manufacturing is affected by environmental concerns. A few case SMEs commented that sustainable practices are critical contributors to enhancing competitive ability. For instance, resource-efficiency and energy efficiency have advantages both in costs and emissions. Moreover, a dynamic nature of markets forces companies to operate in a sustainable way. It was also stated that exporting from Finland is already challenging because of the long delivery routes, which emphasizes the significance of sustainability in ensuring customer satisfaction.

At a national level, sustainability is really important for Finland. Export industry faces challenges already due to remote location of Finland, so resource efficiency is vital in addition to high quality and service, in order to remain competitive. (Company D)

4.2.1 Industry related problems concerning sustainability

The empirical results indicate that the problems regarding sustainability in manufacturing are mainly due to customer preferences and existing industrial structures. A couple of the case companies address the cost factor, which means that customers favor manufacturers with lowest prices. Since profitability is dependent on the customers, their preferences have a crucial influence on the business decisions. This indicates that customers' sustainability awareness should increase in order to affect manufacturing SMEs significantly.

Sustainable actions should be understood from a whole product life cycle and cost point of view. Customers usually think about the monetary cost only. (Company C)

The biggest problem is to make customers understand the advantages of sustainability. (Company A)

Continuing to the cost factor, a case SME brought attention to the internal logistics perspective. It is typical for companies to purchase materials from abroad (e.g. Baltics or Poland) because the price is lower than in Finland despite the longer delivery. However, cost for the environment is hardly considered in delivery prices, which results in a growth of emissions even though the material would be sustainable.

Raw material acquisition and internal logistics has problems; it is cheaper to purchase materials from abroad but delivery prices do not consider emissions. This causes pollution and expels companies from buying local (Finnish) materials. (Company E)

It was also mentioned that challenges in sustainable activities are partly a regional problem. Company D told they have production facilities in separate cities in which recycling and reuse possibilities for materials and components vary; one has sufficient systems and another is lacking in terms of fluency and ease to recycle. Fluency and ease are important determinants for SMEs, and they have development potential in city/municipal planning.

Some cities/municipalities have limited possibilities for sustainable actions and resource efficiency (e.g. recycling systems) which decreases the attractiveness for adopting them. (Company D)

Furthermore, consumers are still affected by old assumptions of industrial manufacturing and easily consider the industry as unsustainable. It was stated that sustainable activities should be more strongly communicated to consumers to address the development made within the industry. However, many SMEs do not have an ability to influence on consumers' perspectives, and actions from large enterprises are seen necessary.

Sustainable activities are not promoted enough in the industrial manufacturing, and old assumptions of processes and products hold on. However, we (component manufacturers) are only a small part of the ecosystem, and our customers have more influence on this. (Company E)

To conclude, problems derive from the ecosystem and fundamental structures of the manufacturing business. There is a lack of awareness and expertise to meet with the demands for sustainability. Cooperative development and actions with all operators in a supply chain is needed to achieve prominent changes. Moreover, the empirical results give an impression that requirements from stakeholders are perceived as challenging to implement due to their versatile and complex nature.

4.3 Current sustainable practices in the stages of the LCA process

Although, the case companies address various problems regarding sustainable development, there are several measures they have already implemented into business. The practices have been combined together from each interview and linked to a corresponding stage of the LCA process. The objective is not only to address the sustainable activities in use but to uncover prevailing bottle necks and weaknesses that could be improved. The results are presented in Table 5.

Table 5 Current sustainable practices in the case SMEs

LCA process

Product planning & design	Raw material acquisition & internal logistics	Production	Delivery & logistics	Use	Services	EoL
○ Advance budgeting of raw material volumes ○ New technology ○ Future orientated desgin	○ Close proximity of suppliers ○ Sustainable and ecological criterion	○ Eliminating resource waste ○ Optimizing machinery ○ Decreasing energy usage ○ Modern equipment	○ Minimizing and optimizing logistics	○ Ease to implement ○ Extented product life cycle	○ Selling of spare parts ○ Mainetenance and repair services	○ Recyclable and reusable products

The LCA process begins with a product planning and design stage. Current sustainable measures are related to the avoidance of excessive resource consumption and waste generation. It is executed with a careful budgeting of raw material volumes in advance and designing products with a focus on future perspective, which means longer life cycles for products. To achieve this, companies are using quality materials and analyzing customer preferences and industry trends. In addition, utilizing new technology and innovations enables companies to plan manufacturing processes more efficiently and to save energy.

For us, product planning and raw materials are interdependent. Advance planning and budgeting help to optimize and possibly decrease raw material consumption in production. (Company A)

We aim to design products which are effective to manufacture and easy to utilize. Effectiveness in manufacturing means speed and ease in utilization and enabling maintenance and repair in various LCA stages in order to avoid fast disposal and short life cycles. (Company D)

The following LCA stage is raw material acquisition and internal logistics. These activities are strongly influenced by the decisions in product planning and design. Sustainable practices that the case SMEs mentioned are an ecology of raw materials and purchasing from suppliers that are closely located. However, the significance of sustainable criterion in raw material acquisition depends also on the customers' valuation and cost factor.

We consider the quality and cost of raw materials as well as the logistics. The objective is to purchase quality material which is better for the environment and customers. However, we may find a cheaper quality material from Europe but its importation may cost and pollute more. Logistics and quality must be evaluated in this situation, but usually, less cost and resources mean more sustainable. (Company A)

Regarding the production stage, the current sustainable practices are optimization of machinery and decreasing all resource usage and wastes. Regular collection and evaluation of production data is seen necessary for decreasing resource consumption. The case SMEs are non-energy intensive, but they mentioned that sustainable practices in production mainly aim to reduce energy usage and improve energy efficiency. However, the interviews did not reveal specific information of the practices, which indicates they are quite company-specific.

In the production, a good occupancy rate for raw materials is at the core. This requires effective optimization of equipment and processes, and leads to energy and material savings. (Company B)

We have various procedures and feedback systems which we use to gather data and reduce waste. This helps to uncover problems in a manufacturing process, which are then developed in the product planning and design. (Company D)

External logistics is the following stage in the LCA process. The results mainly address that sustainability is considered with optimizing logistics. This refers to volumes, scheduling, and routes. A significant amount of the resource waste generates from hurry and unexpected situations, that are attempted to avoid. However, a small number of employees creates some challenges for this pursuit.

We optimize logistics with always driving with full loads. Avoiding urgencies in a supply chain decreases waste generation and is, therefore, good for environment. (Company B)

We are delivering bigger entities and more finished products to reduce the need for logistics. (Company C)

The results indicate that the case SMEs do not have significant activities regarding sustainable practices in the use and EoL stages. It was stated many times that they do not have required data or influence of these LCA stages, and there is a lack of customer communication. The measures mentioned in the use stage are a pursuit to manufacture products that are easy to implement which means not utilizing unnecessary resources for the implementation process. Moreover, interviewees consider long product life cycles as significant. However, product planning and design affect this a lot since the quality of materials and manufacturing techniques are essential in extending the life cycles.

Regarding the EoL stage, the current practice is manufacturing products which components and materials are recyclable and reusable. The prevailing issue is that the case SMEs do not have knowledge whether the products are recycled or reused. However, the possibility for acquiring this knowledge can be challenging to SMEs, since their resources are more limited. Moreover, influencing on the use and EoL can be economically disadvantageous for SMEs.

In the end of the product life cycle, our component is possible to reuse for other purposes. Although, we do not know how much of them are reused and where to. (Company A)

We do not have influence on the use stage when our products are with customers. How-ever, all the materials in our products are recyclable and reusable, and the design is developed with a focus on resource-efficiency which hopefully is beneficial in the usage. (Company D)

In the EoL, our products are scrap material which can be reused, and everything is recyclable as well. I know, that other companies are reusing the scrap material from our products, but I do not have any specific information. (Company E)

Life cycle services are a significant factor in the avoidance of an early disposal and excessive resource consumption due to the need for product replacement. Many of the case SMEs are providing maintenance and repair services or sell spare parts for their products which applies to the CE principles. The case SMEs consider that providing life cycle services is a sustainable practice related to the use stage of the LCA process.

Life cycle services are considered in selling spare parts which is valuable for the length of a product usage. (Company E)

4.3.1 Potential sustainable development areas in supply chains

The results indicate that both customers and suppliers are considered having the most significant potential for developing sustainable practices. The interviewed SMEs state that the beginning and end areas within the supply chain have a more effect regarding sustainability than the case SMEs. The distribution between customer and supplier focused perceptions is quite equable, but customers' customers and suppliers' suppliers are emphasized in the answers.

In a supply chain each operator matters, however, the most important are the extremities whereas the middle (like us) has not much influence in a big scale. Customers' customers should be more sustainability conscious and demand actions whereas suppliers' suppliers should come forward with new innovative materials and resources more actively. (Company A)

Company C discusses how valuable the customers and customers' customers preferences are to their business. The results show that sustainability improvements generate mainly from above in a supply chain since for SMEs, in particular, it is highly essential to maintain long-term customer relationships. When the motivation for sustainability increases within the customer segment, it has an effect for the business of the case SMEs.

The development opportunities locate in between our customers and customers' customers. The sustainable development depends much on their preferences and values regarding environment. (Company C)

Companies D and E have observed that suppliers and suppliers' suppliers would have potential for improving sustainability. The opinions are company-specific, but it was addressed that methods for more resource-efficient operations could be developed. One company also acknowledged the utilization potential of hydrogen, which has been discussed in a research as a sustainable option for various manufacturing processes.

The biggest potential for sustainable development is with suppliers and suppliers' suppliers. For instance, resource-efficiency is more urgent and has potential. (Company D)

4.4 Drivers and barriers

The case SMEs were asked to identify specific drivers and barriers which affect their willingness to implement new sustainable practices and/or strategies. The results have been gathered to Table 6, and they are quite versatile. Social, financial, and operational factors are emphasized in both drivers and barriers. Moreover, the cost perspective is truly fundamental.

Table 6 Results of drivers and barriers for sustainability

Drivers for sustainability	Barriers for sustainability
Proactive and innovative suggestions from suppliers	Lack of political and legislative incentives
Significance of ethical transparency and sustainable reputation	Lack of measurement tools for evaluation
Resource savings = monetary savings	Investment costs and customers' willingness to pay
More valuable products with sustainable resources	Demanding prerequisites for a comprehensive understanding (expertise, technology)
Stakeholders' preferences	Stakeholders' preferences

The interviewees addressed drivers and barriers for sustainability from several perspectives which gave a thorough understanding of the overview. Environmental sustainability is acknowledged as an important and business-shaping topic which will become fundamental in the future for every organization. Although, for industrial SMEs the change is occurring slowly due to deeply embedded procedures and structures. However, technological innovation and growing interest for eco-friendliness motivate SMEs to adopt more sustainable practices already at the moment.

Suppliers who present new and sustainable changes for products can act a strong driver, even though those changes do not always get executed. Innovativeness is valued. (Company A)

It is important to be ethical and transparent in the business, and maintain a sustainable reputation. This is strongly influenced by resource-efficient and environmental factors, and companies are not evaluated by solely financial measures anymore. It is stated that increasing value and competitiveness are drivers. Fortunately, practices that improve recycling and reuse rates or waste reduction have also a decreasing effect on costs.

Cost optimization is a driver. Nowadays, the cost structure includes the whole life cycle, and not only purchase prices. Activities that preserve nature usually decrease total costs as well and people are interested on these issues, which affect us too. (Company C)

Costs are the main driver; we aim to achieve savings. In addition, stakeholders' opinions and requirements have an influence for adopting sustainable practices. (Company E)

Lack of political incentives was mentioned many times as a barrier for integrating sustainable practices. As sustainability can cause uncertainty, it is highly discouraging to implement practices without any support from governments or legislation. However, rapid changes would require more drastic political actions.

Politics and legislation have no influence on improving sustainable business operations. (Company A)

Discussions about sustainability have begun but there are no measures or demands that would guide actions. It will probably take approximately five years before significant changes happen. (Company B)

4.5 Future insights for sustainable manufacturing

A couple of the interviewed SMEs recognize the opportunities that technological innovations will provide. New technologies and machinery will improve the effectiveness of processes concerning resource utilization and waste minimization. However, some of the modern innovations are not yet approved by Finnish governments, but it is likely to change soon. Discussions considered also how sustainability knowledge and expertise within companies must improve for the future.

Technology and "Clean Tech" innovations will enhance sustainable manufacturing a lot. In addition, it will be critical *to have embedded sustainability-mentality more into each organizational level. (Company B)*

Company A states that technological advancement will enable 3D-printing which reduces resource consumption and waste significantly. 3D-printing requires new expertise for product design and development, which is not present in Finland at the moment. However, it is estimated to become extremely relevant soon. Additionally, welding with laser is assumed to generalize in future manufacturing. It utilizes less energy than traditional methods, but it is not yet supported by occupational safety laws.

In the future, life cycle perspective and CE will define manufacturing industry. Calculation of life cycle costs, sharing platforms, and circular resource streams will develop and new business opportunities will be established. Company D also addressed the need for more efficient local recycling systems, and said how there are regional differences for sustainable opportunities which should be equalized in the near future.

The conception of cost will get broader in the future including life cycle and sustainability aspects. Preservation of nature will have an essential role in every business. (Company C)

Circular economy business models will develop in general, and sharing of resources will become more common. Resource efficiency will develop in collecting and utilizing waste energy/heat. In addition, locally I am hoping for better material recycling systems and services. (Company D)

The case SMEs acknowledge that present energy sources and systems are not adequate, and transformation towards renewable energy production is imperative. They understand the need but achieving fossil fuel targets within five to ten years creates doubts. However, it was argued that competition will take care of the sustainable development in every industry, and manufacturing is not an exception. Industrial manufacturing industry may, although, have more challenges in adopting new strategies.

In future, energy perspective which contains renewable energy sources and alternative fuels will affect businesses. Competition ensures the development and exploitation of sustainable practices. (Company E)

4.5.1 Factors affecting the development of sustainable ecosystem within 5 years

The workshop revealed several factors which can support the creation of a sustainable ecosystem, and factors, which may complicate attaining profitability while improving sustainability. The time forecast for the interviewed SMEs was five years, so the following insights consider the year 2026. In addition, the interviewees were asked about their preferences regarding academically recognized sustainable practices, and the results for the categories “easy to adopt” and “challenging to adopt” are presented.

The activities that can boost the creation of a sustainable ecosystem are classified to new innovations and business ideas, organizational competences, and collaborations. New innovations and business ideas refers to finding competitive potential from sustainability. For instance, competing with waste reuse and component remanufacture related services has potential. Identifying new niche-segments can enhance the development of a sustainable ecosystem.

The identification of new marketing segments requires improvements in organizational competences. The case SMEs consider that advanced data and digitalization opportunities, including machine learning and AI, are significant contributors. Technological development will support companies in increasing the informational competences. This is essential in order to adopt new frameworks, applications, and models.

Finally, the workshop results addressed that collaborations have a prominent enhancing impact on the sustainable ecosystem. The discussions included various instances of collaboration possibilities. Firstly, collaboration with other businesses in a form of partnerships or sharing platforms have a potential for mutual resource advantage. Secondly, knowledge sharing among industries could help designing sustainable supply chains. Digitalization provides several applications for effective communication despite the location or time constraints. Thirdly, cooperation with universities and other research facilities is considered beneficial. Participation in research ventures supports the development of organizational knowledge and capabilities with reasonable resource utilization.

The case SMEs mentioned various factors that make it more difficult to build a new sustainable ecosystem. Renewable and resource-efficient solutions are seen too expensive or complicated to adopt into industrial manufacturing sector. For instance, energy storing possibilities and bioenergy exploitation requires a lot of expertise. Additionally, fossil fuels have a substantial position in the current ecosystem, and transition takes more time than few years. Adequacy of bioenergy and electric options also has grown concern among the SMEs.

Regarding the social perspective, proving the sustainable actions to consumers is considered challenging. Moreover, the SMEs require undisputed and clear data that implementing sustainable practices correlates positively with a brand image and turnover. At the moment, the correlation is uncertain. Lastly, it was discussed whether the customers' willingness to pay more for sustainable options will change in five years. It is obvious that customers are more environmentally conscious, but if it will affect purchase decisions is not unambiguous.

The workshop consisted of a segment in which the interviewees were shown a table of the current energy-efficient practices according to the academic literature. The practices were categorized to versatile energy sources, technological innovation, strategy and supply chain, and technical capabilities. The categories and practices have been gathered to APPENDIX 2. The included practices have been presented in the literature review of this thesis. The results to “easy to adopt” and “challenging to adopt” practices in near future are in Table 7. The results were slightly distributed between the practices but here are the ones that received the most corroboration.

Table 7 Perceptions of "easy to adopt" and "challenging to adopt" practices

Easy to adopt	Challenging to adopt
Optimization of logistics	Changing motors and energy sources
Installing air compressors and preventing leaks	Machinery load rate at 75% and measuring it
Workload allocation and good occupancy rate of machinery	Energy storing
Supplier cooperation and close proximity	Smart device utilization
Utilization rate of facilities	Real-time data tracking

Practices that are easy to adopt in near future have already suitable means available or the companies' capabilities are sufficient. These include optimization of logistics, energy saving with air compressors, and leakage prevention with positioning cameras and insulation. Additionally, the SMEs consider that allocating and optimizing workloads, occupancy rates, and utilization rates is easy to adopt. Due to strong relationships with suppliers and economic reasons the cooperation and ensuring the close proximity of suppliers is not demanding.

The challenging adoption is related to the practices that have limited research, established measures, or knowledge among SMEs. For instance, transitioning to renewable energy sources, energy storing, and AI *(artificial intelligence)* solutions are still quite unexplored which causes uncertainty. These limitations decrease the preparedness of the SMEs to adopt the practices and would require a lot of resources.

5 Discussion and conclusion

Considering the definition of sustainability in the manufacturing context, there is coherency between the academic literature and the findings. Energy efficiency and resource-efficiency are emphasized in the SMEs' answers, and they are significant in the literature as well. Additionally, the SMEs recognize CE as part of sustainable manufacturing. Wang. et al. (2019) have defined energy efficiency as adopting practices that reduce total energy consumption and emissions. Cagno & Trianni (2013) state that energy efficiency means increasing the amount of energy produced with renewable sources, which decreases fossil fuel usage. Resource-efficiency is defined as maximum utilization of resources and avoiding waste generation. Moreover, resource-efficient manufacturing is a creation of processes that do not impact negatively on the environment. (Dobes et al. 2017). Bockholt et al. (2020) have determined CE as restorative and regenerative economy, which emphasizes circularity of materials and closed-loop mentality. Recycling and reuse are core practices in CE (Ingarao et al. 2020).

The findings do not define the sustainable concepts as thoroughly but it can be observed that the SMEs understand the fundamentals of them. The quotes mention many times that sustainability is decreasing material and energy consumption in the manufacturing processes. Effective utilization of resources as well as waste reduction are also stated. It is suitable that the findings correspond to the literature because further communication between scholars and businesses will be easier in terms of sustainable development.

The practices in the stages of the LCA process have similarities between empirical results and the literature. However, academia has identified a larger amount and more elaborate practices than the case SMEs have adopted. This is extremely reasonable considering the size, location, and industry of the SMEs. The similarities are found in energy efficiency, resource-efficiency, and slightly in CE. The findings show that the practices are mainly located to the raw material acquisition, production, and EoL stages of the LCA process. In the literature, most of the energy-efficient practices are related to production, whereas resource-efficient practices and CE measures locate to the product development, raw material acquisition, and EoL stages. (Bockholt et al. 2020; Choi et al. 2019; Cagno & Trianni 2012).

In the academia, optimizing and allocating machinery and processes is suggested to eliminate energy waste. Additionally, implementing measures for collecting detailed data for monitor and evaluation is stated. (Özbilen et al. 2019; Trianni & Cagno 2013). The findings indicate that these sorts of practices are currently utilized, including various feedback and data gathering systems. However, the findings do not specify the systems in use. Regarding resource-efficiency, the case SMEs aim to plan products with quality materials and design them effectively, which means removing unnecessary parts. This correlates with the. They also aim to achieve a good occupancy rate of materials in production, and optimize logistics with full loads and consistent routes. This correlates with the CP methods introduced by Dayaratne & Gunawardana (2015) but it is not as extensive. At the center of CP are resource conservation and avoidance of toxic materials, which are valued in the case SMEs. Altmann (2014) states that it is essential to adopt a long-term perspective in product development, and plan the production in advance. This considers all the aspects from raw material volumes to logistics and disposal. Fatimah et al. (2013) have established that a crucial resource-efficient strategy is maximizing the use of each component and material. Regarding the case SMEs, they have adopted a resource saving mentality, which is crucial in enhancing the implementation of sustainable practices.

Recycling, remanufacture, and reuse are significant sustainable practices. These practices improve the circularity of materials, and lead to reduced consumption which is highly relevant in terms of sustainable manufacturing. Considering the LCA process, CE practices are mainly located to the raw material acquisition, production, and EoL stages. Purchasing recycled raw materials, recycling the production wastes, and manufacturing products that are reusable and recyclable are feasible practices presented in the literature. (Ingarao et al. 2020; Paletta et al. 2019). According to the findings, the SMEs recycle their wastes and manufacture products that have a reuse value or can be recycled to other purposes.

Furthermore, academia addresses a sustainable practice of taking-back product at the EoL stage. The reasoning for this is that companies would take responsibility and evaluate their reuse or remanufacture value. If there is not this sort of value, companies would recycle each component properly. (Bockholt et al. 2020; Garza-Reyes et al. 2018). However, there are problems with this strategy considering the logistics for taking-back products, required expertise, and commercialization for reused and remanufactured material and products. Taking-back products can have a sustainable value in terms of decreasing raw material consumption, but the environmental aspect of the additional logistics should be incorporated to the research as well. Additionally, it will add some costs for a company which is a significant factor particularly to SMEs. It is necessary to further research the cost and logistics aspect to ensure the profitability of the “take-back” strategy. Another issue is that remanufacture and reuse processes may require a specialized expertise and organizational capabilities, which may not be present at the moment. In that case companies would have to release resources to training and capacity building. Finally, the commercialization strategies for reused and remanufactured products may need research and development since the topic is still quite unfamiliar in Finland.

During recent years the interest towards PSS strategies has been growing. PSS focuses on providing services instead of products, and the advantages generate from the longer resource utilization and decreases in resource consumption and disposal. (Ünal et al. 2019). In the manufacturing industry, it is highly difficult to transfer solely on providing services, but the case SMEs are increasingly incorporating life cycle services into their business which applies to the PSS objectives. The life cycle services are an attractive solution for customers as well, since repair and maintenance are usually cheaper than purchasing a totally new product. (Ingarao et al. 2020).

The findings address similar challenges to sustainable manufacturing in SMEs as does the literature. Limited resources, practical implications, knowledge, and awareness are the primary barriers to sustainability. The academia has also not emphasized industrial manufacturing SMEs in the research. (Ünal et al. 2019; Wang et al. 2019; Robinson et al. 2015). The case SMEs discuss that legislation does not provide incentives or support for sustainable development. Moreover, the lack of feasible tools and methods and high investment costs are decreasing the willingness to integrate sustainability into business. These barriers are understandable in a SME context since they have less resources compared to large enterprises. In the academic field, Bockholt et al. (2020) and Dobes et al. (2017) have particularly stressed the need for practical tools and economically beneficial sustainable measures.

According to the literature, drivers for the integration of sustainable practices include environmental concern, potential for economic advantages and improved effectiveness of processes, and customer appreciation. (Ünal et al. 2019; Andersson et al. 2018; Dayaratne & Gunawardana 2015; Cagno & Trianni 2013). These correspond to the empirical results which mention resource and monetary savings, advantages from modern technology, and the significance of sustainability to the brand image. The case SMEs acknowledge the existing environmental problems but at the moment, it is not included to the primary drivers, which is likely due to the prominent barriers. On the other hand, stakeholders' preferences have a strong influence on the SMEs which means that if they demand sustainable actions it will have an impact. The literature addresses the effect of stakeholders as well, and it is stated that sustainability can have a significant effect on the brand image (Ünal et al. 2019).

Consequently, findings indicate that industrial manufacturing SMEs need more drivers from political and legislative point of view. Although EU has set out several actions towards sustainability (Garza-Reyes et al. 2018) their usefulness is not much acknowledged among the case SMEs. This can be due to the scale of business or remote location. However, legislative drivers can make a significant change, even when awareness and interest to sustainability is not high. Furthermore, political and legislative drivers can support the positive effect of other drivers.

The future of sustainable manufacturing will be affected by many factors. The academic literature has addressed the development of renewable energy systems, LCA and calculation of emissions, additive manufacturing, CE ecosystem, and increasing partnerships and collaborative networks. (Gonzalez-Varona et al. 2020; Choi et al. 2019; Pechmann et al. 2016; Heidrich & Tiwary 2013). The interviewed CEOs bring forward some of these factors as well. For instance, additive manufacturing is considered having a substantial influence on resource-efficiency and supply chain development. Considering energy efficiency, renewable energy systems will become more developed so their utilization is profitable. However, the time scope of five years is thought to be fairly short for the required progress. This indicates that current R&D and national renewable energy strategies or directives are not persuasive or feasible enough for companies or they are not communicated sufficiently.

Sustainability of industrial manufacturing SMEs will develop as the CE ecosystem does. The common CE strategies are sharing platforms, transition from products to services, and an extensive recycling of materials, components, and wastes. (Ingarao et al. 2020; Howard & Webster 2018). The empirical results already show the impact of CE since raw material wastes are recycled and some SMEs manufacture products from recyclable materials. Additionally, EoL components are possible to transfer to other resource flows. These singular practices enhance the creation of a total closed-loop economy (MacArthur 2013). Furthermore, the case SMEs have transferred towards a servitized business model by providing maintenance and spare part services. As it was stated in the findings, market competition will take care of the sustainable development, but if the changes are required faster than they would naturally occur, additional incentives and research is vital.

To conclude, environmental concerns have grown massively during previous years due to the new scientific data which stresses the urgency for sustainability. (Ludin et al. 2018; Singh et al. 2014). Although, permanent sustainable actions are crucial, it could be considered that what is a reasonable time limit for organizations to achieve prominent results. Regarding the demands for sustainability, it could be evaluated whether the increasing regulations are justified and possible for the industrial manufacturing sector within five or ten years. Do SMEs have sufficient capabilities and potentials to adopt them? If not, establishing more effective measures to support the transition would be justified. As Ünal et al. (2019) have stated, the research limitations contribute to the companies' reluctancy for sustainable development, and for this, the growing amount of regulations without tangible measures to perform them is not a viable solution.

5.1 Conceptual contribution

This work aimed to investigate sustainable manufacturing in Finnish industrial SMEs. The objective was to provide a holistic understanding of sustainability in manufacturing context, address practices throughout the LCA process, and analyze the significance of different factors in achieving sustainable development and building a new sustainable ecosystem for manufacturing. The topic was approached with the following research question.

RQ: How can sustainable manufacturing be clarified and how different factors affect the sustainable development and the integration of practices in the stages of the LCA process in Finnish industrial SMEs?

This work has led to the discovery of new insights concerning industrial SMEs in the sustainable manufacturing perspective. In summary, sustainability is an extremely broad concept that requires a holistic and precise review and analysis in order to attain profitable sustainable development. The literature review and the findings show that SMEs and large enterprises cannot be bundled together regarding the integration of the sustainable practices. Besides, SMEs need more attention and tangible solutions from the research. The academic literature has previously not focused on the SMEs in this topic but within few years this has been altering.

The research problem was the discrepancy that industrial manufacturing sector mainly consists of SMEs, but they have been neglected from academic research regarding sustainability (Bi et al. 2015). The topic is relevant since the total resource consumption and the environmental impact of the SMEs is significant (Dey et al. 2020). This work has examined sustainability comprehensively from the theoretical and academic perspective which has led to reduced gap on the knowledge concerning energy-efficiency, CE, and resource-efficiency among SMEs. Sustainability in industrial SMEs is defined as decreasing total energy and resource consumption, enhancing circularity of materials and products, and avoiding waste generation by integrating measures that support these objectives.

The academic literature has identified several practices throughout the LCA process which relate to energy-efficiency, CE, and resource-efficiency. The empirical results also show that some of these practices have been implemented to business. However, many scholars are emphasizing a more comprehensive approach to sustainable development. It is stated that sustainability should become more fundamentally integrated to business models to attain permanent progress. Traditional structures are considered as deficient for sustainability requirements. Furthermore, this indicates a need to the creation of a new sustainable ecosystem in industrial manufacturing. The empirical results also support this view by stating the need for a collective supply chain development and addressing the existing industry-related obstacles.

5.2 Managerial implications

The results from the empirical analysis can extend the knowledge of other SME managers regarding the current state and future prospects of sustainable manufacturing. The findings can motivate managerial-level to re-evaluate processes which can lead to uncovering weak areas of sustainable performance. This work explores various areas of sustainability holistically, and the presented topics can provide instances for improvement potentials, that managers have not acknowledged. Moreover, the literature review and the empirical findings can be useful for SMEs that know specifically that an area which needs development is energy-efficiency, CE, or resource-efficiency in a supply chain. This work can also provide support for SME managers who are interested in implementing sustainable development to business but have not acquired suitable knowledge and tools for this.

Another implication for managerial purposes relates to the limited emphasis on the LCA in supply chains. The empirical findings indicate that SMEs have difficulties or a lack of interest to extend sustainability thinking to logistics, use, and EoL. However, the literature reveals possible sustainable development areas in these LCA stages that can be interesting to explore. Thus, if managers would aim to enhance the collaboration with their customers and customers' customers, it could support creating new sustainable practices that are mutually beneficial, or in the best case, uncover new niches.

5.3 Limitations of the study and future research

This work has been conducted systematically while considering the reliability and credibility requirements. However, it includes some limitations that should be addressed. To begin with, there is a limitation regarding the size of the research sample and the specific location in Ostrobothnia. Although the SMEs have been selected considering the coherency of the study, the small number of the companies or the limited location may limit the applicability of the results to other manufacturing SMEs in Finland. Secondly, since sustainability is a quite broad concept and the duration of the interviews were only 90 minutes, it may have complicated attaining more detailed data. For instance, the results about the current sustainable practices are not in each case specific but refer more to a principle. If there would have been more time and more limited structure of the interview, the discussions could have been more prolific.

Regarding the future research, this work has addressed the need for structural innovation to achieve sustainable development in industrial manufacturing. Further research could assess the possibilities of industrial networks and sharing platforms. Networking and sharing of resources are recognized as a significant contributor to CE strategies, and tangible measures could facilitate this transition. For instance, virtual power plants have been addressed in the academic research for their potential in terms of flexible energy production without fossil fuel usage and waste of energy, and collective use possibilities. The advantages regard many areas in sustainable manufacturing, and thus, following research could aim to develop this concept and the required infrastructure changes.

Another interesting topic for the future is the commercialization strategies for remanufactured products and recycled materials and components. This could increase taking-back products, and lead to better exploitation of resources. Moreover, it would enhance the circularity of materials and products and add economic advantages. As the economic drivers remain to be the most critical among manufacturing SMEs, the further research in this area could be beneficial.

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Appendix

APPENDIX 1. Structure of the interview

1. Background data

-Company name, size, industry

-Product and services

-Interviewee’s position in the SME

2. Value chain

-Customers and customers’ customers + their industry

-Suppliers and suppliers’ suppliers

-Manufacturing structure (in-house, outsourcing etc.)

-Distribution channels

-Significance of exporting?

-Upcoming trends that will affect the business in 5 to 10 years

3. Environmental sustainability

-Definition of sustainable manufacturing

-The role of sustainability in the business

-The significance of sustainability in the industry

-Problems regarding sustainability in the industry

-Potential development areas in the supply chain

4. Current sustainable practices

-Practices in the stages of the LCA process

-Drivers and barriers

-Impact from stakeholders

5. Future insights

-Factors affecting sustainable manufacturing within 5 years

-Company-specific objectives for sustainable development

-Required capabilities and resources for developing sustainability

APPENDIX 2. The table of the current practices according to the literature presented in the workshop

Group 1: Versatile energy sources	Group 2: Technological innovation	Group 3: Strategy and supply chain	Group 4: Technical capabilities
Delivering with sustainable fuel: Bio ethanol (Eko E85), LPG, natural gas, bio gas	Implementing energy management system (which follows ISO50001 standard or ISO14001)	Optimization of logistics: Effective planning of routes, deliveries with full loads	Machinery workload allocation: Avoiding standby time > choosing start/stop time reasonably
Using biogas/ natural gas for HVAC systems and electricity	Preventive maintenance of HVAC systems with AI based solution	Using biogas/ natural gas for HVAC systems and electricity	Minimization of machinery voltage unbalance: <10%
Producing energy with solar panels, wind technology	Application of smart devices (better performance-cost ratio)	Close proximity of suppliers	Machinery running at 75% load rate
Investments in renewable power plants	Using real-time data tracking tools	Delivering with sustainable fuel: Bio ethanol (Eko E85), LPG, natural gas, bio gas	Utilization of LED bulbs and other higher efficiency lamps/ballasts
	New innovations for storing energy	Supplier selection based on fossil fuel usage	Prevention of leaks in inert gas/compressed air lines
		Participating in energy auditing	Insulation of bare equipment
		Regular internal meetings with energy managers for monitor and evaluation	Installment of compressor air intakes
		Preventive maintenance of HVAC systems with AI based solution	Utilization of brushless DC motors instead of brushed AC motors
		Maximizing utilization rate of production facilities	
		Investments in renewable power plants	