Transition to Circular Economy in the European Union: Focus on the Machinery and Equipment Industry

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Submitted to: Dr. Sabine Sedlacek

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Affidavit

I hereby affirm that this Master's Thesis represents my own written work and that I have used no sources and aids other than those indicated. All passages quoted from publications or paraphrased from these sources are properly cited and attributed.

The thesis was not submitted in the same or in a substantially similar version, not even partially, to another examination board and was not published elsewhere.

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Abstract

As the Circular Economy is praised by many to be the future economic model, many decision-makers look at the opportunities of such a model and how to encourage the industries to switch to a circular model. The European Union in the context of the European Green Deal has the objective to make the European economy circular. To make it possible the Circular Economy Action Plan was created to make actors of the European economy switch to a circular model. However, just few European businesses switched to the Circular Economy so far and the largest portion does not seem to be willing to change. In a context of urgency for environmental measures and sustainable strategies to protect either the nature and humankind such behaviours seem reckless but are motivated for specific reasons. Each industry faces different challenges and has specific needs. This thesis focusses on one industry, the Machinery and Equipment Industry, and seeks to understand how and under which conditions it could switch to Circular Economy. Several factors including economic, biophysical, cultural, technological and regulatory factors are considered and tested in order to answer this question.

In a first part this thesis analyses the Machinery and Equipment Industry in the European Union to gain a deep understanding and shows that remanufacturing activity is the most effective circular technique that can be applied in the Machinery and Equipment Industry. A second part bases its analysis on three case studies, three Austrian companies competing in the Machinery and Equipment Industry; expert interviews have been conducted with representants of these companies. Those interviews in the context of an empirical research confirmed most of the reasons present in the literature to switch to Circular Economy, namely the high EROI, the cost savings of circular technics, the circular culture, the need for better regulations and support in the transition. On the other hand, this research also reveals specific needs and claims of the Machinery and Equipment Industry to switch to a Circular Economy model based on remanufacturing activity, namely the low interest in financial support but rather the call for strong regulation, the desire to gain more knowledge concerning what the Circular Economy is doing and how it is working and the need of a good relationship with or strong influence on the suppliers in order to conduct a remanufacturing activity.

This thesis draws a picture of the most important factors for the Machinery and Equipment Industry to switch to Circular Economy under the given research limitations and aims to be an invitation to conduct further research on this topic in order to greater develop the testing of variables and confirm or challenge the found results.

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Table of content

List of figures

List of tables

List of abbreviations

C2C	Cradle to Cradle
CO_2	Cardon Dioxide
CE	Circular Economy
CIE	Circular Industrial Economy
EC	European Commission
EMF	Ellen MacArthur Foundation
EROI	Energy Return On Investment
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gas
IE	Industrial Ecology
IM	Industrial Metabolism
IR	Industrial Revolution
IS	Industrial Symbioses
MEI	Machinery and Equipment Industry
Mtoe	Million tonnes of oil equivalent
NACE	General Industrial Classification of Economic Activities within the European Communities
NGR	Nicholas Georgescu-Roegen
NGOs	Non-Governmental Organisations
NMVOC	Non-Methane Volatile Organic Compounds

OEM	Original Equipment Manufacturer
RQ	Research Question
ROI	Return On Investment
SMEs	Small and Medium-sized Enterprises
SO_2	Sulphur Dioxide
TPES	Total Primary Energy Supply
UN	United Nations
US	United States
USA	United States of America
USD	United-States Dollars
WEEE	Waste of Electrical and Electronic Equipment
WEF	World Economic Forum
WBCSD	World Council for Sustainable Development

1 Introduction

1.1 Historical context

For centuries human perceived their land, the planet earth, as unlimited in terms of resources and place. The assumption of a flat planet was predominant during the largest human living time and is still existing. Then, during millenniums and centuries the human-kind expanded all around the world and disposed of natural resources of its environment to grow and become stronger. The exhaustion of resources seemed to be a predicament to the human-kind development (Boulding, 1966).

To translate these facts, the first economists in the classical economics (1776-1890) considered the base of economy as the production of goods and services and that three categories are essential to produce economic activities (Hussen, 2004): first the natural resources, second labour and last but not least the capital. These categories were central during the Industrial Revolution (IR) that occurred in the late 17th century. IR tremendously increased the dependence of economic systems on resources and energy use. The exponential economic and demographic growth of humanity allowed by the IR generated many environmental and social issues. For instance, industries were built close to the cities to have access to the maximum of working force and as long as the industries extended, rural exodus increased. This important movement of population to answer the demand of manufacturers for working force forced cities to build housing as fast as possible and as dense as possible. This hastiness and the high level of urbanisation close to polluting manufactories degraded the sanitary situation and exposed the population to air and water pollution (Ivanov, 2009). This situation developed many externalities due to the environmental degradation such as social and governmental crisis.

Many environmental, social and health crises happened all around the world in the early 19th century and environmental associations raised to defend people and nature. The large public awareness really appears in the 1950's by the documentaries of Jacques Cousteau and the first recognition of an environmental movement, the Sierra Club which protested against the construction of the Echo Park Dam in Utah. Then, the number of environmental associations to protect the environment multiplied in Europe and in the US. As a result, the first massive demonstration for the protection of the environment occurs on April 22nd in 1970 in the US under the name of "Earth Day". This protest counted more than 20 million protestors which is still today the largest demonstration ever in the US and its influence has been recognised worldwide, also

because of the important number of pro-environmental legislation which entered into force the following years after the Earth Day (American Experience, 2010).

Scientific papers followed the Earth Day in 1971 that challenge the current way of doing economy and support environmental and ecological movements such as "The Entropy Law and the Economic Process" by Nicholas Georgescu-Roegen (NGR), "Fundamentals of Ecology" by Eugene Odum and "The Limit To Growth" by Dennis Meadows in 1972. All of them make links between the economy and the environment and the emphasis on the danger and unsustainability in continuing to follow the actual economic model. They also insisted on the significant role of the environment for the economy due to the fact that it provides services to humankind and to the economy (Hussen, 2004).

The neoclassical economics (1900 to present) assumes that the economy depends on the natural environment for extracting non-renewable resources, for assimilating the waste that the economy generates and for providing hobbies and other cultural activities for human-being. The mainstream economy admitted the importance of the environment but considered it as an external phenomenon that does not interfere with economic activities, this is why mainstream economy never proposed any measures to preserve the environment.

In 1987, a report led by Gro Harlem Brundtland had the goal to understand the causes of the environmental degradation and to propose a couple of policies and recommendations to preserve it. It was the United Nations (UN) that charged the World Council for Sustainable Development (WBCSD) to make this report in order to have long-term solutions for implementing sustainable development. This report known as "The Brundtland Report" covered topics such as the impact of the economy on the environment, the influence of the world population, the importance of the food security, the importance of the biodiversity, the ecosystems and the strategic sector of the energy to finally finish with legal principles of environmental protection. However, this report is today mostly known for its definition of sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Jarvie, 2014).

Unfortunately, none or too few of the recommendations of the Brundtland Report were applied by the UN or any international communities to stop environmental degradation. In the same time neo-liberal economic policies were widely accepted all around the world which pushed developed countries to increase their consumption even more. The economic vision of the neo-liberalism pursues the maximisation of the profit in the shortest time mostly based on financial exchanges to maximise the activities within the real economy. In order to follow this rhythm, the (real) economy

follows a linear model to focus on the production but it increased the environmental degradation over the last 30 years until reaching a critical situation today.

Therefore, our actual economic model is linear such as the Figure 1 represents and a new one is needed:

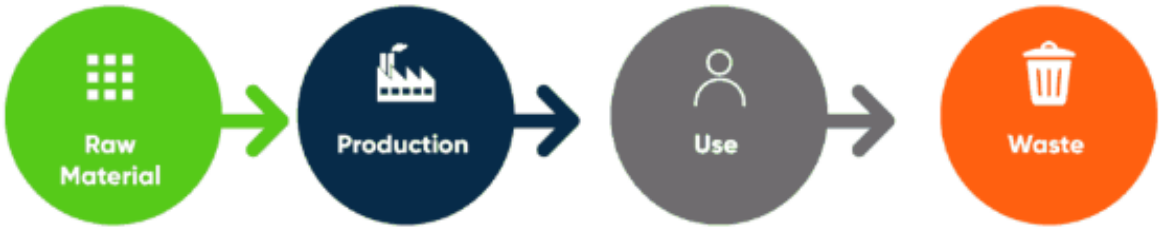


Figure 1: Linear Economy (Source: Ecochain, 2019)

1.2 The implication of the IPAT equation

Chertow (2008) says that in the early 1970s Ehrlich and Holdren devised a simple equation of three factors that created environmental impact, I = P x A x T. I stands for the environmental impact, this impact (I) was expressed as the product of population, (P); affluence, (A); and technology (T). This simple equation is a good starting point and it is still relevant today (Roca, 2002).

The human population clearly has an influence on the environment due the fact that human economy mostly depends on natural resources extraction. Regarding the equation, a reduction of the world population (P) would reduce the human environmental impact but it is a political and deontological difficult subject.

The affluence (A) which represents the consumption and is often calculated as the Gross Domestic Product (GDP) per capita is also a factor to reduce environmental impact. But most of the human population particularly in developed countries is not willing to change them habits. People would consider it as an attack of their individual freedom.

It is well known that new technologies (T) can improve the effectiveness of the product and services to consume less material and energy. Regarding the two previous factors, technology seems to be the only factor which is political feasible to reduce environmental impact (I).

During the twenty last year's our economy leaded by the neo-classic economics invested in technology to reduce energetic consumption and to answer environmental issues such as the global warming for instance. However, this policy is confronted to the rebound effect or the Jeavon's paradox which is according to Ruzzenenti, Wagner, Sorel, Galvin, Vivanco, & Walnum (2013) "when a new, more efficient technology leads to less-than-expected savings or even a greater

energy consumption". In other words, the use of technology increases the efficiency of a process such as the energy consumption for instance, it allows the consumer to save cost but this same customer will be tended to use more often its product because it became cheaper. The car is an often-cited example, the more performant a car is, the less oil it consumes, but due to the low consumption drivers tend to drive more. Moreover, Hertwich (2005) shows that rebound effects price-based can be direct as defined previously and/or indirect (it is not linked to the initial policy). For instance, problem solving or optimizing by technology can create spillovers on an ecosystem later on in another place. Hertwich (2005) talks of rebounds phenomena to mention the secondary effect that a rebound effect can have which increases the complexity when implementing a new technology or conducting a new policy.

The large majority of the environmental policies conducted by neo-classical economics school of thought did not have a real and positive effect on the preservation of the environment because they only focus on technological improvement. Therefore, a change also has to occur in the consumption factors of the affluence (A) in the IPAT equation which implies a change in the global economic model.

As previously presented the linear model of our economy (Figure 1) failed to address sustainability issues. But recently a new economic model gained a wide spread attention, the Circular Economy (CE) as presented in the Figure 2.

Figure 2: The Circular Economy (Source: European Commission, 2017)

The CE claims to change the consumption habits, the affluence (A), by using adapted technology (T) to close the loop of material and energy used in the economy in order to address sustainability issues. However, the CE is a relatively new concept that does not have for the moment an official theoretical background; this thesis will define the CE in theoretical framework section.

1.3 The research context

This thesis on the CE concept which is relatively new, less than 20 years, mostly build by Non-Governmental Organisations (NGOs) such as the Ellen MacArthur Foundation and businesses, thus without official and established theories behind it. Due to the enthusiasm in the private sector and the urgency to change of economic model the European Commission (EC) developed a strategy to switch EU economy in a CE (Mataro, 2015) called the 'Circular Economy Action Plan' which runs until 2030 to accelerate the CE transition in the European Union (EU).

In a first-time a lot of research was conducted to establish the roots and origins of CE. The theoretical framework of this thesis is based on the work of the pioneers of the CE to explain the CE origins.

In a second time researches used the origins of CE to expose the theoretical CE limits as in the paper of Korhonen, Honkasalo & Seppälä (2016).

At the same time, literature reviews were made on the CE topic, for instance by Ghisellini, Cialani, & Ulgiati, (2015) which greatly help researchers who want to embrace the topic.

Then, many researchers tried to compare the CE theoretical implications with the existing economy such as the work of Murray, Skene & Haynes (2015) and Heshmati (2015). The empirical matters of these authors are based on what China has developed so far in terms of CE. China started to implement CE strategies in some of its cities in 2007 with the objective of (Heshmati, 2015 p.12) "improving resource use efficiency and improving the level of material reuse, recycling and recovering solid waste and waste water". The results of the Chinese pilot cities show that the objectives of the Chinese's strategy were achieved, they could preserve energy, water and resource uses. However, it was not in the Chinese agenda to change the consumption culture of the population and some researchers made some doubt on the data quality that the Chinese government communicated.

Therefore, other research was conducted on the analysis of European case studies in order to have better data quality. Broadly, two kinds of researches were conducted in order to determine the barriers that exist within the EU to switch to a CE model.

The first by Kopnina (2019) is based on a case study analysis of companies considered having the best practices. This kind of analysis does not really target a specific industry but is able to show the great potential of CE and in the same time the long way that needs to be taken. The second by Kirchherr et al. (2018) is based on expert interviews among policy makers, scholars and businesses. It shows that CE has four barriers on the macro level which are: cultural, market, regulatory and technological. The cultural barrier refers to the acceptance of CE by businesses.

The market barrier refers to the low cost of virgin material and of the investments that are needed to switch to a CE model. The regulatory barrier refers to the lack of supportive policy particularly concerning materials coming from none-EU-countries. And then the technological barrier refers to the lack of circular design and of knowledge (Kirchherr et al. 2018). However, at the image of Kirchherr et al. (2018), the interviewed businesses are all start-ups or specific companies that are considered as role model.

Moreover, various ideas and concepts were developed before CE became famous, these concepts contributed to the creation of the present broad idea of CE. According to Ellen MacArthur Foundation (2017a), on a macro level the "Performance Economy" (PE) initiated by Walther Stahel and the "Blue Economy" (BE) initiated by Gunter Pauli, both propose an economy in loops. They claim for extending the product-life, for making waste our future input and for preventing environmental degradation in an economy of services and not of product consumption. On the micro level the "Industrial Ecology" (IE) study shows how to connect the industries in order that the waste of one industry becomes the input of another. And on the meso level, the Cradle to Cradle (C2C), Regenerative Design (RD) and Biomimicry are mainly focused on the design of products and services adapted for the nature regeneration and industrial reuse/remanufacture/recycling (EPEA, 2020; Ellen MacArthur Foundation, 2017; Pauli, 2020; Marmey, 2014).

All these concepts were developed with the comprehension of the complexity of the economy and the human-kind ecosystem, with the simple assumption that the actual economy needto produce products and services to work. Therefore, industries are necessary but are also the most polluting sector, this is why these concepts look at solutions to adapt industrial process to our ecosystem.
With these convictions and understanding the thesis wants to look at the implementation of CE within a specific industry. This thesis is influenced by the professional experience of the author and the belief that the production processes are necessary but have to adapt. This is why the thesis focuses on a key industry for production of goods and services, the Machinery and Equipment Industry (MEI).

1.4 Research question

The purpose of this thesis is to find why the very specific MEI in the EU incorporates the Circular Economy (CE) concept in their model of production as desired by the CE. The context mentioned above showed that research on CE in the EU lacks to consider the needs of specific industries. Therefore, the goal of this thesis is to address the specific limitations that MEI is exposed to change to a CE model. Because every industry acts in a different environment, they do not face the same problems. It is likely that the MEI could privilege some of the CE technics compared to others or even conduct some of them partially without being aware of it. Therefore, another goal is to determine if the MEI conducts production models which are compatible with the CE models.

Research question:

The research question of this thesis is: Why would the Machinery and Equipment Industry within the European Union switch to Circular Economy regarding biophysical, economic, cultural and environmental limits?

Having understood the research context, I assume that the CE should be implemented as soon as possible regarding to the environmental emergency. To be feasible I believe that every industry has to be studied in order to receive accurate advises and helps in their transition to a CE model. Until now researches on the CE in the EU did not look at specific industries and even less on highly material and energetic intensive industries such as the MEI which constitutes one of the bases of the high standard of life in western countries. Since there is a lack of empirical evidence for certain industries this thesis aims to fill this gap for the MEI. The industry specific evidence found by the thesis will help to develop and spread industry specific CE analyses in the future.

Regarding my professional experience, I believe that looking at industries that are considered as being the worst cases can give great results, because a small sustainable improvement in this kind of industry can quickly generate great environmental preservations.
I suppose that this research will show that the MEI in the EU is lacking behind in the process of transition to CE models. In the same time, I believe that this industry already has implemented processes which are compatible with CE technics such as C2C design and have specific reasons inherent to their economic environment to not have switched earlier to a circular model.

My claim is that my findings will be correlated to the CE's limitations addressed by Kirchherr et al. (2018) and Kopnina (2019) but will also reveal specific limitations or interests inherent to the MEI such as remanufacturing for instance.

1.5 Thesis content

First of all, a theoretical framework will help to understand what the CE with its theoretical background and with its important concepts that are part of it is. Therefore, a focus on the Boulding's Spaceship Earth will be made due to the fact that it is the first and closest theory to the actual CE (Boulding, 1966). But in order to understand the Boulding's Spaceship Earth theory, an exploration of the implication of thermodynamics in economics is necessary. An explanation of the core of thermodynamics, the first two laws, will be made with their links to the economy and the biosphere. Then a presentation of what is today one of the main tools of CE, the C2C design will follow. It will help to understand how to close the loop in the micro and meso level. And then, a presentation of the Ellen MacArthur Foundation vision which claims today to have established the CE's theory (Stahel, 2019) will be done. Regarding this literature review some hypotheses will be addressed based on secondary research questions in order to answer the research question. A conceptual framework will be proposed based on the theoretical framework assumptions and its ensuing secondary research questions and hypotheses.

Secondly, a part dedicated to the methodology of the thesis will be presented. It explains the conceptual framework of the thesis made with the information and the hypotheses of the previous part. Then, the framework of the thesis' methodology will be presented as the research approach, philosophy and design, followed by the details of the data collection method with its sampling strategy and way of data analysis. To finalise the methodological part a section dedicated to the ethical consideration of the thesis during the research process and a last section treating the limitations of the research will be added.

Thirdly, the three next sections of the thesis are dedicated to the three methods of data collection. In the first place comes the empirical data which is secondary data coming from Statista and Eurostat related to the MEI in Europe. The goal of this section is to determine the position that the MEI has in the economy and its environmental impact.
In the second section follows a document analysis about the MEI. The treated company as reference model is Caterpillar Inc. As a role model in the implementation of the CE in the MEI, Caterpillar benefits of a well-documented literature that treats its CE model. This important actor

of the MEI developed many circular technics over the time and has today a real CE model which will be interesting to analyse in order to discover which reasons drive businesses towards CE.
In the third section an interview data analysis of three case studies follows. This section should bring information coming from people not necessarily experts in CE in order to get more accurate information of what happens in the MEI. This field work is supposed to confirm the criteria for a MEI business to switch to a CE model.

Fourthly, a conclusion will summarise the thesis findings and answer the research question and the hypotheses to present a model for CE implementation within the MEI in the EU. A mention and call for future research on the topic will also be proposed.

2 Theoretical framework

2.1 General

Malhotra (2010, p.051) claims that a researcher should rely on theory for the following reasons:

- It helps the researcher to find the variables that are relevant for its research
- It gives information on how the variables can be found and measured
- It gives a basis for the researcher to interpret his findings

But what concretely is a theory, Bailey (1994, cited by Blaikie, 2010) states that "theories attend to answer why and how questions' by 'relating the subject of interest to some other phenomena". Similarly, Malhotra (2010, p.051) states that "a theory is a conceptual scheme based on foundational statements called *axioms*, which are assumed to be true".
Therefore, it is correct to say that a theory searches truth and explanation to explain what the researcher observes.

In the case of this thesis, a CE theory would constitute the perfect basis for continuing the research. However, due to the relatively recent use of the term CE, there is not yet an established theory for the CE. Regarding this situation, this thesis proposes different concepts, ideas, writings and laws to establish the theoretical background of the concepts that is today known as the CE.

According to Brennan, Tennant & Blomsma (2015), the EMF raised the interest for the term CE when they presented their report "Towards the Circular Economy" during the 2012 World Economic Forum (WEF). Korhonen, Honkasalo & Seppälä (2016) state that "the concept of CE and its practice have almost exclusively been developed and led by practitioners, i.e., policy-makers, businesses, business consultants, business associations, business foundations etc." Therefore, the concept of CE is mostly unexplored by science. The closest theory of the concept of CE is the Spaceship Earth from Kenneth Boulding but for a proper understanding of this concept and of the challenges that CE must deal with, a presentation of thermodynamics is necessary.

2.2 Thermodynamics

Glucina & Mayumi (2010, pp.11) states that "thermodynamics is the study of energy and its transformations. Born in the 19th century, during studies on steam engine efficiency, it is now one of the pillars of physical sciences." Thermodynamics is composed of 4 laws, the first and second

law co core of thermodynamics when the third and the zeroth laws exist to ensure the coherence of the first and second law in order to facilitate specific physic' fields. Therefore, the thesis focuses on the first and the second law in order to understand thermodynamics and its implication in economics.

2.2.1 The first law of thermodynamics

The first law of thermodynamics also known as the law of conservation of the energy states that total energy is conserved, or the energy of the universe is constant, in other words, the total amount of energy in the universe remains the same and energy cannot be created or destroyed but can only change its form. To simplify the first law states that energy quantity remains constant.

2.2.2 The second law of thermodynamics

The second law of thermodynamics also known as the entropy law states that entropy of the entire universe will always increase over time and the changes in the entropy in the universe can never be negative. By simplifying, the second law states that energy quality degrades over time. It is not possible to use all the available energy to produce something because energy will inexorably dissipate, it is a loss, because a part of energy becomes too diluted to be used as energy, in other words it is waste. According to Wolfram (2002), some founders of thermodynamics, Rudolf Clausius in 1854 and William Thomson (Lord Kelvin) in 1847 refer to the entropy as a tax that nature exerts during the conversion of energy into work. It is interesting to notice that entropy can only increase as a whole such as in large and closed systems like the universe or our planet.
But in the same time subsystems can decrease their entropy at the detriment of another system. Therefore, two states of entropy exist, the 'high entropy' refers to low-quality energy, after being used or degraded and the 'low entropy' refers to high-quality energy. For instance, crude oil has low entropy but companies by refining the oil can decrease the entropy of the crude oil to improve the quality of the energy but the refining process needs energy that would be lost (high entropy) and after consuming oil in cars the oil will be degraded and diluted in the air. It is the pollution which has a very high entropy. (Glucina & Mayumi, 2010).

2.2.3 Thermodynamics' systems

As mentioned, thermodynamics is the study of energy in different systems. Thermodynamics study makes important distinctions between three types of systems. According to Glucina & Mayumi (2010):

- In an open system matter and energy pass through the system boundary;
- in a closed system matter cannot leave the system boundary and energy may go in and out of the system boundary;
- and then, in an isolated system matter and energy cannot leave the system boundaries.

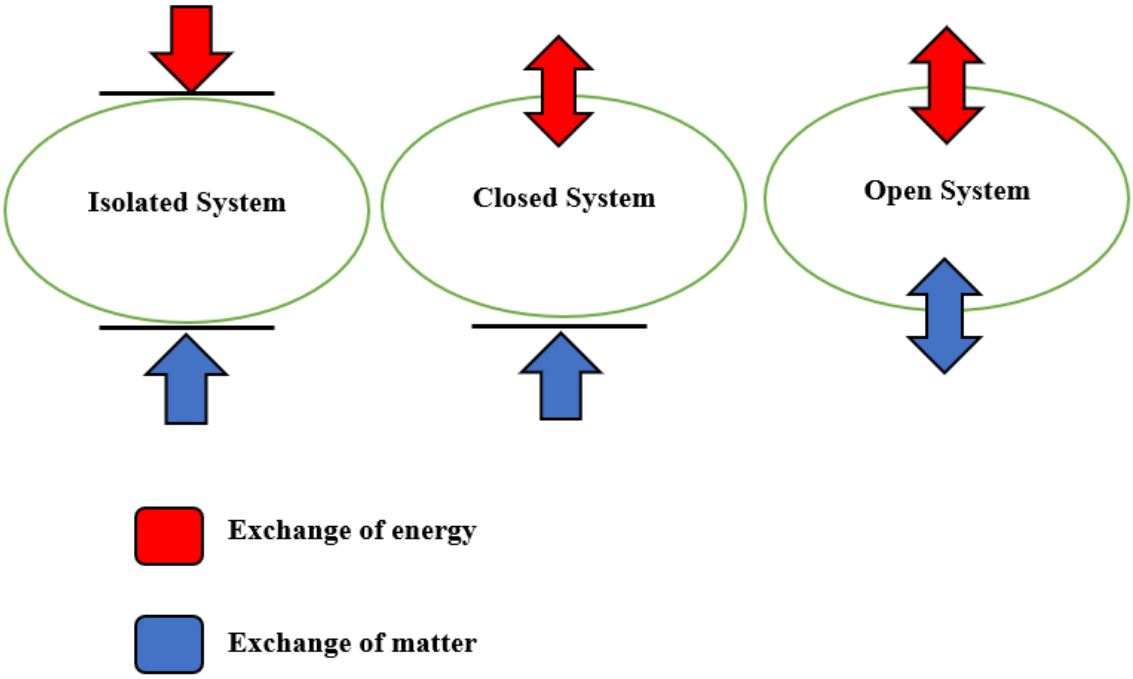


Figure 3: Thermodynamics' systems (Source: Danjou, 2020a)

Thermodynamics assumes that the universe is an isolated system, the planet earth is a closed system because it receives radiation from the sun and that main stream economics acts as an open system because it uses and disposes of the matter and energy as it wants.

2.2.4 Thermodynamics in economics

The economy can be considered as the human's system, it focuses on the production and the consumption of human-beings. Thermodynamics becomes relevant for economics regarding the constraints that it puts in the transformation of energy necessary to produce and consume. Some economists, aware of the mainstream economics' incoherence used thermodynamic laws to prove it. According to Glucina & Mayumi (2010, pp.23) "Boulding applied the first law through the material balance principle to show that waste cannot be ignored. Nicholas Georgescu-Roegen (NGR) went a step further by invoking the second law to emphasise the irreversible nature of production". These authors, Kenneth Boulding, NGR and their successors (Herman Daly for

instance) applied thermodynamics also to the matter and not only to energy that allows them to explain the physical flows of matter and energy in our ecosystems.

The last presented researchers could show that thermodynamics implies five things for economics:
Firstly, from the first law, matter and energy cannot be created; therefore, resources are scared.
Secondly, from the first law, matter and energy cannot be destroyed which creates waste with potential negative effects.
Thirdly, from the second law, the irreversibility of real process implies that the energy can only be used once.
Fourthly, from the first and second law, thermodynamics has a maximum; technology which transforms energy into work cannot surpass the thermodynamics maximum of our system (earth), therefore, technological improvement has limits.
Fifthly, from the first and second law, Economic growth has ultimate limits. Regarding that, economic growth is based on energy consumption and the energy use has ultimate limits; therefore, according to Glucina & Mayumi (2010, pp.19) "perpetual growth in energy consumption is impossible".

2.2.5 Thermodynamics' limits for the CE

Thermodynamics taught us that waste or emissions are unavoidable, therefore CE can create systems as circular as possible it will consume resources and will create waste and/or emission. Thermodynamics also tells technological improvements have limits notably because the more transformations (by using technologies) that occur in producing or using energy and/or matter, the more of the energy and/or matter will be lost as a waste or emission. Therefore, using too many technologies in CE processes will generate cost (money).
More specifically to the entropy says that resources and energy on a certain extend are scarce due to the fact that earth is a closed system which confirms the need for circular economy to make the maximum use of a given resource.
Last but not least, the entropy tells us that any decrease of entropy in a subsystem will have an impact in another subsystem. Therefore, every economic system is interlinked and affects the largest system, our planet. Then, CE should look at not affecting negatively the regions or systems that do not belong to the CE system.

2.3 Spaceship Earth

Kerschner & O'Neill (2015, p.243) states that "in the late 1960s and early 1970s, a number of critical authors pointed at runaway economic growth as the underlying because of the increasing environmental problems that were becoming apparent at the time. Future growth would be limited, they argued, due to the depletion of natural resources and the exhaustion of environmental sinks to absorb pollution (e.g. Boulding, 1966; Daly, 1968; Georgescu-Roegen, 1971; Meadows et al., 1972)." These critics, the steady-state for Herman Daly and the degrowth for NGR, focused on the biophysical limits to the economic growth pursued by mainstream economics and proposed theories to give an answer to the impasse of the economy. The theory that interests us the most is the spaceship earth of Kenneth Boulding because it is the closest to the actual vision of the CE.

Kenneth Boulding published in 1966 an essay titled 'The Economics of the Coming Spaceship Earth' which had in that time important influence and reflection on economics and sustainability questions. Boulding introduced the metaphor of Spaceship for our planet Earth as an analogy of Earth systems in order to facilitate the comprehension and to raise the environmental concerns in the 1970s (Spash, 2013). Kenneth Boulding used the terminology of Spaceship Earth to make used of the popular interest of the space conquest at that time. Just as a reminder, the first footstep on moon occurred in 1969.
Kenneth Boulding used the thermodynamics to explain the biophysical limits of the planet and of the economy. He applied the thermodynamics' systems (isolate, close and open) to the human economy and to emphasis its evolution.

2.3.1 The Boulding spheres

Boulding (1966, p.04) states that "all human societies have likewise been open systems. They receive inputs from the earth, the atmosphere, and the waters, and they give outputs into these reservoirs; they also produce inputs internally in the shape of babies and output in the shape of corpses". Understand the inputs and outputs is essential in system study, according to Boulding (1966, p.05) there are three important classes of inputs and outputs, the matter, the energy and the information.

2.3.1.1 Biosphere

The biosphere is the natural world, the planet earth as the whole with its natural resources as capital stock and energy that flows with it such as the water system for instance. As a whole the biosphere is a closed system.

On a material point of view, matters cannot leave the earth's system and enter either. Researchers exclude the meteorite phenomenon, because it is rare and have a limited impact on the biosphere due to their destruction when entering the earth's atmosphere. Therefore, the material of the biosphere is in a closed system, the natural capita of the biosphere is limited in its ability to regenerate.

On an energetic point of view, energy comes from outside the biosphere, it comes from the sun which provides an almost unlimited but spread amount of energy. Part of this energy is assimilated by the biosphere, notably by plants. The energy can only be used once, therefore, the energy cannot leave the biosphere system, it is used or does not enter the system.

2.3.1.2 Econosphere

The econosphere is the economic world which is the total of capital stocks such as corporations, people, products, services and so on. The econosphere as a whole is an open system, form a material point of view the inputs are mostly outside of the economic systems (noneconomic) matters (natural resources) that pass in the production process of the economy to be transformed into output. After the consumption process, the output is degraded and disposed in the noneconomic reservoirs (outside the economic system), the oceans and the atmosphere that belong to the biosphere for instance (Boulding, 1966).

Form an energetic point of view, Boulding (1966) says that the econosphere used input from all the potential inputs like waterpower, fossil fuels, biofuel, sunlight and so on in order to create the material throughput necessary to the actual economy (consumerism). Only some form of agriculture (biologic), solar machines and waterpower use the permanent available energy flow created by the sun radiation to work. But in our advanced and modern societies we largely depend on non-renewable energy sources such as fossil fuels as an energy provider which exponentially increased the energy use of the humanity. To work, the actual econosphere takes freely as input what Boulding (1966, p.05) called "capital stock of stored-up sunshine", fossil fuels for instance, and as we saw in the thermodynamics section, energy can only be used once, therefore after use the energy is lost. The econosphere from the energy is also an open system where energy comes in freely and out after use by disappearing or transforming into waste (pollution). From an information point of view, the econosphere is also an open system due to the fact that human

society captures the information coming from the universe (by astrologist, physicists and so on) and these same actors emit (signal of our existence) from the earth to the universe.

2.3.1.3 Noosphere

According to Boulding (1966, p.06) the noosphere is the information generated within the planet, most of this information is created by humans themselves. As a whole, the noosphere is an open system where living-beings lose knowledge by aging and death. In the same time, they also gain knowledge by giving birth, providing education and learning from life experience. There is no barrier to the noosphere, the living-beings have to capture the available knowledge that is available in their environment. Boulding (1966, p.06) considers that the knowledge is the most important class of input and output that is available for human-beings due to the fact that matter and energy that enter the econosphere do not make sense without being part of the human knowledge.

2.3.1.4 The spheres and the entropy

The Boulding spheres show that the noosphere (the knowledge) is an open system as the econosphere (economy + society) that use energy and matters without considering the biosphere as a closed system. Kennet Boulding shows that the econosphere reduces the material entropy of the matter by using knowledge and energy, but as says thermodynamics, the entropy of a closed system (earth) can only increase, therefore a cost in the form of waste (pollution) must be paid somewhere to increase the earth's entropy.

Kenneth Boulding believes that a balance can be found between the three spheres in order to maintain the earth's entropy constant. Boulding (1966, p.07) states that "In regard to matter, therefore, a closed system is conceivable, that is, a system in which there is neither increase or decrease in material entropy. In such system all outputs from consumption would constantly be recycled to become inputs for production, as for instance nitrogen in the nitrogen cycle of the nature ecosystem".

2.3.2 Cowboy vs spaceman economy

2.3.2.1 The cowboy economy

During most of the human-beings history, the planet earth was perceived as having unlimited place and possibilities of development for humankind. The mode of consumption and development is also linked to this old believe that resources, places, energy are unlimited, as a result the production and consumption are considered as a good thing in our economy. According to Boulding (199,

p.09) “the success of the economy is measured by the amount of the throughput form the factor of production”. He condemned the linear economy model presented in the introduction. Then, to emphasis the unsustainability and the picturesqueness of the economy he stated (Boulding, 1966, p.09) “the open economy the 'cowboy economy,' the cowboy being symbolic of the illimitable plains and also associated with reckless, exploitative, romantic, and violent behavior, which is characteristic of open societies”.

Therefore, Boulding claimed that the open economy is the past economic model and that the economy of the future must be a closed economy.

2.3.2.2 The spaceman economy

Kenneth Boulding (Boulding, 1966, p.09) states that “the closed economy of the future might similarly be called the 'spaceman' economy, in which the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy." In the spaceman economy (closed economy), throughput needs to be minimised instead of maximised (Britto dos Santos, 2017), the spaceman economy should see the extension, the increase of the complexity and the maintenance of the total natural stock as a measure of success. The technological change involved to maintain constant the total natural stock and limiting the total throughput should be seen as desirable and necessary in the spaceman economy.

2.3.2.3 The Boulding spaceship and the actual situation

The Boulding spaceship earth taught that humankind should change its relationship with nature by adapting its economic model, the econosphere. He also taught that a change of behaviour towards the consumerism and the productivism must happen, he argued that adapted legislation and strong governmental will can create the spaceman economy of the future (Barbier & Burgess, 2017). He also said that regarding entropy it is possible to maintain the material entropy at a constant value by using adapted technologies, methods and renewable energies.

Spaceship earth put the basis of the school of thought that surrounds the actual famous CE. It is possible to say that the CE, which wants to create loops, is a modern version of the spaceman economy. The present shows that the need for a change of economic model is urgent and that the Kennet Boulding’s vision is totally relevant today, however the world has changed during the last 60 years. This is why Barbier & Burgess (2017) claim that the transition to a circular model cannot

just involve governments and policy makers but must also involve more exclusively the businesses in order to make possible the economy of the future.

2.4 Cradle to Cradle

2.4.1 Eco-efficiency and cradle-to-grave

As previously treated, the IR generated important negative social and environmental effects which raised the awareness of the population towards environmental questions. The concept of sustainable development popularised in 1987 by the Brundtland report (Jarvie, 2014) which is one of the main results that environmental awareness created. It is widely accepted despite the large number of possible interpretations that can be made of the term sustainability. The reduction of the different forms of pollution such as the waste production and emissions were understood, which involves the effort and participation of business and government to reduce pollution in the environment.

To answer this new demand of more sustainability an association of businesses was officially created in 1995, the World Business Council of Sustainable Development (WBCSD). Its creators conceptualised the concept of eco-efficiency in 1991 in order to give sustainable solutions and to develop economic activities (McDonough & Braungart 2002, p.058; wbcsd, 2020). The overall goal of the WBCSD and its concept to eco-efficiency is to make use of the new ecological awareness to generate profit while reducing the material and emission of businesses, in other words, doing more with less or decoupling. This concept has been massively followed by industries, the common strategy followed by companies doing eco-efficiency was to reduce the amount of dangerous substances and the emissions of their facilities. For instance, concerning the physical waste by itself, a common strategy of eco-efficiency was to incinerate their available wastes to produce energy which is a form of recycling. Recycling is the privileged solution of eco-efficiency concept to give a second life to waste which indirectly reduces the need for more extraction of natural resources (McDonough et al. 2002, p.054-056).

To summarise, the application of the eco-efficiency takes the form in our economy to the following strategies (Braungart, McDonough & Bollinger, 2006, p.02): dematerialisation, increasing the resource productivity, reducing the toxicity, recycling and extending the product lifespan.

2.4.2 Eco-efficiency vs eco effectiveness

Braungart and McDonough state that eco-efficiency is built on a linear model where this system (Braungart et al. 2006, p.02) "inevitably transforms resources into waste and the Earth into a graveyard". They called this linear way of production and consumption the cradle-to-grave flow. The method of eco-efficiency reduces the value of the material at every recycling steps because the 'wastes' are not considered as a resource.

For instance, reducing the toxicity of the product does not change the fact that toxic substances are extremely harmful for the environment and human health and will continue to be disposed in the biosphere due to the inability of the eco-efficiency concept to manage these residues. Furthermore, recycling methods which increase the lifespan of products follow a downcycling strategy which means that the products after recycling will lose much of their value that could have been used more effectively. Another point is that recycling facilities cannot treat properly the toxic wastes that they receive, due to the fact that the chemicals that those products contain are not designed to be entirely treated, as a result a part will be released in the biosphere (McDonough et al. 2002, p.058-059).

Therefore, eco-efficiency can have positive effects but only on the short-term, on the long-term the degradation of the environment continues, and it creates undesired side effects (rebound effect). As thermodynamics and Boulding's spaceship told us, wastes are unavoidable, the key of the success is in an adapted management of those wastes. So far it seems that the main reason that eco-efficiency strategies are not sustainable on the long-term reside in the fact that products and services are not made to be reused and recycled. Based on this recognition comes the concept of eco-effectiveness.

Braungart et al. (2006, p.06) states that "eco-effectiveness is modelled on the successful interdependence and regenerative productivity of natural systems. In nature, all outputs from one process become inputs for another. The concept of waste does not exist." Therefore, eco-effectiveness sees the waste as a resource that never loses its value, it is a mimicry of nature but applicated to human production and consumption system. Where the approach of the eco-efficiency reduces the amount of negative waste that would finish in the biosphere, according to Braungart et al. (2006, p.06) the "eco-effective approach takes the position that the quantity of the emissions is not the problem, it is the quality of the outputs that must be addressed by making the emissions healthy". Eco-effectiveness is in accordance with thermodynamics for considering the waste as part of a system, similarly to the Boulding spaceship by seeing the waste generated by industry as part of the ecological system.

The Figure 4 shows how Braungart and McDonough see the development of eco-efficiency and the eco-effectiveness over time:

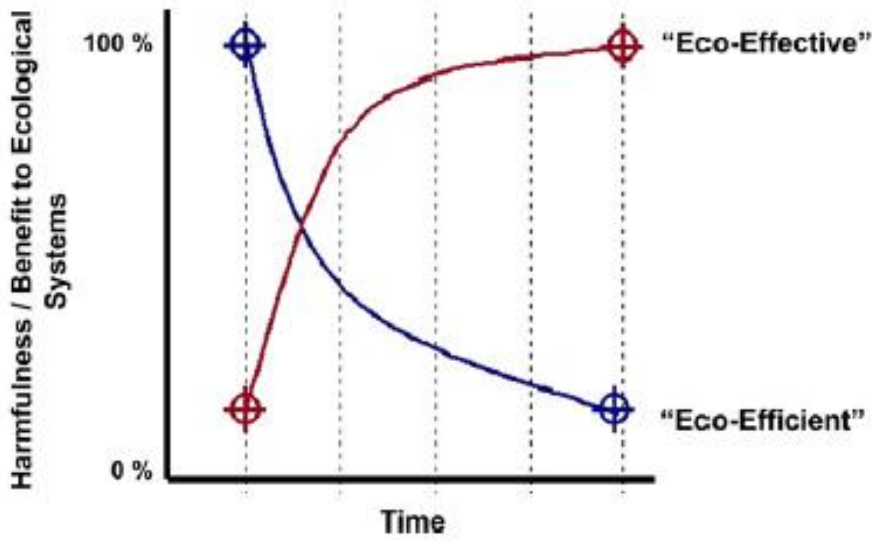


Figure 4: Eco-effectiveness strives to generate an entirely (100%) beneficial impact upon ecological systems (Source: Braungart et al. 2006, p.07)

As we can see in the Figure 4 the eco-efficient concept is able to answer environmental problems on the short-term but its first positive effect will reduce over time until becoming harmful for the environment. While the eco-effective concept takes time to address the overall pollution of the environment (in the short-term) but creates a healthy environment on the long-term.

2.4.3 Eco-effectiveness = C2C

The Cradle-to-cradle (C2C) is a design concept invented and developed by the German chemist Michael Braungart and the American architect Willian McDonough in the 1990s (Brennan, Tennant & Blomsma 2015, p.224). They claim that C2C is an application framework of eco-effectiveness principle. They believe that the eco-efficiency or zero-waste followed by most of the businesses today in order to reduce their emission and pollution is not appropriate for several reasons and notably due to the rebound effects that they generate on the long term. Willian McDonough and Michael Braungart remind us to thermodynamics by claiming that emissions and waste are fundamental to life (Brennan et al. 2015, p.224). Therefore, it remains only the solution to find a good way to deal with the waste that the economy generates. This is why they argue that severe negative social and environmental degradation happen because the materials are not in the good place and not designed for it.

According to Braungart, McDonough & Bollinger (2006, p.07) the overall goal of the C2C is “the creation of wholly beneficial industrial system driven by the synergistic pursuit of positive

economic, environmental and social goals". In order to reach this goal, Braungart et al. (2006, p.07) state that "cradle-to-cradle design defines a framework for designing products and industrial processes that turn materials into nutrients by enabling their perpetual flow within one of two distinct metabolisms: the biological metabolism and the technical metabolism". These two different metabolisms are represented in the Figure 5:

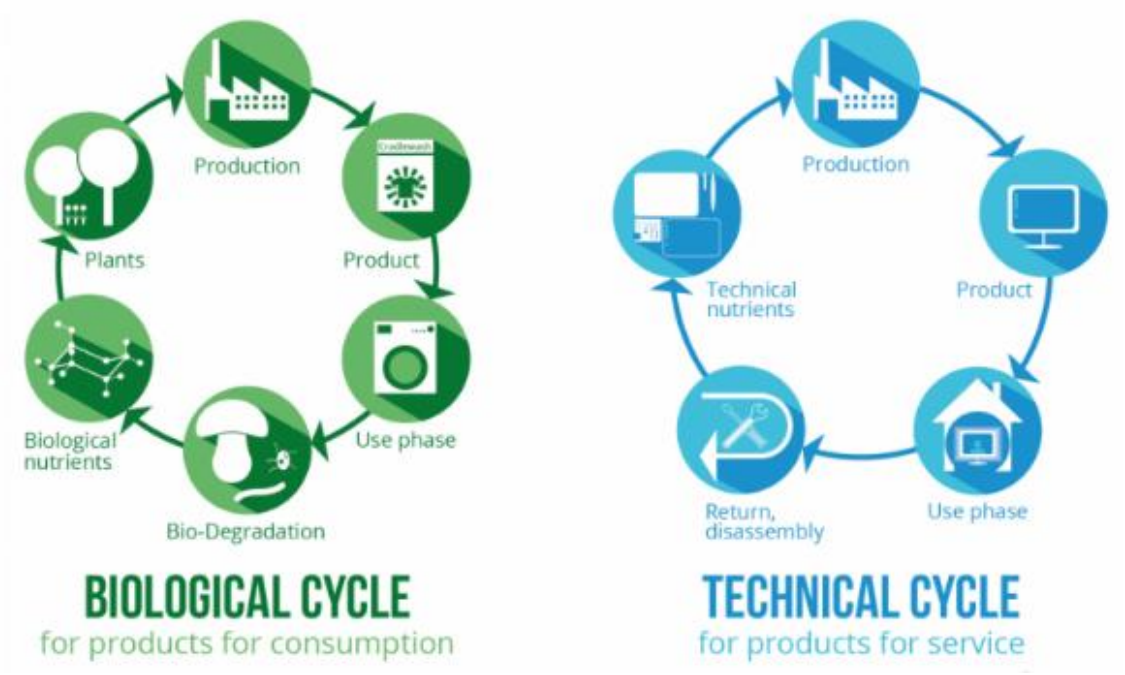


Figure 5: Eco-effectiveness strives to generate an entirely (100%) beneficial impact upon ecological systems (Source: Braungart et al. 2006, p.07)

The two metabolisms represented in the Figure 5 by the biological cycle and the technical cycle, deal with two different kinds of nutriments, the biological nutriments and the technical nutriments. According to Braungart et al. (2006, p.07) the biological nutriments are the biodegradable matters that can safely return in the biosphere and or be safely used by humans. The biological nutriments are not only natural matters such as wood, food, plants, trees, corps and so on but it also includes plant-based materials and synthetic substance such as biopolymers that are safe of nature and human (non-toxic and biodegradable). The figure 5 shows that in the biological cycle, products used for human consumption can be returned in the natural system, for instance with C2C design textile can be used after its useful life for human as garden mulch. Or ice cream wrapper can be designed to liquify at room temperature and containing seeds, therefore when throwing away it contributes to the plant-life growth.

The technical nutriments are the materials that cannot be safely returned to the biological metabolism, mostly mineral based, but can be returned in a closed-loop system of manufacture. The figure 5 showed that in technical cycle, after the use of the product by consumer, the product

is returned to the manufacturer to be disassembled in order to get the technical nutriments available in the product to be able to produce, remanufacture a new product that will enter again the market. In order to do that, the perception of the ownership must be challenged. The product must be used by the customer in order to get the service that he wants but the product with its useful matter belongs to the manufacturer. This method pushes the manufacturer to look at methods to extend the product life with a closed-loop system of production in order to save costs to be competitive. In the same time the consumer benefit from the service without assuming the material liability and it maintains a closer relationship between the consumer and the provider to look after the product (Braungart et al. 2006, p.07). This vision to see the interaction between the consumer and the producer is also shared by the Performance Economy (PE) of Walter Stahel that will be examined in the next part treating of the Ellen MacArthur Foundation (EMF) vision of the CE.

C2C considers waste as food, because the waste of one process becomes the food (nutriment) of another process. Therefore, in theory, applying an optimum C2C design only creates healthy waste (food or nutriments) with high quality and productivity potential that participate to the process of production in closed and interconnected loops. By avoiding the production of negative waste, the C2C concept claims to solve the environmental degradation by acting at the source of the problem (waste creation) and allowing in the same time positive development of the economy, the environment and the social aspects (Brennan et al. 2015, p.225).

2.4.4 How to concretely shift into C2C design

McDonough & Braungart (2002) created for business a strategy in five steps to realise a transition into eco-effectiveness concept (Braungart et al. 2006, p.07).
The first step is called (Braungart et al. 2006, p.08; McDonough & Braungart, 2002, p.166-168) “free of…”. Companies conduct researches and analysis in order to know the toxicity and the characteristics of the substances that are contained in their products. As explained in McDonough et al. (2002, p.166-169) most of companies do not have the knowledge about the toxicity of their products for the simple reason that most of them buy the elements necessary to their production of other companies that themselves buy primary matters without knowing how it is extracted, refined, treated and so on. During all the processes of production of every component constituting a final product, different substances potentially dangerous for nature and human health are used without informing the buyer. All the components constituting a product might not be possible to find, however, businesses can find what are the most harmful substances in their product. Obviously, removing the most dangerous substances recognised extremely dangerous by sanitary institutions

is the best to do regarding the customer. In the same time, McDonough et al. (2002, p.166-169) warn that overcommunicating on removing such substances could be counterproductive in the opinion because it is perceived normal by the customer to do not be exposed to such substances as long as these substances were known as dangerous for human life. Therefore, in this first step, companies should know which substances can substitute the most harmful substances in their products.

The second step is called "personal preferences" (Braungart et al. 2006, p.08; McDonough & Braungart, 2002, p.168-173). This step is aiming on companies to incorporate, communicate and educate their process to the new chosen substances. The fact is that eco-effectiveness is not widespread in the enormous marketplace, therefore it is almost certain that the alternatives substances available for business will not be optimal for the environment and human health. Yet, decisions must be taken by business to be at least better than they were in the past. To take decisions concerning which substitutes to privilege, business should have the knowledge concerning the impact that their available substitutes have. Due to the fact that all substitutes are not ideal and could generate environmental and/or social negative impact, business will have to take a decision based on their "personal preferences" and will have to assume it.

The third step is called "the passive positive list" (Braungart et al. 2006, p.08; McDonough et al. 2002, p.173-177). This step consists of making a detailed list of all the ingredients, substances that are present in the product and ranking them depending of their toxicology and their eco-toxicology. The most harmful products as previously mentioned belong to the commonly called X list. All the substances present in this list must be removed of the production in priority. Then comes the grey list which contains the substances considered by the business as problematic. Most of the time the products of this list, despite their low toxicity are necessary for the manufacture but do not benefit of a viable substitute. To illustrate this case McDonough et al. (2002, p.174) give the example of the cadmium, a very toxic substance but which is necessary for the production of photovoltaic solar panels. Therefore, the only way to empty the grey list is to rethink and redesign the way that product is build, but this is the last step of the McDonough & Braungart (2002)'s strategy. Then the P list or the McDonough & Braungart (2002)'s "positive list "is constituted of substances that are healthy and safe for human health and that can flow within the biological metabolism presented before. The P list constitutes the starting point for further improvement, but at this step these lists are an analysis of the ingredients and help to find more potential substitutes.

The fourth step is called (Braungart et al. 2006, p.08; McDonough & Braungart, 2002, p.177-178) "the active positive list". At this step the eco-effectiveness concept becomes more active within the production process. Based on the ingredients within the positive list (P list), new products are designed in order to become the food of either the biological or the technical metabolisms. This step is a research and development process using ingredients of the P list and may be by adding new ingredients compatible with the P list (biodegradable) to conceptualise new ways of production. To simplify, this step designs biological and technical cycles. As an example, McDonough & Braungart (2002, p.178) used their experience in the car industry, by applying their methods and the P list they could create and implement biodegradable paints for cars. Furthermore, by redesigning the car disassembly process and the design of most of the technical nutriments within the car such as the pieces of steel, plastics and so on, they allowed business to reuse these nutriments in other production processes.

The fifth and last step is called (Braungart et al. 2006, p.09; McDonough & Braungart, 2002, p.178-180) "reinvention". Using their experience in the car industry and combining it with their strategy McDonough & Braungart (2002, p.179) state that "instead of aiming to create cars with minimal of zero negative emissions, imagine cars designed to release positive emissions and generate other nutritious effects on the environment". For instance (McDonough & Braungart, 2002, p.179), instead of releasing emissions on the atmosphere, cars could be designed to separate and store the water vapor for another purpose. Additionally, the carbon dioxide created when burning the gasoline could be stored and condensate in canisters to be sold to manufacturers who need carbon dioxide in their process of production such as rubber manufacturers. The goal of this step is to reinvent the products and services to generate positive effects for the environment and the economy. It is also the most challenging step due to business as usual mentality among businesses.

2.5 The CE of the Ellen MacArthur Foundation

2.5.1 Linear economy vs circular economy

As mentioned in the introduction, the linear model of production and consumption 'take-make-dispose' creates many externalities (social and environmental) and relies on a large amount of energy and natural resource consumption that largely exceeds the biological ability of the planet to recover. The largest part of the throughput generated by the linear economic model cannot be

reused, the resources are fundamentally lost for businesses and it generates pollution in the biosphere. These throughputs considered as wastes are also a financial burden for businesses in the sense that corporations have the duty to treat their wastes which generates additional costs or they can be charged if they do not manage their own wastes (Ellen MacArthur Foundation, 2013, p.014).

Moreover, due to the nature of the linear economy model which extracts large amounts of natural resources and energy, the resource scarcity creates a high volatility of resource prices. For instance (Ellen MacArthur Foundation, 2013, p.018), the large and increasing demand for metal in the last decades generated many extraction sites to cover this demand, the bigger is the demand the smaller becomes the price on the market. But the large extraction of natural matters like ores has exhausted the easy-to-access stock of minerals. As a result, in order to cover the continuous increasing demand on the market, companies must dig even further and find new ways (by technologies) or sites of extraction which largely increases their costs. In addition, the risk of disruption of the production increases with the difficulty to access natural resources which disturb the supply-chain on the global level. For those reasons, natural resource prices are today high and volatile which threats the whole economy.

Economic actors are conscious about all the problems previously exposed and tried different studies and strategies to be able to maintain their economic activities (production and consumption) and conducting environmentally friendly actions. Those strategies are commonly called the green strategies like the Industrial Ecology (IE).
According to Brennan et al. (2015, p.220-221) the IE which looks at biological ecosystem to incorporate its process in industrial activities got its inspiration from the Kenneth Boulding spaceship (1966) and from the Industrial Metabolism (IM) of Robert Ayres and Allen Kneese (1969) that aim to quantify the interactions and exchanges of energy and matters between industries and their environment. These two concepts gave birth to the Industrial Symbioses (IS) with the city of Kalundborg as the biggest ambassador. According to Kalundborg Symbiosis. (2012, p.07) “Industrial Symbiosis is a business relationship focus on sharing resources. This kind of cooperation reduces the total impact of the industry on the environment, and the individual businesses improve their bottom-line figures as well as their competitiveness.” Nine private and public companies within the city of Kalundborg in Denmark made partnerships allowing that the residue from one company becomes the resource of another company (Kalundborg Symbiosis, 2020).

However, Stahel (2019, p.004) states that “Industrial Ecology and Industrial Symbioses, involve cascades of reusing wastes from production processes within the linear industrial economy. These concepts manage production waste, reduce the environmental impairment and increase the economic efficiency of production. But their aim is not to maximise the use of physical assets: closed loops of water or heat would often be more resource efficient than a cascading use of excess heat or water.”

The Circular Industrial Economy (CIE) wants to maintain as high as possible the value and purity of resources. According to Stahel (2019, p.006) “This model contrasts with the linear industrial economy in that its objectives are to maintain value (not to create value added), to optimise stock management (not flows) and to increase the efficiency of using goods (not of producing goods).” The CE by the intermediate of the CIE claims to be able to create absolute decoupling while answering the demand of the market and maintaining the natural resource stocks, managing the manufactured goods to create economic activities and limiting the needs in natural resources, increasing the life of products and services by refining economic models and using news methods and technologies.

But what is the concept of decoupling? According to Eurostat (2020a) “decoupling can be either absolute or relative. Absolute decoupling occurs when the relevant environmental pressure is stable or decreasing while the economic driving force is growing. Decoupling is relative when the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variable.” Therefore, decoupling is the relationship between economic growth and its environmental impact, the Figure 6 of Montevecchi (2016) illustrates the different kinds of decoupling:

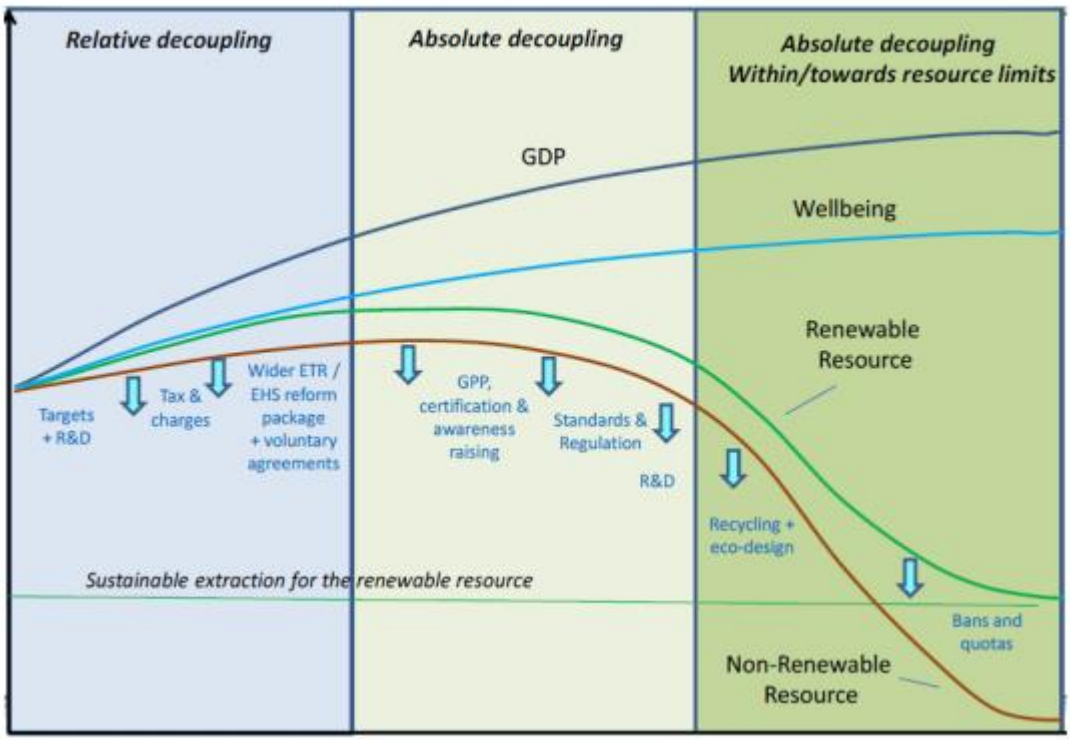


Figure 6: Relative and absolute decoupling of resource use from well being (Source: Montevecchi, 2016, p.03)

As we can see in the Figure 6, the relative decoupling implies an increase of the environmental pressure by the economy which is achieved by the linear model of the economy. While the absolute decoupling reduces the environmental pressure of the economy and generated economic growth. However, regarding the urgency, there are uncertainties concerning the ability of the CE to create an absolute decoupling with the resource limits, as shows on the right side of the graph, within the time remaining to answer the most harmful problem such as the global warming.

The EMF worked in the past decades to gain the theoretical background to represent the CE of today and tomorrow. To implement the CE model in order to achieve an absolute decoupling the EMF supported by many corporations and researchers created concepts and strategies which are illustrated in the Figure 7:

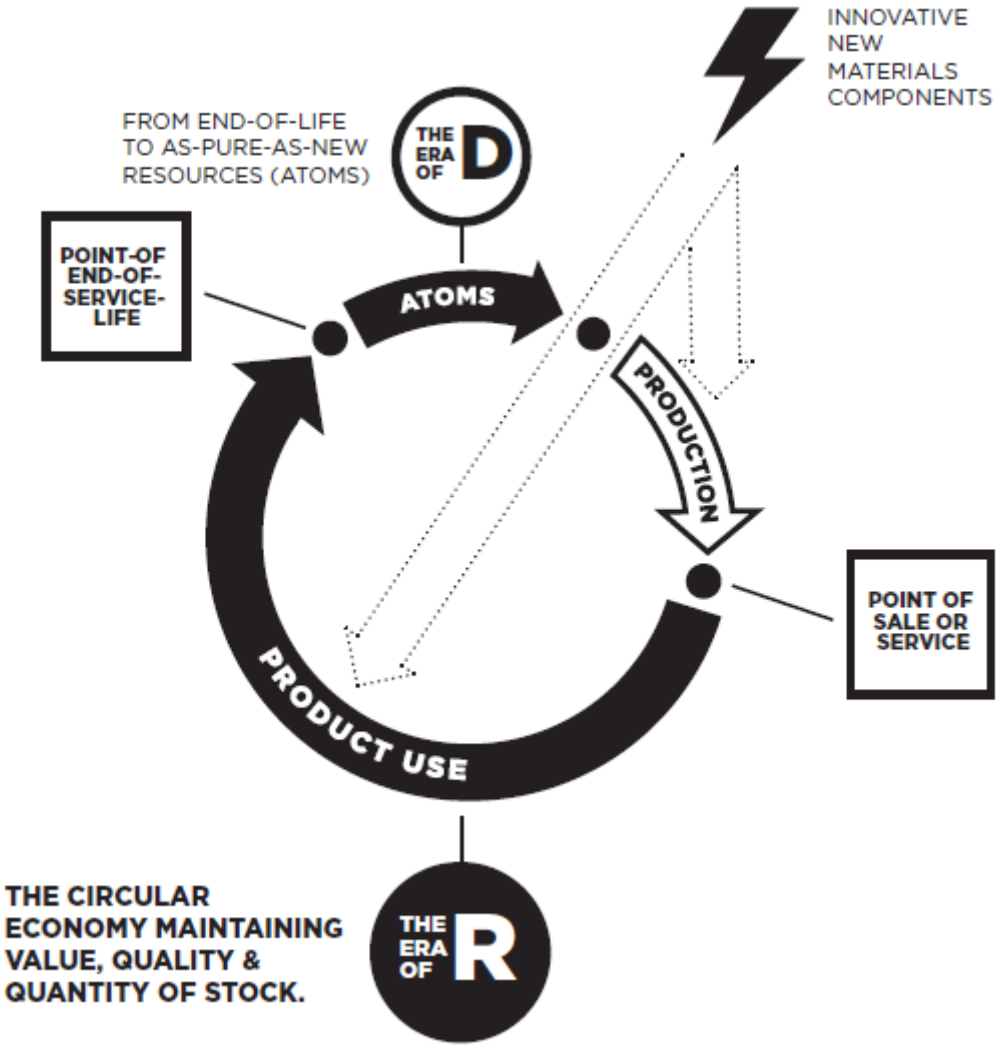


Figure 7: The circular economy maintaining value, quality & quantity of stock (Source: Stahel, 2019, p.027)

As we can see in the Figure 7, the EMF's CE wants to close the production and the consumption loops, starting at the production involving CIE's principles, the distribution in the point of sale or service, the consumption and use of products by the era of R the largest area of CE that targets to extend the life of products and services. Then, passing by the end point of service life that can take different forms before entering in the other strategic area of CE, the era of D aims to recover the

products. Therefore, an understanding of the two strategic principles, the era of R and the era of D is necessary to understand the EMF's CE.

2.5.2 The era of R and D

Among the two eras (R and D) of the EMF's CE, the era of R is the most resource efficient because it intervenes during the product life. The era of R uses technological and commercial strategies to maintain the goods at the highest value possible. These strategies are: reusing, repairing, remarketing, remanufacturing, re-refining and re-programming goods. For instance, it is more profitable for the owner-buyer of a good to sell his product that he does not want any more to another person instead of throwing away, in the same spirit it is much better for the environment to reuse a glass bottle than recycling it (Stahel, 2019, p.026). The era of R insists on prioritising the order previously mentioned, as a result, reusing must be privileged over all the form of reconditioning such as repairing and remarketing, reconditioning must be prioritised over remanufacturing, re-refining and re-programming and recycling must be the last resort (Brennan et al. 2015, p.226).

These strategies privileged the creation and the utilisation by consumers of smaller and local businesses specialised in maintaining the product life. It is a counter to the manufacture of a maximum of goods at a low quality to keep the global production flowing. Privileging the small-medium local businesses focuses on the era of R's philosophy by reducing drastically the need of energy, infrastructure and transport to manage goods. Moreover, the era of R can mainly be done by manpower, which means that it substitutes the need of energy and machinery of the linear economy by human forces. Therefore, the era of R has the potential to create many jobs which would answer the job precarity that many western countries face (Stahel, 2019, p.029-032).

The era of D is responsible of the after-like of goods, when none of the actors in the era of R can find a value at the present stage of the goods. The era of D at the inverse of the linear economy and similarly to C2C, makes the distinction between goods that can be safely returned in the biosphere and the goods that cannot be returned safely to the biosphere such as the manufactured goods. The goal of the era of D is to collect the unwanted goods to treat with different technics dependent of the products in order to keeps the highest value and purity as possible. The actions conducted by the era of D to recover the atoms and molecules of goods are: to de-polymerise, to de-alloy, to de-laminate, to de-vulcanise, to de-coat materials and to de-construct products or infrastructures. These actions preserve from natural extraction such as mining and save large amounts of waste, water and energy. The recovered materials are separated in two different

categories depending of their ability to be return into the biosphere. On one side the renewable materials flow which correspond to the biological nutriments of C2C and on the other side the non-renewable materials which correspond to the technical nutriments of C2C. The Figure 8 from the Ellen MacArthur Foundation (2018) represents these two cycles of C2C within the era of the R and D of the EMF's CE:

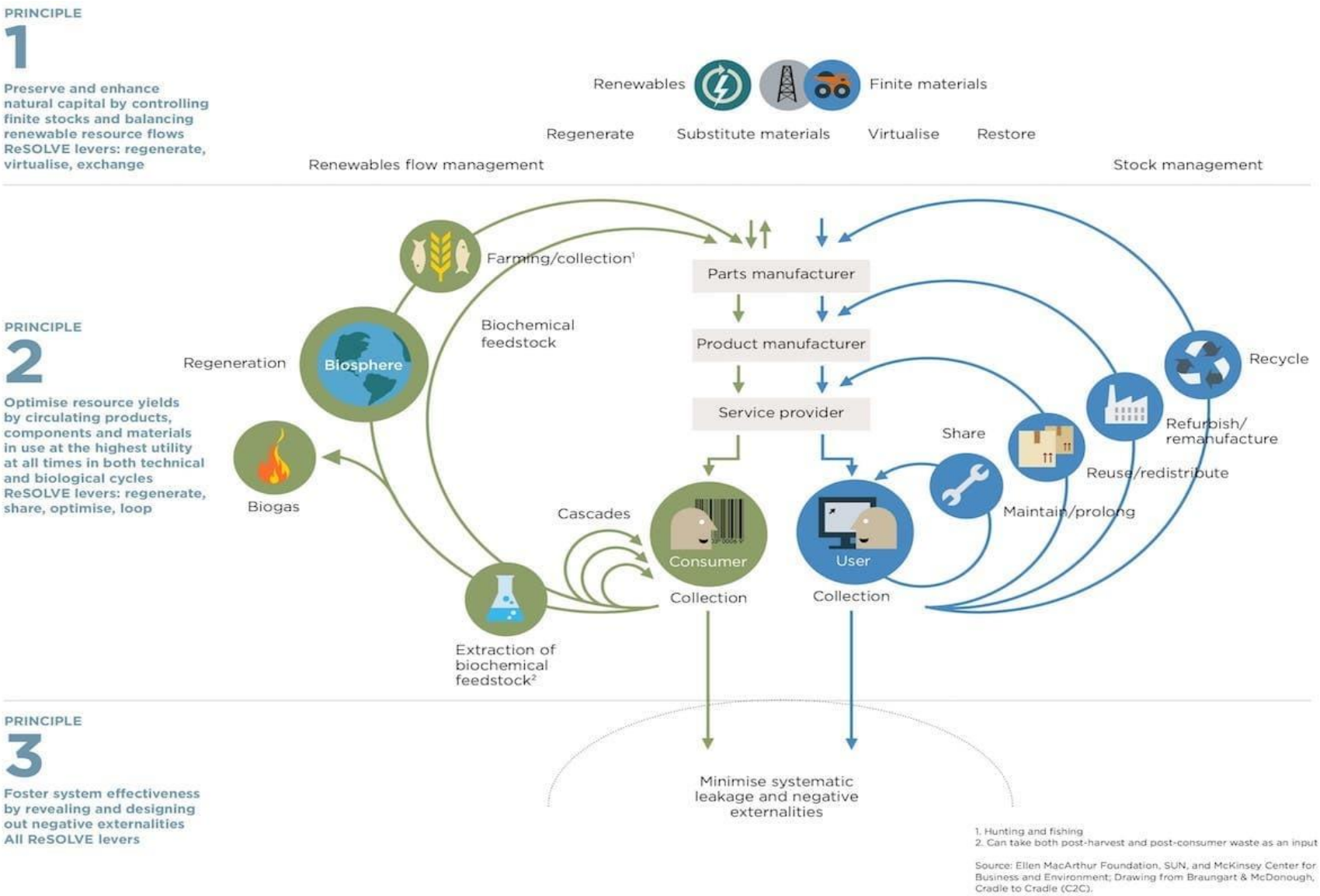


Figure 8: Circular Economy System Diagram (Source: Ellen MacArthur Foundation, 2018)

As we can see on the Figure 8, the right wing corresponds to the technical nutriments that are managed regarding the era of R and D of the EMF's CE. Therefore, the smallest loop of sharing or reusing goods, flowed by the maintaining/repairing/reprogramming and so on loop which is a bigger loop because more demanding in term of resources and energy. Then comes the remanufacturing loop that is even bigger than the previous loop regarding energetic and resource consumption and then the largest loop, the recycling which corresponds to the era of D of the CIE detailed previously. The left wing of the Figure 8 corresponds to the biological nutriments, three kinds of loops can be seen. One concerning the matters that can be used in a very short loop when they are not polluted and directly reusable by consumers. And two others that need much more time to generate results, one of them is constituted of clean biodegradable matter that can be safely returned to the biosphere to help its regeneration and another that passed by the era of D in order to be purified. The safe product can be used for livestock, creating biogas or returning to the biosphere, and the harmful substances extracted from matter during the actions of the era of D can be reused in the manufacturing process.

The CE has the potential to radically reduce the resource and energy consumption as to generate new jobs and new kind of businesses. This is why the EMF has estimated that implementing the CIE in the EU would generate 700 USD million per year of cost saving for the consumer goods industry, 48% of carbon dioxide reduction in 2030, 550 billion USD of cost saving related to health care, an increase of 3000€ of disposal income for households. China has on a certain extend already implemented such policies and has already reached such numbers after implementing CIE (Ellen MacArthur Foundation 2020).

2.5.3 The challenges and the Performance Economy (PE)

The CE is in confrontation with the actual linear economy and must become attractive for businesses and for the consumers in order to be implemented. At the present stage, few producers propose maintenance or take back services despite they have the knowledge concerning the goods that they produce and few researches have been conducted into user's behaviour towards the era of R strategies (reusing, repairing and so on). These strategies involve much more efforts from everyone to look after their goods. Moreover, the high volume of waste is today seen by businesses only at a solution to reduce waste costs, for these reasons most of the businesses do not have incentives to research and invest in better recycling solutions. Additionally, the CIE has to challenge the famous planned obsolescence strategy employed by many manufactures that generate incredible amounts of waste and limit the ability of the era of R to be efficient.

The legislation within the EU can also be a threat for the CIE development. For instance, Stahel (2019, p.044-045) mentioned that the EU's directive on Waste of Electrical and Electronic Equipment (WEEE) involves a contractual obligation between the manufacturer and the business specialised in the treatment of waste. This obligation to give wastes to a specialised company blocks the opportunity for the era of R which is the CIE's most effective strategy to preserve the environment.

The CIE proposed two approaches that can be combined to help the transition to the CE. Stahel (2019, p.050) states that "ownership of objects includes the right to reuse or remarket, the right to repair or upgrade – or to dispose of. The owner of the object controls the object's use and decides how long the object will 'live', and what 'R' services, do-it-yourself skills and such social schemes as repair cafés will be used to extend an object's service-life. A caring attitude and access to operation and maintenance (O&M) services of high quality are important, because with increasing product-life, O&M quality becomes more important than manufacturing quality." To make it happen couple of legislations and behaviours would have to be adapted, this is why policymakers play a key role. An example given by Stahel (2019, p.059) shows that most of fiscal policies target the labour and not the capital which is most of the time based on non-renewable resources and energy. Then, in order to be in phase with the CE and sustainability, taxes should focus on all the form of non-renewable resources and energy and should in the same time be drastically reduced for all the forms of renewable resources and energy such as human labour, biological matter and renewable power. Policymakers need to create strong legislation for manufacturers to extend their product life. Several policy options must be taken in this direction and should be supported by the high potential for growth and saving costs. In the same time policymakers should also not forget to help future businesses of the era of R and D to rise, also by increasing the awareness of the population towards CE and facilitate the task for citizens to get involved in the era of R.

However, if the prevention is not possible, another approach is proposed by the EMF's CE, the Performance Economy (PE). The PE was created by the architect and industrial analyst Walther R. Stahel. The concept known today as the PE was developed under the name of "Functional Service Economy" by Stahel (2010). He claims that instead of business selling goods they sell a performance. By performance Stahel (2010, p.086) refers to the utilisation of a product or the results of goods and services. Therefore, the buyers of a good get the benefits from the utilisation of a good but are not the owner of the material that constitutes the product. By doing so, the manufacturers have strong incentives to increase its product-life in order to do not be charged of the returns from the clients and by the waste costs if staying in a linear economy model. To avoid

waste costs, it is in the interest of the manufacturer to develop methods to reuse its own materials and to produce goods that it can sell again by avoiding buying new matters. The PE counts on the development of adapted technologies allowing business to reuse, repair and remanufacture their products, the C2C is the privileged strategy within the PE to increase the product value and its durability (Stahel 2010, p.086). However, similarly to the previous approach, the implementation of the PE concept needs the involvement of policymakers to help businesses to switch to this model. It is one of the main reasons that the EMF's CE tried during the past years to gain the maximum of influence (by politics and business) particularly in the EU in order to make the CE becoming a reality.

It is possible to argue that the EMF's CE is a mix between the PE and the C2C.

3 Methodology

3.1 Hypotheses development

Malhotra (2010, p.053) says that “a hypothesis (H) is an unproven statement or proposition about a factor or phenomenon that is of interest to the researcher”. The hypothesis considers the analytical model and the theoretical framework with the different variables that link the theory to the research question. Using the outcomes of the theoretical framework, the hypothesis makes relationships between the variables to eventually answer the research problem and the research question. Hypotheses are supposed to be tested in order to prove their verity or not, therefore a hypothesis is a presumption.

The Figure 9 shows the interaction and interdependence between the research problem, the research question, the analytical model and the hypotheses.

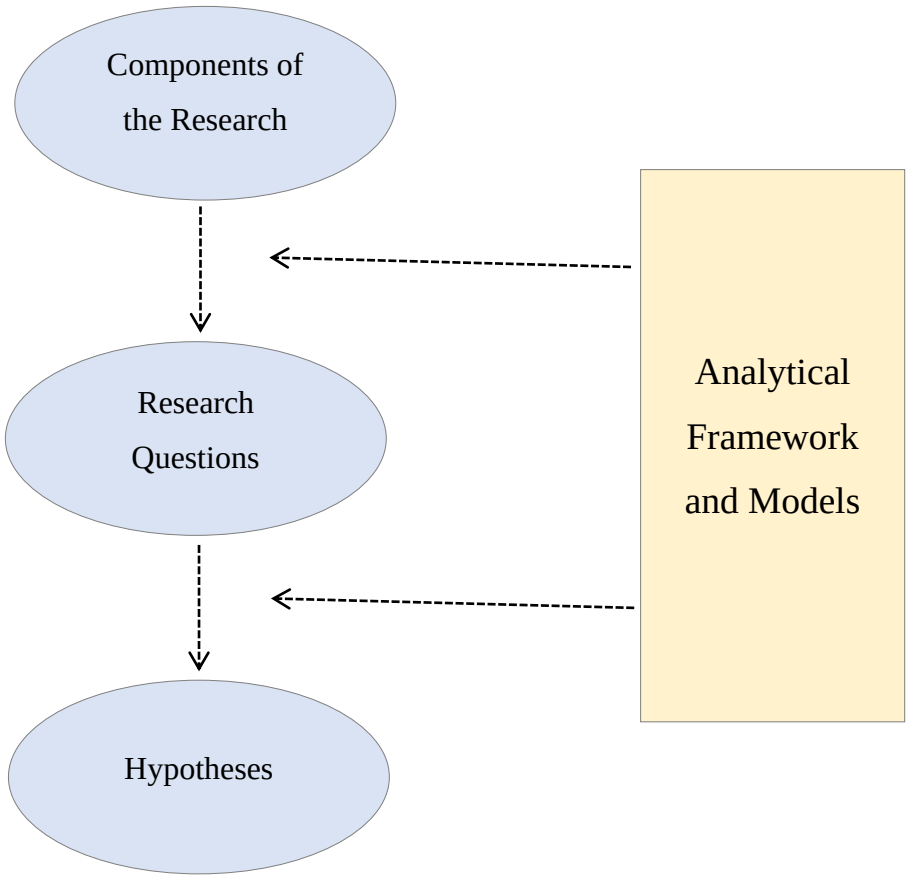


Figure 9: Development of research question and hypothesis (Source: Danjou, 2020b, derived from Malhotra, 2012, p.051)

To create hypotheses, this thesis needs to collect all the variables identified in the theoretical framework. Then, as the Figure 9 suggest, an analytical model will be built to implement the variables in the research context and a conceptual framework will be drawn to illustrate the hypotheses (Malhotra, 2010, p.053; Malhotra, 2012, p.050).

3.1.1 Industry overview

To find all the potential variables necessary for this thesis, an overview of the MEI is necessary so that the variables fit to the specific position of this industry. As presented in the introduction, this thesis wants to understand and explain how this specific industry would switch to a CE model in the EU. The MEI sector is classified by the European Commission (EC) under the appellation "NACE, Number 28". NACE is an acronym coming from the French 'Nomenclature générale des Activités économiques dans les Communautés Européennes' which means General Industrial Classification of Economic Activities within the European Communities. The machinery and equipment manufacturing sector or the Machinery and Equipment Industry (MEI) was previously coded under the number NACE 29, this is why some of the oldest sources mentioned by this thesis uses the number 29 instead of 28 (EU-MERCI, 2020, p.32). The goal of the NACE is to represent the EU's economic activities. Consequently the NACE is divided in different sections which represent different types of industries which are also divided into more specific activities within each industry (Eurostat, 2018). As a result, the machinery and equipment manufacturing sector or MEI correspond to the NACE Subsection DK (Division 28) which is itself divided into subgroups. This section looks at the general facts of the MEI in order to visualise the environment of the MEI and thus the research context. (Eurostat, 2007; EU-MERCI, 2020).

According to Albertone et al. (2009, p.238) the MEI (NACE 28) provides equipment for mining, manufacturing, producing energy, producing domestic goods, farming and for the construction sector. From an economic point of view, the machinery and equipment manufacturing sector supplies the economy in capital goods dedicated to a variety of different actors of the economy. According to Eurostat (2007), the machinery and equipment manufacturing sector "tends to follow investment cycles, predominantly within the EU but also in the global economy" which means that the development of its clients has a direct impact on the activity of the industry. The main reasons for businesses to get new machinery and equipment is to improve their productivity and/or the quality of their production, another reason is the need of some businesses to diversify their offer. However, it does not change the fact that the MEI plays a key role in our economy for the following reasons (Albertone et al., 2009 & Eurostat, 2007).

Firstly, the MEI has a strategic importance for nations. Many countries can produce desired products by helping manufacturers of goods to produce in their country. Nevertheless, countries possessing the knowledge to produce the machines and equipment which produce goods benefit of a special attention by nations. Such awareness is explained by the fact that nations having the control of machines that can produce goods, can control the production of other countries. Rynn (2011) refers to the countries that benefit of this strategic advantage under the name of 'Great Power' and could prove in his study that 80% of the world production has been controlled by the countries that benefit of this 'Great Power' (Rynn, 2011).

Secondly, as mentioned, the MEI is the base for manufacturing goods. In the actual economic context, the exchange of goods constitutes the base and the majority of the global trades, according to Eurostat (2019a) "in 2017, goods accounted for just over three quarters (76.6 %) of the world's total trade". Consequently, the production and trade of goods is the principal reason for economic growth with the MEI at its base.

Thirdly, the activity of delivering a service is mostly the act of using goods. For instance, the rental services or the real estate business could not exist without the product that other industries propose. And these industries can produce only because of the MEI businesses. It increases even more the importance of goods in our economy and the MEI is the base of this process (Rynn, 2011).

However, despite the importance of the MEI in the economy, this industry can be impacted on different ways. According to Romanow (2013) the MEI is an important purchaser of the metal industry and more specifically the steel industry that provides the basic components and the metallic forms that the MEI needs. In the case of the metal industry, it is a purchaser of the mining industry which provides in mineral, ores and others raw resources for the creation of different metal such as steel. Therefore, the metal industry is directly impacted by the mining industry which is itself one of the main purchasers of the MEI. The main point of convergence of these interlinked industries is the steel, regarding World Steel Prices (2020) the price of steel is relatively low which greatly facilitated these industries to invest and develop over time. Despite the strategic position of the steel industry in this ecosystem, the global demand for steel has been reduced compared to the 19th century due to the apparition of other metals such as the aluminium and the plastic that took an important part in the household consumption. Schifman (2018) claims that in order to be competitive the method of steel production has evolved over time to mix and smelt different minerals and metals to create steel with different proprieties and reduce even more its production

costs. Due to this increase of complexity of its process of production, the steel price is low but also volatile, thus depending of the period it can impact the MEI (World Steel Prices, 2020).

3.1.2 The variables in the analytical model

Analytical models can take different forms depending of the researcher's preferences but all of them, according to Blaikie (2010, p.148), "can represent a hypothetical explanatory structure or mechanism, perhaps derived by the use of analogies, or they can be a method of organizing and communicating research results". For this thesis the analytical model will be used primarily as a hypothetical explanatory structure that includes different variables. If the hypotheses are proved, it can become a way of communicating the results. Malhotra (2010, p.051-052) explains that analytical models are commonly used in 3 different forms, verbal, graphical and mathematical.

The verbal model is a (Malhotra, 2012, p.050) "summary or restatement of the main points of the theory". The graphical models are used to give a visual representation of the theory; Malhotra (2012, p.050) states that "they are used to isolate variables and to suggest directions of relationships". This kind of model will be used as a conceptual framework in the next section to illustrate the development of the thesis theory. The mathematical model, according to Malhotra (2012, p.050) "the strength and direction of relationships among variables, usually in equation form" will be used in this thesis in order to show the importance and the interconnections of the variables and potentially be a basis for the thesis results.

Based on the theoretical framework and the industry overview, some variables can be found to determine how and why the MEI would switch for a CE model.
First of all, we saw that the more of transformation of products occurs, the more of matters and energy will be lost in each step of production according to thermodynamics. At the same time the MEI has to modify its process and adapt its technology to be able to repair/remanufacture the broken components for future reuse and/or to extract the harmful substances during and after the production process for future reuse and so on. In this case the main question is to know if the investment (matter, energetic and knowledge) in such circular process will be able to save enough of good quality matters to be profitable. In other words, the Energy Return On Investment (EROI) must be high enough. Murphy & Hall (2011, pp.64) state that EROI "is defined as the gross energy produced divided by the energy invested to produce the gross energy". In the economy, to produce energy, humans must invest energy and matter to get more energy. But Hall (2017, pp.18), emphasises, that "the more transformations that occur in producing or using a given energy source,

the more of the energy will be lost as waste heat". Therefore, to increase the EROI the MEI must implement circular technics with the smallest amount of operations and transformations of the product as possible to be interesting.

Secondly, also the financial reality has to be considered. The implementation of circular methods as the C2C and or the era of R and D of the EMF's CE must allow substantive cost savings in order to be a desirable alternative for the businesses competing in the MEI. Depending on their economic environment some MEI businesses would rather prefer to invest in the era of R or D depending of the ability to save costs. This dilemma is a reference to the Return On Investment (ROI) that must be high enough, Stahel (2010, p. 082) makes an interesting comment by stating that "remanufacturers know that the Return on Investment (ROI) in remanufacturing combustion engines is five times the ROI in manufacturing similar objects, but academia is hardly interested". The principal question here is to know if such a high ROI is possible for the MEI.

Thirdly, beside the already mentioned physical, technical and financial limits, the legal aspects play an important role. Mentioned in the EMF's CE section of the theoretical framework some of the EU regulations are limiting the potential for business to implement some CE models. The waste regulation limits the MEI in the EU to treat itself their own waste which should not be considered as waste anymore regarding C2C and the CE but rather as nutriment or food. The creation of an organisation recognised by the EU to support the CE implementation would be a great signal for all businesses to switch to a CE model, which is the fight of the EMF. All of these legal changes within the EU involve strong moves from policy-makers of all EU members in order to be achieved and certainly dedicated funding of the EU for the CE.

Last but not least, this paragraph focuses rather on the cultural aspect that CE involves. The cultural aspect can take two forms, particularly regarding the repaired, remanufactured or recycled products that the MEI could use. On one side exists the very persistent mentality of business as usual that limits the intention of companies at changing something that already brings benefit. On the other side, there is the reaction of the client or customer regarding repaired, remanufactured or recycled products. Most of them consider this kind of product as weaker than the virgin and new ones, which can be particularly harmful for the MEI businesses that are supposed to deliver robust products. This vision of second hand products mainly comes from the linear economy that prones the rapid use of products often privileging the quantity over the quality. The CE must overcome this vision of second hand products and production but habits and believes are difficult to overcome.

Regarding the last arguments it is possible to create a mathematical model that considers all the variables previously mentioned.

Machinery and Equipment Industry switch to CE = Y

Higher ROI and EROI = a_i

Cost saving by era of R technics = b_i

Cost saving by era of D technics = c_i

Implementation of C2C design in the production process= d_i

Better EU's regulation and funding in favour of the CE = e_i

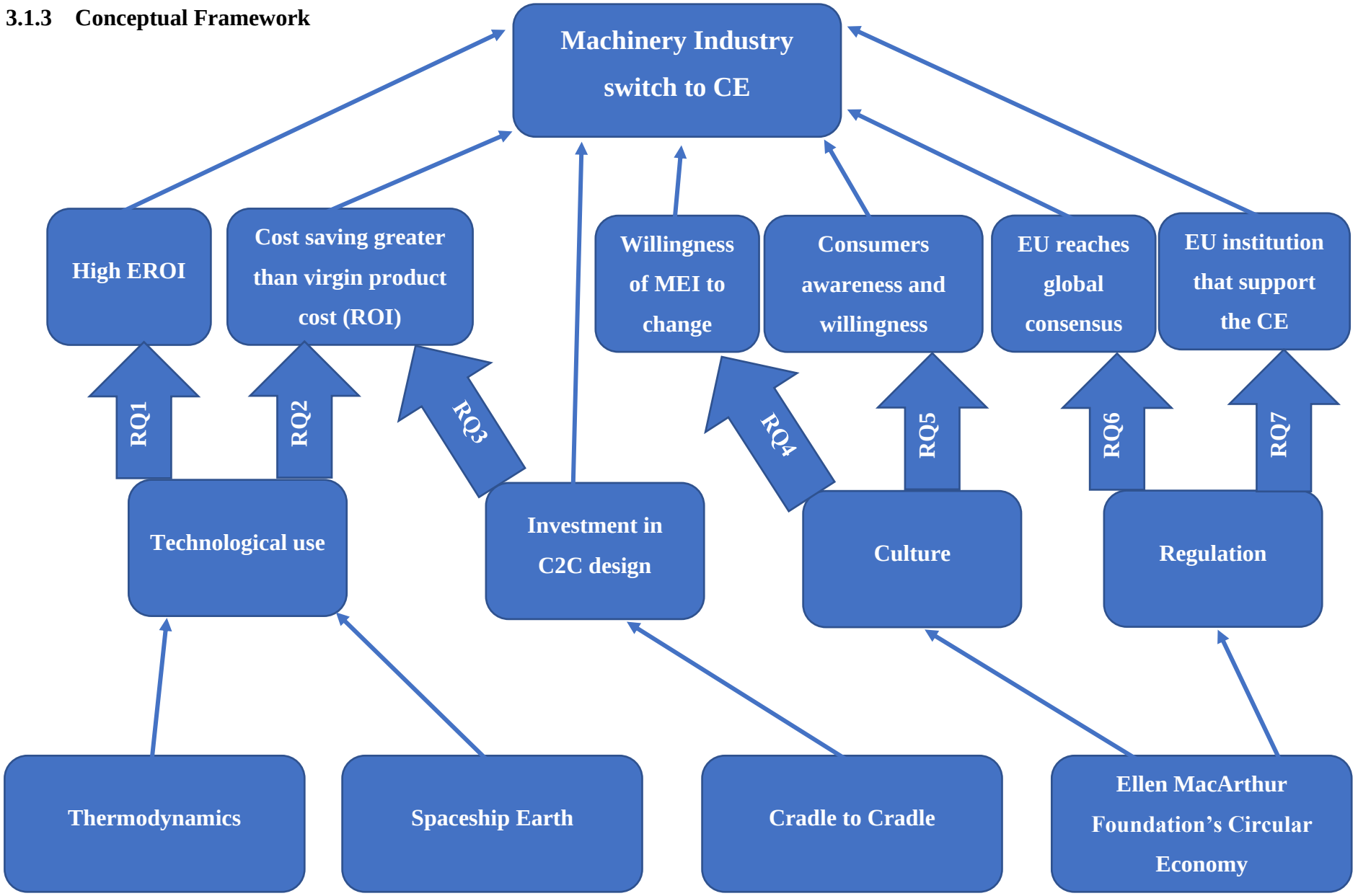
Creation of institutions of CE in the EU = f_i

Culture change of the businesses = g_i

Cultural change of the customers = h_i

$$Y = a_0 + \sum_{i=0}^{n} a_i + b_i + c_i + d_i + e_i + f_i + g_i + h_i$$

3.1.3 Conceptual Framework



According to Blaikie (2010, p.150-151) a conceptual framework shows how the concepts (theoretical framework) is linked to the real world with its influence. The thesis' conceptual framework shows how the theories (concepts) influence 4 domains that are directly linked to the MEI, the technological use, the investment in C2C design, the culture and the regulation. Each of these domains generates MEI's variable to switch to a CE model as shown previously in the mathematical model. Therefore, regarding the theoretical framework, all the variables have to be fulfilled in order that the MEI switch to a CE model. To make it possible the four domains must fulfil the need of all the variables: this is where the different hypotheses of this thesis have to be explained.

3.1.4 The hypotheses

RQ1: Does the use of circular technologies and methods in the MEI generate a sufficient EROI?
H1: The EROI of circular methods is as high as or higher than the classic processes
H2: Implementation of circular methods has a low EROI or decreases the EROI of MEI businesses.

RQ2: Does the investment in circular methods such as the era of R and D generate enough profit and cost saving to be profitable for MEI?
H3: Implementation of the era of R and D strategies are profitable for MEI.
H4: Implementation of the era of R and D strategies are not or not enough profitable for the MEI.

RQ3: Does the implementation of C2C design in the MEI processes have an ROI high enough for the MEI?
H5: The ROI of the C2C design implementation is beneficial for the MEI businesses.
H6: The ROI of the C2C design implementation is negative or not high enough for the MEI businesses.

RQ4: Are the MEI's decision-makers afraid to change their production model due to cultural habits?
H7: As long as the new model is profitable businesses are willing to change.
H8: MEI businesses are not used to these new processes and prefer to continue the business as usual.

RQ5: Are the MEI's consumers willing to purchase a remanufactured or repaired product with guarantee of quality as if it was a regular product?
H9: As long as the price is low enough and the performance is guaranteed the customers are willing to pay.
H10: Customers emit doubts about the certifications and do not believe that the product can have a similar quality as a virgin product, therefore they do not purchase.

RQ6: Are the not adapted EU regulations and the lack of financial support to the CE transition key factors for the European MEI businesses to not switch towards CE?
H11: Financial or better regulations constitute a key factor for MEI businesses to switch to a CE model.
H12: Adapted regulations or financial support are not determinant for the MEI in the EU to switch to a CE model.

RQ7: Would an institution supported by the EU to increase the knowledge and the comprehension of CE be a determinant factor for the implementation of CE within the MEI?
H13: An institution bringing knowledge and advise to MEI businesses is essential for the MEI to switch to a CE model.
H14: An external institution is not necessary for the MEI businesses to switch to a CE model.

Each of these research questions will be tested using different data analysis technics. Along the data analysis process each hypothesis will be verified or falsified depending of the findings.

3.2 Methodology

The methodology of the thesis is organised according to the research onion of Mark Saunders as shows the Figure 10:

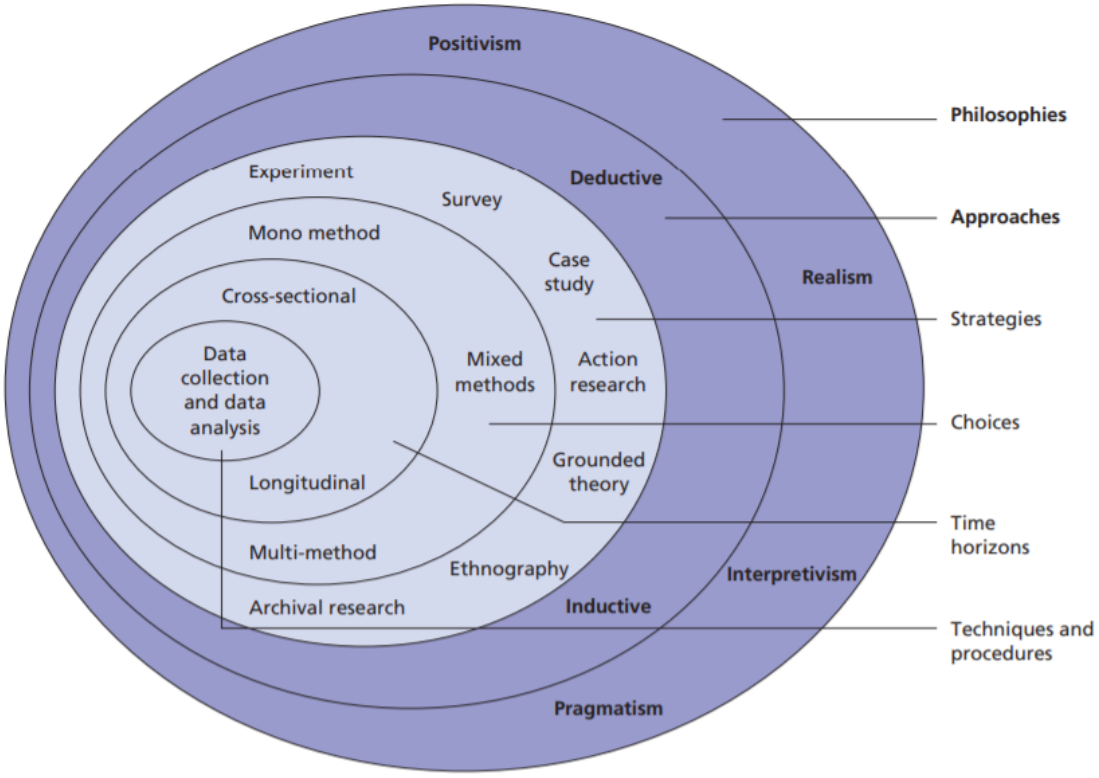


Figure 10: The research onion (Source: Saunders et al., p.108)

Noko (2019) states that "The Saunders Research onion illustrates the stages involved in the development of a research work" which means that all onion layers are steps that the researchers have to follow to conduct their research. The Saunders' research onion (Figure 10) was initially designed to help business students to conduct their research. The biggest strength of the Saunders' research onion it is its adaptability for all the research methodology (Noko, 2019).

It is important to note that the Saunders' research onion (Figure 10) asks the researcher to start by the outer layer and go inside layer by layer. Therefore, the first step of this thesis methodology will be to identify the research philosophy of the thesis. Then, a research approach will be determined before choosing which research strategies the thesis focusses on to choose a research design. Then, in accordance to the Saunders' research onion, a data collection method and its analysis will be determined for the thesis. This section will be concluded by a section dedicated to the ethical considerations that the research had to consider and the limitations of the research.

3.3 Research philosophy

According to Noko (2019) the "research philosophy refers to the set of beliefs concerning the nature of the reality being investigated. It is the underlying definition of the nature of knowledge".

3.3.1 The Creswell's philosophical worldviews

However, concerning the philosophy in research Creswell (2009, p.06) talks of four worldviews. Creswell (2009, p.06) sees "worldviews as a general orientation about the world and the nature of research that a researcher holds. These worldviews are shaped by the discipline area of the student, the belief of advisers and faculty in a student's area and past research experiences". The four worldviews of Creswell are the postpositivism, the social constructivism, the advocacy and participatory and the pragmatism such in the Table 1:

Postpositivism	**Constructivism**
• Determination • Reductionism • Empirical observation and measurement • Theory validation	• Understanding • Multiple participant meanings • Social and historical construction • Theory generation
Transformative	**Pragmatism**
• Political • Power and justice oriented • Collaborative • Change-oriented	• Consequences of actions • Problem-centered • Pluralistic • Real-world practice oriented

Table 1: Four Worldviews (Source: Creswell, 2009, p.06)

The Table 1 shows that each worldview is composed of four different characteristics or beliefs. Broadly, the postpositivist worldview is considered as a scientific method, it needs to identify and assess the causes of a reaction similarly to experiences. The postpositivism considers that researchers should build a theory, then collect data that would support or refute their theory and makes corrections afterwards. The postpositivism is more adapted to conduct quantitative research. This thesis wants to test and give a practical answer to the research problem. However, the limitation on only quantitative data does not allow the thesis to properly answer the research problem regarding the lack of available data in this format. Most of the available data concerning the MEI are available in words and by human interactions which are qualitative information. Therefore, the thesis will not follow this philosophy.

The social constructivist worldview takes a different stand, Creswell (2009, p.08) states that it holds “assumptions that individuals seek understanding of the world in which they live and work. Individuals develop subjective meanings of their experiences-meanings directed towards certain objects or things”. Therefore, this philosophy relies mostly on the perception that the participants have of a situation which can lack of pragmatism because it does not represent and support the participant opinions with impartial numbers and statistics. This complex and broad approach of research involves broad questions and needs to look at the social and historical context that the participant of the study is exposed to. Naturally, the social constructivism is typical for a qualitative research. This thesis will not follow this philosophy due to the fact that such research is subject of too many interpretations from the researcher, that it limits the research to qualitative data and that finding large numbers of interviewees is impossible for the topic.

According to Creswell (2009, p.09) the advocacy and participatory worldview appears because postpositivism imposed a too narrow sets of theories and laws that did not fit with some issues of individuals, the marginalised. Creswell (2009, p.09) states that the research inquiry of this philosophy “needs to be intertwined with politics and political agenda. Thus, the research contains an action agenda for reform that may change the lives of the participants, the institutions in which individuals work or live, and the researcher’s life”. Regarding that this thesis does not want to target a marginalised population, and despite the political interest of the EU for CE this thesis cannot follow properly this political agenda. Therefore, this thesis will not follow the advocacy and participatory worldview.

According to Creswell (2009, p.10) the pragmatic worldview “arises out of actions, situations and consequences rather than antecedent conditions (as in postpositivism)”. This worldview focusses on the comprehension of the research problem and claims to use all the possible methods to understand the problem instead of being focussed on the methods like the other worldviews. This research philosophy grants freedom to the researcher to apply the approach that he judges adapted to answer the research problem. For these reasons the pragmatic worldview is particularly adapted for mix-methods studies. Regarding the freedom of the pragmatic worldview to give an answer to a problem, this thesis will follow this philosophy.

3.4 Research approach

According to Saunders et al. (2009, p.124-127) there are two kinds of approaches, the inductive and the deductive. Each of them has a different vision of the relationship between theory and research.

Blaikie (2010, p.154-155) claims that in inductive approaches the "theory consists of generalization derived by induction from data". A research applying an inductive approach starts to collect data and then studies the data to look at patterns with the data. Blaikie (2010, p.154) states that "patterns become generalisations, and network of organizations is considered to be a theory".

On the other side, the deductive approach is considered by Saunders et al. (2009, p.124) as the "dominant research approach in the natural sciences". This approach asks the researcher to study theories and concepts from many sources that are related to his research to afterwards move to the data collection process. In order to do that a deduction process has to be conducted to established hypotheses that will be tested later by the data analysis (Blaikie 2010, p.155; Saunders et al. 2009, p.125).

The Table 2 from Saunders et al. (2009, p.127) resumes the main differences between the two approaches:

Deduction emphasises	Induction emphasises
• scientific principles • moving from theory to data • the need to explain causal relationships between variables • the collection of quantitative data • the application of controls to ensure validity of data • the operationalisation of concepts to ensure clarity of definition • a highly structured approach • researcher independence of what is being researched • the necessity to select samples of sufficient size in order to generalise conclusions	• gaining an understanding of the meanings humans attach to events • a close understanding of the research context • the collection of qualitative data • a more flexible structure to permit changes of research emphasis as the research progresses • a realisation that the researcher is part of the research process • less concern with the need to generalise

Table 2: Major differences between deductive and inductive approaches to research (Source: Saunders et al., 2009, p.127.)

The thesis clearly wants to move from the theory to the data in a structured approach in order to answer the research question which is in phase with the deductive approach. On the other side the

researcher already has knowledge of the topic and wants to increase his understanding, for this reason qualitative data collection seems more adapted for digging in the subject and I consider myself as a part of the research process that could be modified depending of the findings, which corresponds mostly to the inductive approach. Therefore, this thesis will use a mix between the two approaches.

3.5 Research strategies

The research strategies can take many forms but they are determined in a first step by the purpose of the research and in a second by the research context. According to Robson & McCartan (2011, p.039) the research purpose can take three forms. It can be an exploratory, a descriptive and an explanatory study.

The exploratory studies want to find out what is happening, Saunders et al. (2009, p.139) claim "It is particularly useful if you wish to clarify your understanding of a problem, such as if you are unsure of the precise nature of the problem".

The descriptive studies want to describe the most accurately as possible a situation or an event. Saunders et al. (2009, p.140) add that a descriptive purpose can be an extension or a part of an exploratory study.

The explanatory studies want to give detailed explanations of a situation or a problem in order to explain the relationships between the variables that the researcher determined (Saunders et al. 2009, p.140). Robson & McCartan (2011, p.039) state that "it is sometimes claimed that exploring or describing are inferior to explaining; that research worthy of the name should seek to provide explanations". However, as the world is continuously increasing its complexity it becomes even more important than before to ask why, in order to be able to give accurate description and explanations.

The research purpose of this thesis is mostly explanatory by essence and will also increase the understanding along the way to the answer to the research question.

Each of the research purpose just presented (explorative, descriptive and or explanatory) are also linked to some approaches (deductive vs inductive), it is the combination of the research philosophy, purpose, and approach that will influence the strategies of the thesis. Therefore, this thesis will look at the different strategies that are adapted to an explanatory study by being pragmatic and using a mix between the deductive and the inductive approach. Regarding these criteria, the survey, the case study and the archival research which is often considered as secondary

data analysis are the possible research strategies that fit with the philosophy, the approach and the purpose of this thesis Saunders et al. (2009, p.141-150).

The survey allows the collection of large amounts of quantitative data by using questionnaires. The interpretation should conduct the researcher to answer the questions "who, what where, how much and how many". However, the research question does not want to answer such questions, but Saunders et al. (2009, p.145) emphasises that interview methods of data collection fall under the survey strategy which allows to answer the question of how and why.

According to Priola, C. (2016, p.21) the case study strategy is "an in-depth investigation of a single case (e.g. one organisation) or a small number of cases. In case study research generally, information is sought from different sources and through the use of different types of data such as observations, survey, interviews and analysis of documents". The case study strategy is particularly adapted to get strong understanding of the research context with all the involved processes. Saunders et al. (2009, p.146) also claim that the case study strategy is excellent to answer the research questions "how, what and why" which is exactly corresponding to the research question of the thesis.

According to Saunders et al. (2009, p.150) the archival research strategy "makes use of administrative records and documents as the principal source of data". These kinds of data are well known as secondary data but using it in the context of an archival research strategy stipule that these data are collected by a day to day process by the researcher. Regarding the actual understanding of the research context, the student's state and the lack of resources make archival research strategy difficult to put in place for this thesis. However, secondary data can be collected for a similar result and by needing less resources but cannot be called archival research but either document analysis and or secondary data collection for instance.

Therefore, this thesis will be composed of one section dedicated to primary research which will be a qualitative version of the survey strategy such as interviews to support case studies analysis. Then, two sections of secondary research, one of them will be a secondary data collection about the MEI in the EU in order improve the understanding on the MEI and its environment. The other secondary research will be a document analysis focus on a role model in CE as a restricted archival research strategy. These three strategies have the purpose to create a triangulation that has the goal to strengthen the research quality.

3.6 Research design

According to Creswell (2009, p.003) there exist three types of design for research, the quantitative, the qualitative and the mix-method. The choice of the research design is strongly influenced by the philosophy, the approach chosen by the researcher and by the strategies presented previously. The design is also influenced by the nature of the research problem and by the difficulties of the research context.

The quantitative research designs or also called fixed design according to Creswell (2009, p.004) "is a means for testing theories by examining the relationship among variables. These variables in-turn can be measured, typically on instruments, so that numbered data can be analyzed using statistical procedures." This design has a very strong scientific base due to the fact that every variable has to be proved, tested, measured and supported by numbers. Moreover, the structure of the report follows a specific order such as introduction, theory, methods, results, discussion. One of the main characteristics of the quantitative research is to use numbers to validate a theory and hypothesis and to use close-ended questions in order to obtain a binary sequence which is in opposition to the next design. The most used strategies for quantitative research design are different types of experiments such as true-experiment, quasi-experiment and single-case experiment that can be applied in laboratory, in nature or within a sample of persons. Some non-experimental strategies can also be applied with the quantitative research design such as measuring the relationship between variables and making group comparison by using survey for instance.
On one side this thesis wants to test the theories and make them applicable by other researchers too but the availability of the data and their nature does not make possible the use of experimentation. On the other side this thesis is based on theories and follows a defined structure that belongs to a fixed design. Therefore, the quantitative research design is not adapted to this thesis despite the mentioned aspects that this thesis will get inspired of (Creswell, 2009, p.004; Robson & McCartan, 2011, p.103-144).

The qualitative research design, also called flexible design according to Creswell (2009, p.004) "is a means for exploring and understanding the meaning individuals or groups ascribe to a social of human problem." This design involves the researcher to collect data in various participant's settings to analyse and interpret the data. One of the main characteristics of the qualitative research is to use words as data and to use open-ended questions for collecting and treating the data. The most often used strategies for qualitative research design are the case study analysis, the ethnographic studies and the grounded theory studies.

Most of the data collection strategies of this thesis fall within the qualitative research design. Firstly, the case studies analysis is the primary research of the thesis' strategies which will participate to answer the research question and confirm or not the hypotheses. Moreover, despite that the interview of experts belong to the survey category, the expert interviews of this thesis look for qualitative data in order to confirm the thesis' hypotheses. However, despite that the thesis wants to increase its understanding of the relatively unexplored MEI in the EU, this thesis also wants to be explanatory and not only explanatory or descriptive as is often affiliated qualitative research (Creswell, 2009, p.004; Robson & McCartan, 2011, p.146-160).

The mix-method research design according to Creswell (2009, p.004) "is an approach to inquiry that combines or associate both qualitative and quantitative forms. It involves philosophical assumptions, the use of qualitative and quantitative approaches, and the mixing of both approaches in a study." Regarding the philosophical section it is clear that the author believes in the pragmatic worldview which is in line with the mix-method design and thus the research design of this thesis. As mentioned previously the thesis mixes the approaches (deductive and inductive) and the design (qualitative and quantitative). Therefore, the thesis is mainly explanatory and follows a fixed structure which is theoretically based as for the quantitative research. In the same time a deeper understanding has to be done by the thesis to be certain to not miss any important information in order to make the final result as relevant as possible. The thesis proposes a mix between exploratory and explanatory in order to answer the research question as most accurately as possible. In order to do that a data triangulation is followed to insure the relevance of the research strategy. The triangulation is built as follows, one secondary data collection for the quantitative part to increase the understanding of the MEI and its challenges. Then a secondary research focus on a document analysis of a role model company as a qualitative part to explore even more the MEI's environment and acquire a deep understanding of the MEI's challenges. And then, three case studies analysis based on expert interviews as a mix between quantitative and qualitative to confirm the hypotheses and the research question. The case studies analysis is not only qualitative due to the fact that close-ended questions and prompts compose each interview in order to test each research questions.

3.7 Data collection methods

Before going in depth in the analysis of the field work research of this thesis (interviews) some words concerning the two firsts data collection methods are necessary.
First of all, the thesis wants to increase the understanding concerning the situation of the MEI in the EU and Austria. In order to do that, secondary data will be collected mostly within different documents and research conducted by Eurostat to get the economic place and implication of the MEI in the EU. This data also informs about the environment of the MEI and how the MEI is composed. After having conceptualised the economic environment of the MEI another couple of secondary data also provided by Eurostat will be used to determine the environmental impact of the MEI. A differentiation between pollution types will help to understand the environmental impact of the MEI caused by its activity.
Secondly, as previously mentioned a document analysis will bring qualitative data in order to have a deep understanding of the good practises within the MEI. The selected company for this document analysis will be Caterpillar. Inc., mainly due to the large amount of well documented literature that it is possible to find about this company and due to its implication within the CE. Caterpillar. Inc. is a company competing with the MEI with a long history well documented within the website of Caterpillar. Other researchers such as Walter Stahel also conducted analysis of Caterpillar's business model to understand the reasons of Caterpillar's circularity. These sources constitute the basis of the data that the thesis uses to conduct its own analysis. As a result, a presentation of Caterpillar history, activity and circularity will be made before conducting a comparison of Caterpillar's activity with the thesis' hypotheses. Then, to finalise the document analysis, a SWOT analysis of Caterpillar's CE model will be conducted. Links between the findings of the document analysis and the research model and hypotheses will be made in order to confirm or not the initial assumptions and eventually improving the analytical model and the conceptual framework.

The case studies focused on expert interviews constitute the principal field work of the thesis, they will be conducted among actors of the MEI within Austria. The presentation of these companies, the interview of experts and their analysis have the objective to confirm or not the different hypotheses. A comparison with the findings of the document analysis of Caterpillar will also be made to accentuate the relevance of the information. The expert interviews also allow to compare industries that are in different stages in the CE implementation and compare the key factors of the implementation or none implementation of the CE with the analytical model, research questions and hypotheses of the thesis. By combining the information provided by the triangulation, this

thesis will have sufficient knowledge and proofs to propose a realistic model that will answer the research question:
Why would the MEI within the EU switch to a CE regarding biophysical, economic, cultural and environmental limits?

3.8 Sampling strategy

Concerning the population target or focus group of this thesis, the initial plan was to contact CEOs of each relevant company, but the experience revealed, that they were not able to explain the production process and the circularity of their own business. Instead they were focussed on business models, financial challenges and representativeness on the market. Therefore, the author looked for directors of production and operation and the directors of quality and environment working in the MEI in Austria as a focus group.
Before contacting such people, an identification of the most relevant companies involved in the MEI was necessary. In order to do that, some lists of Austrian businesses divided by sector of activity were found provided by the Austria Chamber of Commerce, the world of manufacturer association and Ezilon Europe. Every company of those list was analysed in order to determine the exact sector of activity and ensure that they belong to the NACE 28, the MEI. Then, a new list of potential businesses has been created and each of them was contacted several times to reach the director of production or the director of quality and environment. Contact was made with the following companies: Doppelmayr/Garaventa Group, Andritz Group, Krause & Mauser Holding GmbH, Wittmann Group, Engel Austria GmbH, Pöttinger Landtechnik GmbH, Liebherr-Werk Bischofshofen GmbH and Oberhammer Maschinenfabrik GmbH. In February, all of them accepted that one of their representants participates in an interview except Doppelmayr. However, the corona-virus crisis greatly disturbed the companies and most of the contacts were lost or unable to conduct an interview anymore. As a result, only interviews with representants of Engel Austria GmbH, Pöttinger Landtechink GmbH and Wittman Group could be conducted by making Skype interviews, because meeting them in person was forbidden by law in the time of the interview.

The sampling method is a non-probability sampling due to the fact that the population target is homogeneous because belonging to the same specific industry and having a similar position within their respective company. Therefore, the thesis follows a judgement sampling which is very convenient and adapted to the thesis which targets the comprehension of a specific sector. The judgment sampling allows to choose the best and most relevant experts and firms for the thesis' needs. However, this method does not give scientific proofs that founding would be true for all the

EU. Despite the pertinence of my choice, my explanation and my reasons, the judgement sampling remains subjective.

Concerning the sample size, the thesis applies the technique of the data saturation. The document analysis of Caterpillar will give a basis of information and confirmation that the interviews of the case studies will complete. Therefore, three organisations that represent the MEI in Austria will be presented and analysed. I initially estimated that after total of 3 or 4 expert interviews the collected data will become redundant. However, the difference of CE implementation within MEI in Austria, the difference of size and economic power of each company and their difference of production made me realised that more interviews would have been better. As mentioned previously nine companies were contacted and agreed to be my interview partner, unfortunately my interview period happened exactly during the covid-19 crisis. As a result, most of my contact refused to continue or just stopped the contact, in the end I could only conduct three interviews on the ninth potentials.

The questionnaire used during the expert interview is structured to follow the conceptual framework and answer all the research questions and their hypotheses. Therefore, the interview guideline is divided into topics inherent to the research questions displayed in a logical order. For each of these topics a set of structured and unstructured questions were asked to the interviewees. The structured questions take the form of multiple-choice questions and of scaled questions. The unstructured questions take the form of open-ended questions often used to get more information from the choice that the interviewee made during the structured questions. The interview guideline can be found as Annex of the thesis and the next section gives more details about its use in the research.

3.9 Coding scheme

The interview guideline follows a semi-structured strategy, which means that during the interview this guideline was used as a checklist to cover all the relevant topics for the thesis by allowing at the same time the natural flow of the interviews. Each interviewee has a different opinion and perspective influenced by his personality and environment which determined his center of interest and the information that they will provide.

As mentioned in the previous section, the interview guideline used different types of questions that contribute to the semi-structured design of the interviews which will maintain a natural flow during the meeting with the interviewees. Some of the questions within the guideline and some reactions

in the interview are probes, they will influence the interviewee to expending his answers. The introduction of each side and the warm-up will allow the creation of a good atmosphere for each interview which will greatly help the interviewer to ask and use probes as for the interviewees to answer them. In addition to the probes some prompts will also be used during the interviews to propose a range of possible answers to the interviewees. The prompts that will be confirmed by the interviewees will be present in the interview record (Robson & McCartan, 2011, p.288-290).

As the interview guideline is closely related to the research questions and the hypotheses, the coding schemes also have to be adapted to them. Therefore, the coding scheme chosen in this research is a content analysis or more precisely a "thematic content analysis" by Canary (2019) or "quasi-statistical approach" by Robson & McCartan (2011, p.460) when adapted to the extraction of information coming from interviews. The goal of such coding approach is to interpret the comments and statements of the interviewees to answer the hypotheses. The specific sentences, meanings and statements are considered as themes in the thematic content analysis. The themes will be firstly the hypotheses themselves secondly the prompts and thirdly the CE strategies that are related to each hypothesis. In other words, the themes will be anything that is relevant and appropriate to answering the hypotheses (Canary, 2019; Robson & McCartan 2011, p.460-461).
The sequence of the thematic content analysis will also have two functions. The first is the differentiation between the interviewees, each of the interviewees will have a dedicated number in order to differentiate the statements. This differentiation will reveal potential points of agreement or disagreement and how many times an event occurs in each interview. The second is the implementation of a time scale in the coding scheme in order to see in which order the themes occur. This time line also shows how the different interviews ran by giving the time when each interviewee mentions topics and confirms themes (Robson & McCartan, 2011, p.335-340).
Therefore, each time that a theme will be confirmed by an interviewee a number will be attributed depending on the interviewee and when he said it. An excel sheet will be used to show the themes, the number (interviewee) that was attributed to them and their occurrence. These excel sheet will be a resume of the thematic content analysis results and will be used as a basis for the interview data analysis of this thesis. This excel sheet have the name of coding table and it is showed in the Table 9 for the first part of the coding table and the Table 10 for the second part of the coding table.

Each interview lasted between 38 and 46 minutes which gave plenty of time to collect all the relevant data without getting the interviewees bored.

Some quotations of the expert interviews will be made to support the results that will be presented in the coding table. Due to the fact that the English is not the mother tongue of the interviewees and that the analysis of the interview is based on a content analysis, the quotations will be corrected. Thus, the familiarities and the English mistakes that the interviewees might use will not be quotations of the interviews.

3.10 Research limitations

The limitations to this research can take several forms. It can be inherent to the chosen data collection strategies such as the document analysis and the case study supported by expert interviews. The limitations can also be more general and linked with the chosen geography that the thesis decides to cover.

Firstly, concerning the data collection strategies, the thesis only covers the case of Caterpillar which is considered as one of the best practitioners of CE within the MEI. However, the thesis does not analyse a more classic company that does not officially switch towards a circular model such as Caterpillar. The comparison of very different stages of CE's implementation like executed with the expert interviews could have helped to find hidden information.
Another point concerning the document analysis of Caterpillar is the size of the company. Caterpillar is a large corporation that is present all around the world and has a powerful economic influence. Nevertheless, the small and familial companies (less than 50 persons) constitute the most of the MEI businesses, this is why it could have also been interesting to conduct a document analysis on a small company competing in the MEI. Unfortunately, the availability of data for such companies is limited. Future researches with more resources could dig in this direction to increase the sampling range.
Concerning the expert interview, the actual sampling does not cover the 5 different branches existing within the NACE 28 (MEI). A comprehension and comparison of the different branches of the MEI might have revealed differences and further challenges that would be interesting to consider in the study. Due to the sanitary crisis of the covid-19, the ability of the thesis to cover all the MEI branches has been greatly impacted. This limitation reduced the range of the thesis which could be improved in future researches.

Secondly, the geographic limitation. In order to improve the comprehension and to get an easy access to relevant data, the thesis makes the choice to represent the MEI in the EU by using Austria as the main sample. However, Austria is not one of the biggest producers of machines and

equipment, instead Austria is relatively specialised particularly in agriculture machinery. Therefore, future research could choose bigger producer countries of the EU such as Germany and Italy.
Furthermore, the EU is a specific market that obeys to a unique legislation and regulation system. This is why the findings of this thesis should be different or not accurate if applied in another place than the EU such as the US or China for instance.

4 The MEI and its impact

Before looking how the MEI performs in a CE model it is important to get a deeper knowledge of the MEI. As presented in the previous sections, the CE offers solution to limit the material use and the Green House Gas (GHG) emissions in order to reduce the environmental pressures. Therefore, understanding the power, the influence and the environmental impact of the MEI in the EU will help to understand the importance and the necessity of the implementation of the CE within the MEI. In a first section the thesis looks which role the MEI plays within the EU economy and how this industry is structured. In a second section, the thesis will look at the environmental impact of the MEI in the EU.

4.1 The placement of the MEI in the EU

4.1.1 The machinery sector in EU

According to the EU-MERCI (2020, p.29) the machinery sector in the EU is composed of four NACE divisions:

- C25: the manufacture of fabricated metal products, except machinery and equipment;
- C26: the manufacture of computer, electronic and optical products;
- C27: the manufacture of electrical equipment;
- C28: the manufacture of machinery and equipment not elsewhere classified.

This four divisions represent 560,000 companies and 6.9 million employees around the EU. The turnover generated by the machinery sector in the EU reached the 1,600 billion in 2012 (EU-MERCI, 2020, p.29).

As previously mentioned, and broadly presented, the thesis focuses on the NACE 28, the manufacturing of machinery and equipment. It is important to note that the MEI is the largest machinery division in the EU due to the fact that it represents 40% of the employment and turnover

of the machinery sector in the EU, which means that MEI employed 2.76 million people and generates 640 billion €. It is interesting to notice that the majority (more than 50%) of the companies that constitute the MEI are small and medium-sized enterprises (SMEs) and most of them family-owned companies which employ less than 50 employees (Eurostat, 2009, p.239; EU-MERCI, 2020, p.29).

The MEI or NACE 28 in the EU is dominated by Germany that hosts around 36.6% of the MEI activities in the EU, which is the double of the second member state, Italy that contributes to 16.2% to the MEI's activities. These two countries constitute the largest manufacturing member states in terms of output and value added.

The Figure 11 helps to see and understand the repartition of the MEI activities around the EU, it shows the percentage of persons employed by the MEI in the different regions of the EU.

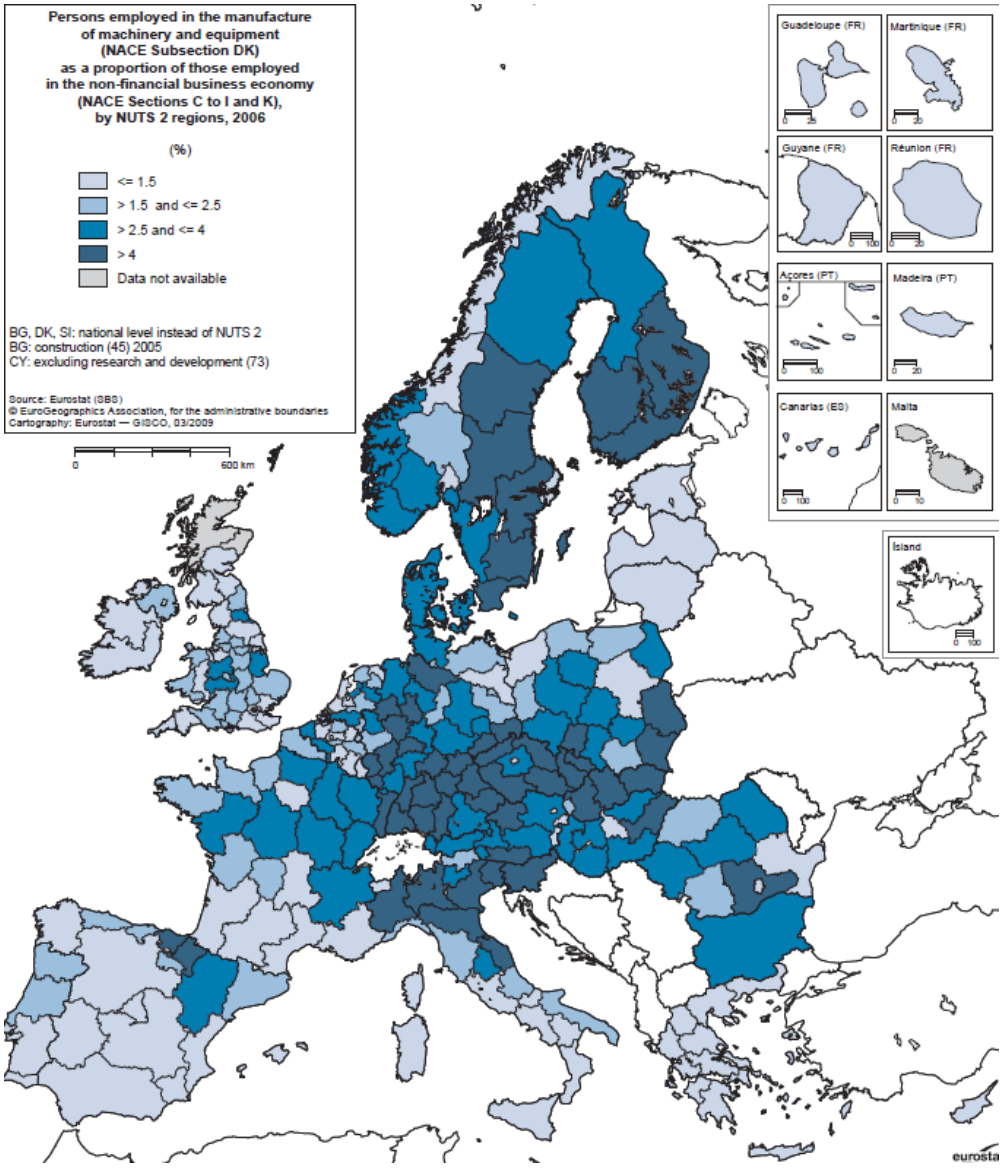


Figure 11: Manufacture of machinery and equipment n.e.c. (NACE Division 29). Persons employed in the manufacture of machinery and equipment (NACE Division 29) as a proportion of those employed in the non-financial business economy (NACE Sections C to I and K) (%)

As expected, the Figure 11 shows that the majority of the manufacturing regions of machinery and equipment are localised in Germany and Italy but also extended to all central Europe. Therefore, the Figure 11 also shows that a number of regions located in Czech Republic, Slovakia, Slovenia, Austria, Poland Finland and Sweden are also specialised in the MEI, certainly in the form of niches. The Table 3 resumes the previous information:

	Highest value added (1)			Largest number of persons employed (1)			Most specialised: share in the non-financial business economy (%)	
	Country	(EUR million)	(% of EU-27)	Country	(thou-sand)	(% of EU-27)	Value added (2)	Persons employed (3)
1	Germany	70 548	36.6	Germany	1 056.4	28.9	Germany (6.1)	Germany (4.9)
2	Italy	31 184	16.2	Italy	567.4	15.5	Italy (4.9)	Slovakia (4.7)
3	United Kingdom	18 960	9.8	France	305.8	8.4	Finland (4.7)	Czech Republic (4.6)
4	France	18 047	9.4	United Kingdom	278.1	7.6	Slovenia (4.6)	Finland (4.6)
5	Spain	9 319	4.8	Poland	196.6	5.4	Austria (4.5)	Slovenia (4.5)

Table 3: Manufacture of machinery and equipment n.e.c. (NACE Division 29). Structural profile: ranking of top five Member States, 2006 (Source: Eurostat 2009, p.239.)

The Table 3 shows that Germany and Italy largely dominate the MEI activities in terms of value added and/or employment. But it is also interesting to note the specialisation of each country towards the MEI on the right column of the table (share in the non-financial business economy). Therefore, Czech Republic, Slovakia, Slovenia, Austria, Poland, Finland and Sweden are also specialised the MEI activities but cannot compete with the value added of Germany.

This section showed the key role that Germany plays in the MEI in the EU but also the importance of smaller countries that are specialised in the MEI. The next chapters of this section, a detailed research of the different groups composing the MEI will be conducted in order to see where these smaller countries have their role. Due to the fact that the expert interviews are conducted among Austrian business, a special emphasis will be made on Austria to understand the position and the specialisation of the MEI in Austria. Before going into detail, the next chapters focus on the characteristics of the European MEI by comparing it with the global industry and exploring its business environment.

4.1.2 The MEI business

The Figure 12 compares the performances of the MEI in the EU with the total industry:

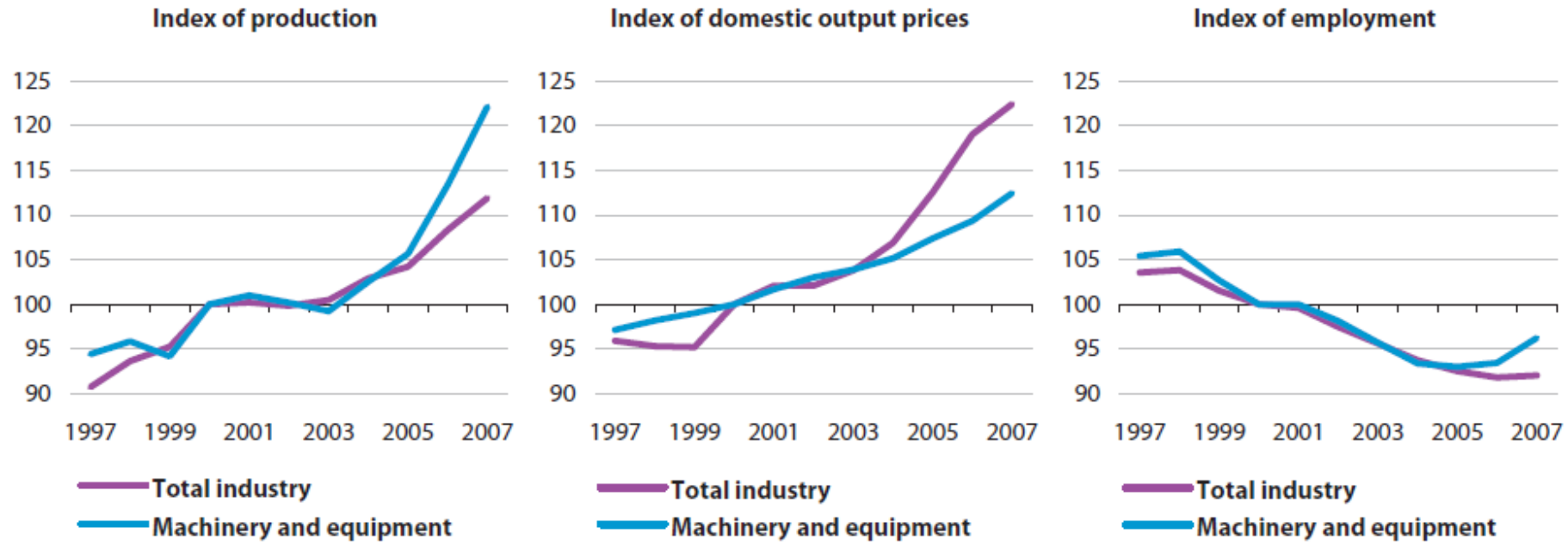


Figure 12: Manufacture of machinery and equipment n.e.c. (NACE Division 29). Evolution of main indicators, EU-27 (2000=100) (Source: Eurostat 2009, p.241)

As we can see in the Figure 12, the MEI in the EU tends to follow the patterns of the total industry except for some cases. For instance, in the last period of the index of production the index of the MEI raised sharply compared to the total industry in the EU despite the global lack of expenditure and investment in the MEI. According to EU-MERCI (2020, p.32) and the Table 4, the trends on the left side of the Figure 12 shows that the MEI production followed the same path, which is an important reduction after the crisis of 2008 followed by an increase so that the index stays higher today than the total industry as the Table 4 suggests.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Total industry	1.6	3.8	3.5	-1.8	-13.7	6.7	3.1	-2.1	-0.7	1.3	2.5	1.8	3.2	1.1
Intermediate goods	1.0	4.9	4.0	-3.5	-18.5	9.3	4.0	-3.5	-0.8	1.8	1.6	1.5	3.9	0.9
Energy	-1.1	-1.0	-1.2	-0.4	-5.9	2.1	-4.7	-2.0	-2.0	-4.4	0.8	0.3	1.0	-0.6
Capital goods	3.2	6.3	6.4	-0.6	-19.7	9.5	8.0	-0.9	-0.3	2.5	5.9	2.3	4.6	2.1
Durable consumer goods	-0.3	4.8	2.4	-5.1	-15.5	3.5	0.2	-4.3	-2.6	0.9	2.7	3.1	4.2	1.3
Non-durable consumer goods	1.5	2.3	1.4	-1.5	-2.9	2.0	1.1	-1.5	0.0	2.2	1.6	1.5	1.5	1.5
Mining of coal and lignite	-5.9	-1.8	-3.7	-2.6	-12.1	-2.4	-2.6	-6.1	-9.3	-6.0	-3.6	-12.7	-8.9	-4.9
Extraction of crude petroleum and natural gas	-8.1	-7.4	-4.0	-3.2	-8.7	-0.5	-11.0	-7.5	-5.4	-6.8	-5.6	-2.1	-2.1	-1.6
Mining of metal ores	0.7	-2.9	-1.8	-1.0	-7.9	10.0	2.6	3.4	-1.8	0.6	-1.3	1.4	1.1	-0.9
Other mining and quarrying	2.5	8.0	-1.1	-5.3	-16.7	3.8	2.4	-7.8	4.1	-0.4	-2.0	0.7	5.2	2.1
Mining support service activities	-1.1	7.8	2.6	-5.4	-9.1	7.1	3.6	8.8	4.6	5.3	-3.5	-20.6	-3.0	3.0
Food products	2.1	1.3	1.9	-0.7	-0.9	2.1	1.9	-0.1	-0.3	1.4	1.0	1.5	1.9	0.4
Beverages	1.5	4.4	1.1	-2.3	-2.9	-1.3	6.1	-2.5	-0.3	1.6	-0.2	1.0	2.2	2.7
Tobacco products	-6.3	-4.6	0.6	-14.9	-0.7	-5.4	-6.5	-5.6	-6.0	-9.8	-7.7	-10.8	-2.0	-8.0
Textiles	-5.6	-0.9	-1.3	-9.6	-17.5	8.0	-2.2	-5.4	-0.3	1.9	-0.7	1.5	3.5	-2.0
Wearing apparel	-12.8	-1.7	-2.3	-8.3	-14.5	-1.0	-2.8	-6.3	-5.0	-0.1	-1.6	0.3	-1.7	-2.5
Leather and related products	-9.0	-2.7	-5.4	-8.2	-14.6	1.8	5.1	-4.9	0.6	0.4	-4.3	-1.6	2.2	0.8
Wood and wood products (exc. Furniture)	0.0	3.7	1.0	-9.1	-15.9	2.8	1.7	-5.4	-1.2	0.9	1.3	2.1	4.3	1.3
Paper and paper products	0.0	3.7	2.6	-3.2	-9.0	6.3	-0.8	-1.6	-0.4	0.7	1.5	-0.1	2.9	0.7
Printing and reproduction of recorded media	2.0	-0.1	0.5	-2.2	-7.9	-0.4	-1.9	-6.2	-3.7	-0.5	-2.2	-1.1	-1.3	-2.0
Coke and refined petroleum products	-0.4	-0.2	-0.4	1.2	-7.6	-1.1	-1.1	-1.2	-2.0	-1.4	3.4	-0.1	2.1	0.8
Chemicals and chemical products	2.2	4.0	3.4	-2.9	-12.4	10.5	2.1	-1.4	0.2	0.5	1.7	0.0	2.1	-0.6
Pharmaceuticals	5.3	5.6	0.5	0.6	2.9	3.6	0.8	0.0	2.4	6.8	6.3	4.1	1.4	5.1
Rubber and plastic products	0.8	4.0	4.4	-4.4	-14.1	7.0	4.1	-3.0	0.4	3.6	2.2	2.4	4.3	0.2
Other non-metallic mineral products	0.9	4.1	1.9	-6.7	-19.3	1.7	4.0	-8.3	-2.9	1.6	1.4	3.7	4.1	0.9
Basic metals	-0.5	6.4	1.7	-3.4	-27.3	19.4	5.2	-4.1	-1.6	2.2	-0.6	-1.1	3.6	0.3
Fabricated metal products (exc. machinery)	1.6	4.7	6.1	-2.9	-22.5	7.0	7.2	-3.2	-0.7	1.5	1.0	2.7	4.7	1.7
Computer, electronic and optical products	3.4	8.5	6.4	0.4	-18.6	3.3	-1.3	-1.1	-3.2	1.2	46.6	1.0	5.1	2.6
Electrical equipment	0.7	8.3	4.0	-1.0	-21.6	11.2	4.1	-3.0	-2.3	-0.8	0.8	1.3	4.3	1.8
Machinery and equipment n.e.c.	3.6	8.2	8.2	1.3	-26.9	11.2	11.8	0.3	-3.0	1.1	-0.6	1.0	6.2	3.1
Motor vehicles, trailers and semi-trailers	2.8	2.4	5.8	-6.0	-25.9	21.8	12.7	-2.9	2.6	5.2	5.2	4.9	4.3	-0.3
Other transport equipment	3.5	9.0	4.5	3.4	-5.3	0.2	4.5	2.4	4.3	0.4	2.6	3.7	4.0	4.3
Furniture	0.5	3.1	3.5	-4.9	-16.5	-0.6	2.1	-5.7	-4.3	2.3	2.7	4.4	1.9	0.3
Other manufacturing	0.9	4.9	1.6	-1.8	-6.8	8.7	3.6	0.0	3.1	5.2	2.9	6.1	1.4	3.8
Repair and installation of machinery and equipme	1.2	9.2	4.4	4.2	-10.0	3.2	4.7	-1.7	-0.5	0.5	1.4	-0.6	3.5	3.1
Electricity, gas, steam and air conditioning supply	1.3	0.8	-0.3	0.1	-4.3	3.8	-3.7	-0.2	-1.0	-4.5	1.9	1.2	1.7	-0.2

Table 4: Annual rates of change for total industry, main industrial groupings and NACE divisions, calendar adjusted, EU-28, 2005-2018 (Source: Eurostat, 2019b)

Concerning the index of domestic output prices in the middle of the Figure 12, we can see that the MEI has a constant and stable increase over the time while the total industry is inconsistent and increases sharply. Based on this recognition and the production index it is possible to argue that the European MEI is much more stable and stronger than the large majority of the other industries which confirms the initial assumption that the MEI is a strong base of the economy.

Then, concerning the employment index on right side of the Figure 12 the MEI and the total industry also followed the same trends but when comparing the work of EU-MERCI (2020, p.32) and Eurostat (2009, p.239) show that the crisis of 2008 had a strong impact on the employment index for all industries. However, the employment within the MEI in Europe could never come back to its previous state of 3.2 million, it is actually at 2.9 million. It can be explained by the loss of companies due to the crisis of 2008 and the strong concurrence of China, as a result 92,930 companies compose the MEI today against 174,000 in 2006.

4.1.3 The exportation and importation of the European MEI

According to Eurostat (2009, p.243) "the EU's internal market accounted for a relatively small majority (55.6 %) of the EU-27's total trade in machinery and equipment". The rest (44.4%) is dedicated to the exportation and creates economic surplus. Eurostat (2019c) states that "in 2018, the top 5 EU export products were machinery and equipment (13.5 % of total exports), motor vehicles (11.0 %), pharmaceutical products (8.9 %), chemical products (8.3 %) and computer, electronic and optical products (7.6 %)". The Figure 13 shows the difference between the 5 best exporting industries and tells us that the 13.5% of the MEI exportation represents € 264 billion in 2018 which make the MEI as the biggest non-financial industry in term of exportations.

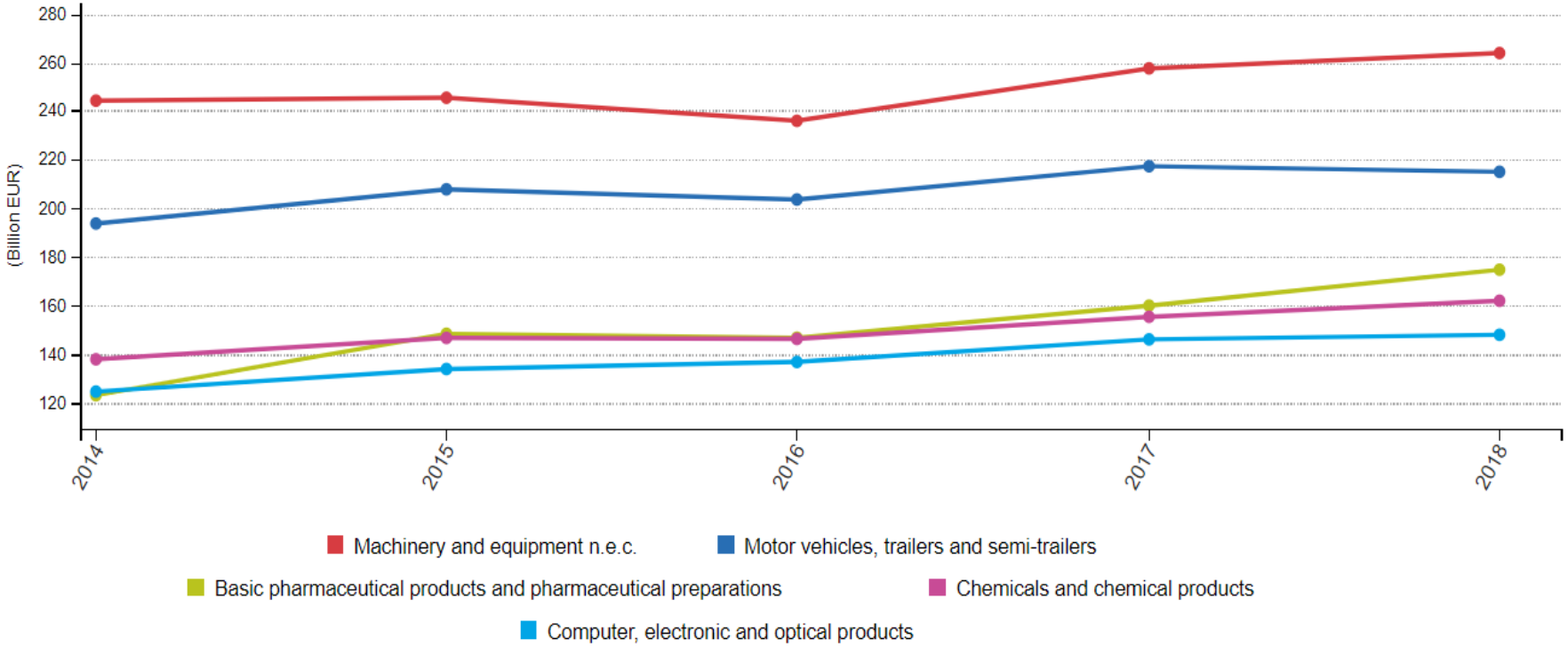


Figure 13: Top 5 CPA categories in extra-EU exports, 2015-2019 (Source: Eurostat, 2019c.)

When comparing these data with the older one of Eurostat (2009, p.243), in 2007 the extra-EU export of MEI was € 193 billion. Therefore, despite the loss of companies after the crisis of 2008 the European MEI became even more profitable than before to stay the industrial sector generating the most trade surplus in the EU.

Concerning the geographic orientation of these exportation, Figure 14 of WITS (2018a) shows that the United States with 21.4% of the exportation and China with 13.8% of the exportation constitute the privileged states of the MEI's exportation. In the same time the rest of the world represents 51.5% of the total amount of the MEI's exportation, which means that the European MEI is in contact with a lot of countries in order to sell its products.

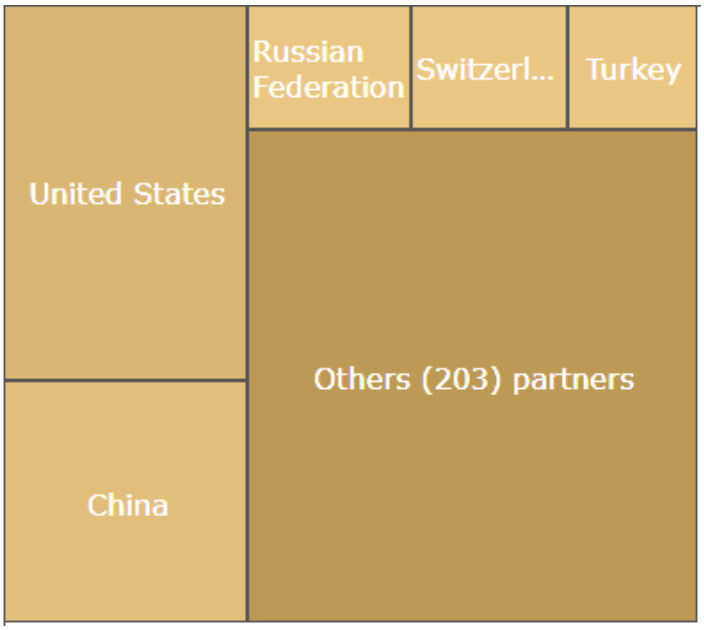


Figure 14: European Union 2018 Export Partner Share (Source: WITS, 2018a.)

Concerning the importation of the EU's MEI, the Figure 15 of WITS (2018b) shows many similarities with the exportation model of the MEI. The privileged states are China with 34.4% and the United States with 17.7% of the importation which represents more than 52% of the MEI's importation. The other countries also represent an important participation of 30.3% of the MEI's importation.

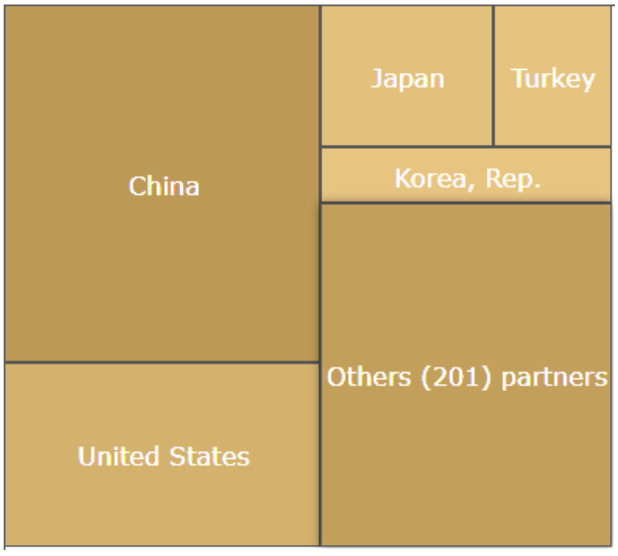


Figure 15: European Union 2018 Import Partner Share (Source: WITS, 2018b.)

This section showed that the MEI is a European leader in exportation which proves the expertise of the EU in this industry. It is able to create a large surplus due to the fact that the exportations of the European MEI are largely superior to its importations.
It also shows the potential threat that can be constituted by the actual repartition of the European MEI's exportations and importations due to the high dependence of only 2 countries, China and the United States. The actuality with the implication of the coronavirus on the economy gives a good example of this threat.

4.1.4 The MEI's subsectors in detail

Regarding the reorganisation of the NACE groups operated in 2008 some of the classification used in the sources does not have the same code. This is why a brief summary is necessary.
The seven groups that compose the MEI cover 5 thematics such as the general purpose machinery (NACE groups 29.1 and 29.2 or the actual C28.1 and C28.2), the agriculture and forestry machinery (NACE group 29.3 or actual C28.3), the industrial processing machinery (NACE groups 29.4 and 29.5 of the actual C28.9), the arms and ammunition (NACE group 29.6) and the domestic appliances (NACE group 29.7). The last 2 groups have been removed from the actual MEI classification but are relevant in this thesis to understand the MEI (Europa, 2020; Eurostat, 2008).

Firstly, the thematic of general purpose machinery, the NACE group 29.1 is in charge of (Eurostat, 2009, p.244) "the manufacture of power machinery including internal combustion engines, as well as steam, gas, wind and hydraulic turbines, pumps, compressors, taps, valves, bearings and transmission equipment" when the NACE group 29.2 is in charge of (Eurostat, 2009, p.244) "the manufacture of other general purpose machinery includes furnaces and burners, lifting and handling equipment and non-domestic cooling and ventilation equipment".
The general purpose machinery (groups 29.1 and 29.2 or C28.1 and C28.2) represents more than the half (52%) of the MEI's value added in the EU and is largely dominated by Germany that represents 36% and followed by Italy with 16.5%. Germany and Italy are also the EU members the most specialised in the general purpose machinery. The specialisation shows that Sweden, Denmark and Slovakia also choose a strategy of specialisation in this sector (Eurostat, 2009, p.244).

Secondly, the thematic of the agricultural and forestry machinery, the NACE group 29.3 is in charge of (Eurostat, 2009, p.246) “the manufacture of agricultural tractors and other agricultural and forestry machinery, but not agricultural hand tools”. This activity is one of the smallest among the MEI in the EU and it declined over the past years. The main reason to this decline is that (Eurostat, 2009, p.246) “the number of agricultural holdings in the EU has been declining rapidly for many years”. This decline is the cause of a gradual change in the land use, the picture of a farmer working in a large farm which is likely to need agricultural machinery switches progressively into small-sized holdings which have the strategy to produce organic products (bio label) and being closer to their consumers. The Table 5 gives information of the actors in the agricultural and forestry machinery sector in the EU.

	Highest value added (1)			Largest number of persons employed (1)			Most specialised: share in non-financial business economy (%) (2)	
	Country	(EUR million)	(% of EU-27)	Country	(thou-sand)	(% of EU-27)	Country	Value added
1	Germany	2 390	26.8	Germany	38.3	18.1	Finland	0.4
2	Italy	1 578	17.7	Italy	35.7	16.8	Austria	0.3
3	France	1 219	13.7	France	27.3	12.9	Italy	0.2
4	United Kingdom	441	5.0	Poland	17.2	8.2	Denmark	0.2
5	Austria	435	4.9	Spain	11.2	5.3	Germany	0.2

Table 5: Manufacture of agricultural and forestry machinery (NACE Group 29.3). Structural profile: ranking of top five Member States in terms of value added and persons employed, 2006 (Source: Eurostat, 2009, p.246)

The Table 5 shows that Germany, Italy and France are the main contributors in the agricultural and forestry machinery sector in the EU in terms of value added and of employment. It is interesting to note the presence of Austria at the fifth place of the value added with a similar score to the United Kingdom despite the large difference of size and power between Austria and the four other countries. This presence in the value added is confirmed by the high specialisation of Austria (right side of the Table 5) in the agricultural and forestry machinery sector almost like Finland (Eurostat, 2009, p.245-246).

Thirdly, the thematic of the industry processing machinery that includes the NACE group 29.4 and 29.5. According to Eurostat (2009, p.248) “industrial processing machinery producers make specialist machines and applications to aid the manufacturing processes in a range of diverse sectors: for example, special purpose machinery for mining and quarrying, metallurgy, food and beverages processing, textiles and clothing production, paper and paperboard production, or construction”. The industrial processing machinery sector represents more than a third (34%) of the value added of the MEI in the EU which is the second most important after the general purpose

machinery sector. The Table 6 gives information about the actors in the industrial processing machinery sector in the EU:

	Highest value added (1)			Largest number of persons employed (2)			Most specialised: share in non-financial business economy (%) (3)	
	Country	(EUR million)	(% of EU-27)	Country	(thou-sand)	(% of EU-27)	Country	Value added
1	Germany	27 597	42.2	Germany	429.9	35.4	Germany	2.4
2	Italy	9 975	15.3	Italy	175.9	14.5	Finland	2.0
3	United Kingdom	4 902	7.5	Poland	75.4	6.1	Austria	2.0
4	France	4 240	6.5	Spain	73.7	5.9	Czech Republic	1.8
5	Spain	3 143	4.8	France	71.8	5.9	Italy	1.6

Table 6: Manufacture of machine-tools; manufacture of other special purpose machinery (NACE Groups 29.4 and 29.5). Structural profile: ranking of top five Member States in terms of value added and persons employed, 2006 (Source: Eurostat, 2009, p.249)

The Table 6 shows that Germany largely dominates this sector and is followed as usual by Italy in terms of value added as for persons employed. Concerning the specialisation (on the right side of the Table 6) of member states that can reflect the importance of the industrial processing machinery for smaller countries. The Table 6 also shows the high specialisation of Germany which confirms its position of leader. In contrast Finland, Austria and Czech Republic also have a high specialisation in the industrial processing machinery sector.

Fourthly, the sector of the arms and ammunition represented by the NACE group 29.6. is in charge of (Eurostat, 2009, p.251) “the manufacture of tanks and other fighting vehicles, artillery material and ballistic missiles, small arms and ammunition. This activity also includes the manufacture of hunting, sporting or protective firearms and ammunition, as well as explosive devices such as bombs, mines and torpedoes”. This particular and strategic sector of the economy and of the MEI is the smallest in terms of value added for the MEI in the EU, accounting only 2.4%. Compared to the other group the availability of data is limited and a proper analysis is more difficult than for the other sectors. The available data shows that United Kingdom and Germany have the highest value added and persons employed. Bulgaria is the member state the most specialised in the arms and ammunition sector.

Last but not least, the thematic of the domestic appliances covered by the NACE group 29.7 which is in charge of (Eurostat, 2009, p.253) “the manufacture of domestic electrical appliances (such as refrigerators, freezers and dish washing machines), heating appliances, and non-electric domestic cooking equipment” is the only sector of the MEI that has the households as a direct and main customer; this sector applied during the past years the green strategies mentioned in the theoretical framework. Eurostat (2009, p.253) states that the “Product innovations have tended to concentrate

on efficiency and environmental considerations such as energy and water consumption, lifestyle changes, the incorporation of new materials, design and ergonomics". The Table 7 gives information about the actors in the domestic appliances in the EU:

	Highest value added (1)			Largest number of persons employed (2)			Most specialised: share in non-financial business economy (%) (3)	
	Country	(EUR million)	(% of EU-27)	Country	(thou-sand)	(% of EU-27)	Country	Value added
1	Germany	3 613	28.4	Italy	57.7	20.0	Slovenia	2.0
2	Italy	2 621	20.6	Germany	55.9	19.4	Hungary	0.6
3	United Kingdom	1 324	10.4	United Kingdom	24.4	8.5	Italy	0.4
4	Spain	1 183	9.3	Spain	20.6	7.2	Poland	0.3
5	France	925	7.3	Poland	18.5	6.6	Romania	0.3

Table 7: Manufacture of domestic appliances n.e.c. (NACE Group 29.7). Structural profile: ranking of top five Member States in terms of value added and persons employed, 2006 (Source: Eurostat, 2009, p.253)

The Table 7 shows Germany and Italy are the leaders of sector in term of value added as for persons employed but this time without a clear domination of Germany. The most specialised EU member in domestic appliances is Slovenia with a specialisation rate of 2.0 which is much higher than any other member state.

This section allowed a deep understanding of the MEI in the EU with a description of its characteristics and the main contributors for each subsection of the MEI. This analysis shows the domination of Germany in the European MEI and also which are the other contributors. Due to this analysis and the focus that this thesis gives on Austria regarding the expert interviews that will be later conducted, some assumptions can be made. Therefore, the two MEI sectors in which Austria is performing are the agricultural and forestry sector and the industry processing machinery sector.

4.1.5 Focus on Austria

Regarding the results exposed in the previous section, Austria performs in two MEI sectors, the agricultural and forestry sector and the industry processing machinery sector.
Concerning the place of Austria in the MEI subsector of agricultural and forestry, Austria does not have a high level of specialisation (only 0.3) but is able to generate a non-negligible added value. This means that the few actors in Austria competing in this sector are able to generate high wealth. Concerning the place of Austria in the MEI subsector of industry processing machinery, Austria has a very high level of specialisation (2.0) in this sector which is the second most important in the MEI. The potential to generate wealth is more important in this sector than the agricultural and forestry sector. Therefore, it is likely that the large majority of the experts that this thesis will

interview would work or represent the interest of companies competing in the industry processing machinery sector.

The following Table 8 of Huhn (2019) helps to dress a complete overview of the MEI in Austria, by the revenue that each of the MEI sectors within Austria generates with forecasting.
The Table 8 shows that Austria generates most of its revenue in the MEI sector in which it is the most specialised, the industry processing machinery which corresponds today to the NACE C28.9.: manufacture of other special-purpose machinery. This sector is also the one which has constantly grown with the highest growth rate showing the health of this sector in Austria. It is natural that the industry processing machinery is forecasted to increase.
The agricultural and forestry sector of MEI in Austria, despite being one of the specialised sectors represents a small portion of the MEI's revenue in Austria. This sector is certainly small but we can see that it is not the smallest, that it has gradually increased over time and that this tendency is not going to stop.
It is also interesting to note that the general-purpose machinery (C28.1 and C28.2) has the second and third place, it generates more revenue than the manufacture of other special-purpose machinery (C28.9). The fact that this sector of the MEI is so big compared to the other sectors (more than 54%) seems to have inevitably an influence on the MEI in Austria. The opportunities of this sector in the EU make it an important sector in the Austrian MEI. However, the table shows that both groups (C28.1 and C28.2) remained quite stable during the past 7 years, despite this tendency, the general purpose machinery sector is forecasted to slightly increase in the coming years but with a lower growth rate than the manufacture of other special-purpose machinery (C28.9).

Industry revenue of “manufacture of machinery and equipment n.e.c. “ in Austria 2011-2023

Industry revenue of “manufacture of machinery and equipment n.e.c. “in Austria from 2011 to 2023 (in million U.S. Dollars)	manufacture of other special-purpose machinery, NACE: C28.9	manufacture of other general-purpose machinery, NACE: C28.2	manufacture of general-purpose machinery, NACE: C28.1	manufacture of agricultural and forestry machinery, NACE: C28.3	manufacture of metal forming machinery and machine tools, NACE: C28.4
2011	8 433,02	7 014,53	3 886,97	2 196,88	1 524,17
2012	8 801,04	7 206,67	4 117,89	2 392,1	1 492,62
2013	8 726,68	7 712,63	4 061,67	2 437,29	1 713,22
2014	8 705,57	8 165,69	3 960,98	2 462,67	1 771,45
2015	9 221,85	7 897,17	4 009,84	2 322,6	1 777,5
2016	9 765,17	8 560,87	3 908,2	2 423,17	1 808,93
2017	10 012,45	8 458,99	3 924,69	2 667,5	1 996,32
2018*	10 228,82	8 194,34	4 130,28	2 711,73	2 019,18
2019*	10 464,74	8 192,59	4 169,44	2 773,49	2 098,92
2020*	10 688,86	8 190,88	4 200,98	2 829,07	2 177,08
2021*	10 901,78	8 189,26	4 228,67	2 879,09	2 253,73
2022*	11 104,05	8 187,72	4 253,9	2 924,11	2 328,94
2023*	11 296,21	8 186,26	4 277,32	2 964,62	2 402,78

Table 8: Industry revenue of “manufacture of machinery and equipment n.e.c.“ in Austria 2011-2023 (Source: Huhn, 2019)

In order to complete and actualise the information on the MEI and its impact on the economy. A map has been created to show the MEI in Europe by using QGIS as part of the project of the Measuring and Assessing Sustainability (0303) course, the Figure 17 is the result of this.

The numbers with each European region that the Figure 16 shows are the numbers of MEI business within each region, these data come from Eurostat (2020c) and date from 2017. The other important data showed in the Figure 17 are the different shades of green colour which represent the GDP per regions. Darker is the green higher is the GDP and lighter is the green lower is the GDP of a region, these data come from Eurostat (2020c) and date from 2017. Then, the orange colour represents the countries that do not belong to the EU. The Figure 17 confirms the finding previously showed that most of the MEI business are in North Italy and Germany, it is interesting to notice that those regions also have one of the greatest GDP in Europe, a certain degree of correlation can be establish so far despite some outliers like in Ireland which have a high GDP per regions without having any MEI business.

The Figure 16 is the legend of the Figure 17 to understand and visualise more easily the colour code of the Figure 17.

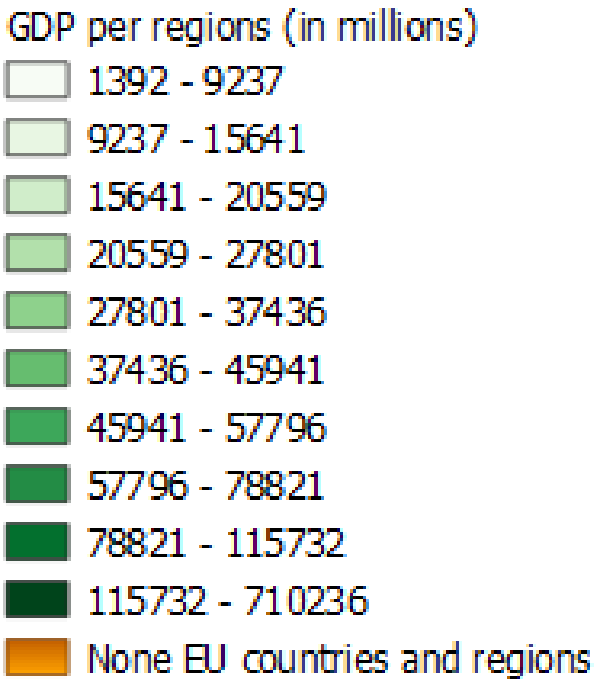


Figure 16: Legend of the Influence of the Machinery and Equipment Industry (MEI) in the European Economy (Source: Danjou, 2020c)

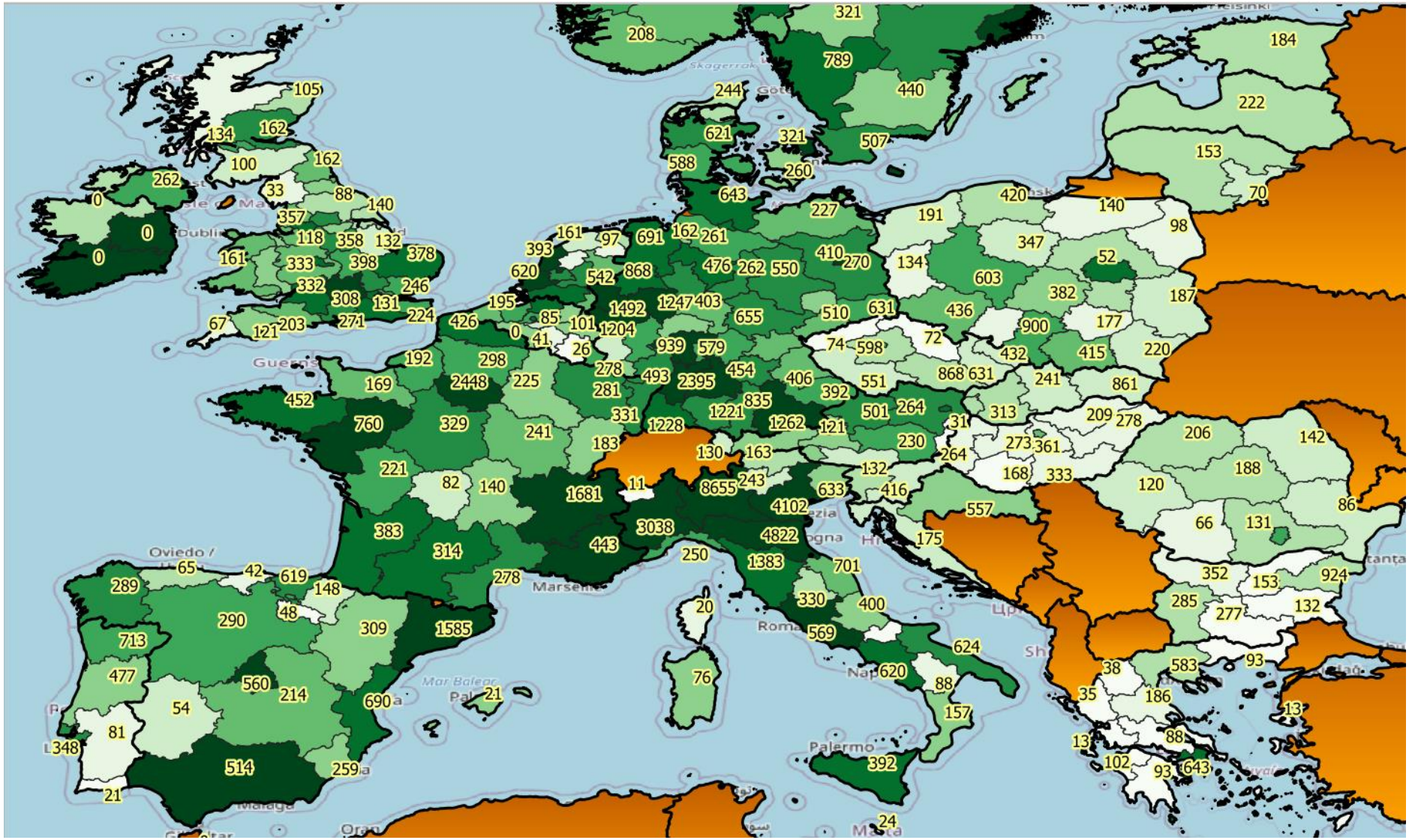


Figure 17: Influence of the Machinery and Equipment Industry (MEI) in the European Economy (Source: Danjou, 2020c)

The numbers with each European region that the Figure 17 shows are the numbers of MEI business within each region, these data come from Eurostat (2020c) and date from 2017. The other important data showed in the Figure 17 are the different shades of green colour which represent the GDP per regions. Darker is the green higher is the GDP and lighter is the green lower is the GDP of a region, these data come from Eurostat (2020c) and date from 2017. Then, the orange colour represents the countries that do not belong to the EU. The Figure 17 confirms the finding previously showed that most of the MEI business are in North Italy and Germany, it is interesting to notice that those regions also have one of the greatest GDP in Europe, a certain degree of correlation can be establish so far despite some outliers like in Ireland which have a high GDP per regions without having any MEI business.

The Figure 18 also coming from Danjou (2020c) focus on Austria, as we can see the Austrian region with the most of companies competing in the MEI are located in Upper Austria which also benefit of a quite high GDP.

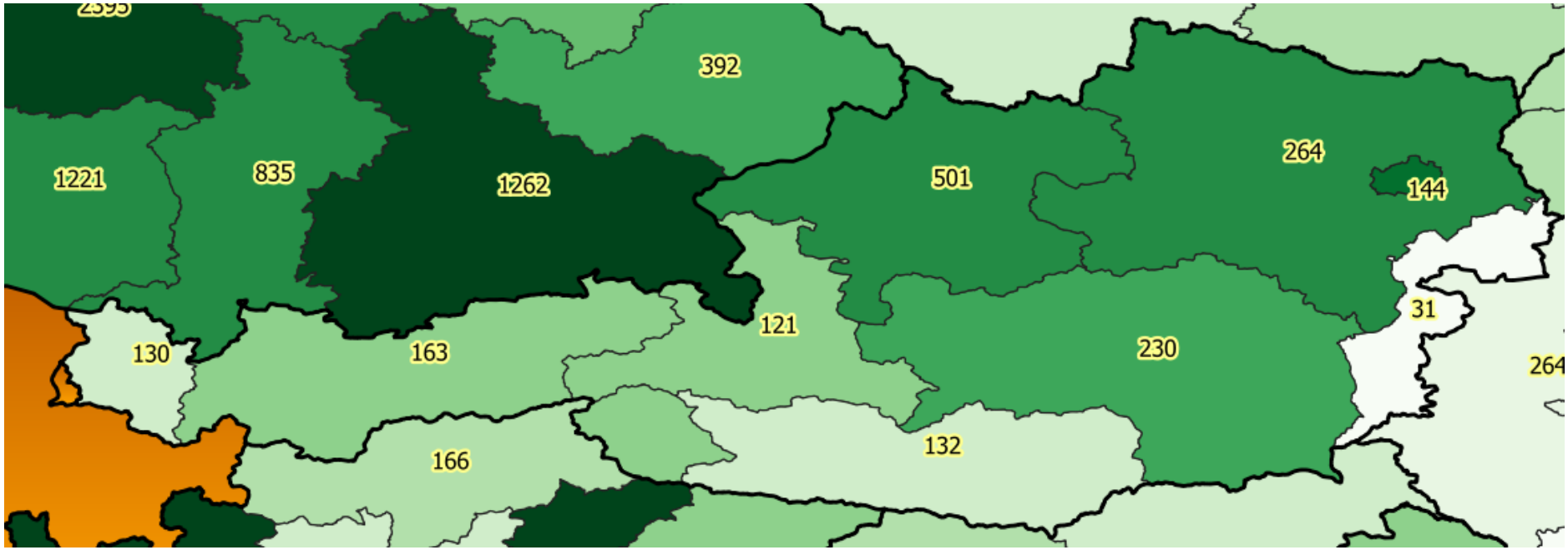


Figure 18: Influence of the Machinery and Equipment Industry (MEI) in Austria (Source: Danjou, 2020c)

On the opposite Burgenland is the Austrian region with the fewest MEI businesses and with the lowest GDP which tends to confirm the assumption emitted for the EU regarding the positive influence of the MEI in the European economy. Regarding the reparation of MEI businesses in Austria it is more likely that companies that will be analysed in the cases study analysis would be located in Upper Austria rather than in other Austrian regions.

4.2 The environmental impact of the MEI in the EU

4.2.1 Direct vs indirect environmental impact

Before going further in the exposition of the MEI's environmental impact it is important to make the distinction between the direct and the indirect impact of industries. According to Watson et al (2013, p.32) the production system of the economy can be considered as the direct source of environmental pressure and the consumption system of the economy represents the indirect source of environmental pressure.

In the case of the thesis, the production perspective can be resumed as being all the economic actors that create and supply goods and services for consumption in the EU or abroad. It means that the production perspective includes the goods and services that are dedicated to the exportation and not only to the EU's consumption. The direct environmental impact caused by the production is the most common used indicator for environmental pressure due to its simplicity. It considers all kind of emissions emitted in a certain territory; in this case it is the EU. The direct environmental impact can also be divided by economic sectors within a territory by recording the emission that each company emits (Watson et al., 2013, p.32).

In the case of the thesis, environmental impact caused by the consumption in the EU looks at all the final products consumed by states and households within the EU. It means that it includes all products produced in the EU for the EU's consumption and all the imported products that Europeans consume. The main purpose of calculating the indirect environmental impact caused by the consumption in the EU is to identify the products that generate the most of pollution. However, the environmental impact caused by the consumption can be divided in two categories. One is more direct due to the fact that the emissions are caused by the combustion of goods such as the petroleum or woods. The other and more difficult to assess is for a purchased good by the consumer, which has already passed by the production and the delivery process having generated pollution. Unfortunately, the pollution generated by producers and transporters for each good is

information that is often not transmitted for corporate confidentiality or simply not existing (Watson et al., 2013, p.48).

Regarding the difficulty to get exact data in the case of the environmental impact caused by the consumption and that the thesis does not focus on the environmental impact of a specific product, the following section focusses on the direct environmental impact caused by the production of the MEI and not on the consumption of the MEI products.

4.2.2 The emissions of the MEI in the EU

The Figure 19 shows the direct emissions of greenhouse gases (GHG) by economic sector. The manufacturing sector as a whole represents 26.5% of the direct GHG emission or Carbon Dioxide (CO_2) in the EU. But the manufacturing sector is divided into several different groups that correspond to different NACE codes. Therefore, an analysis of the different NACE groups represented in the Figure 19 is necessary in order to understand the place that the MEI takes in the Figure 19.

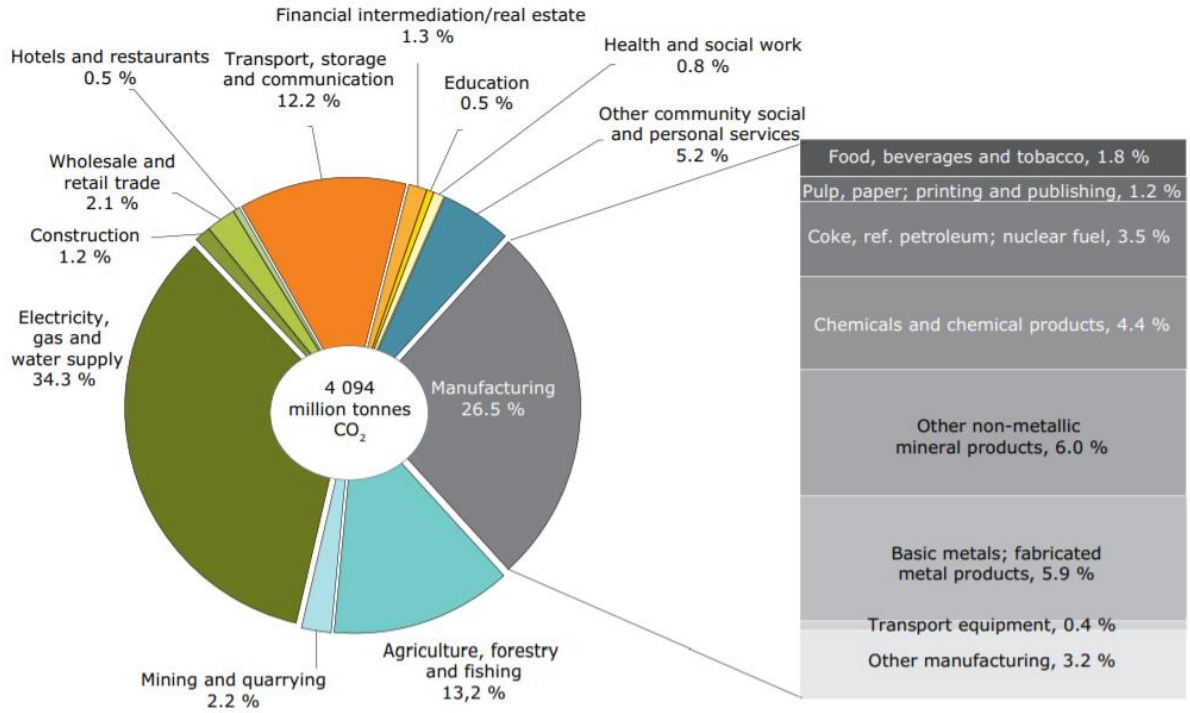


Figure 19: Direct emissions of greenhouse gases by economic sectors in the EU-25, 2006 (Source: Watson et al. 2013, p.34)

According to Europa (2020) and EU-MERCI (2020) the different categories under manufacturing correspond to:

- The food, beverage and tobacco represent the NACE groups: C10, C11 and C12
- The pulp, paper; printing and publishing represent the NACE groups: C17 and C18
- The coke, ref. petroleum and nuclear fuel represent the NACE groups: C19
- The chemicals and chemicals products represent the NACE groups: C20 and C21
- The other non-metallic mineral products represent the NACE groups: C22 and C23
- The basics metals and fabricated metal products represent the NACE groups: C24, C25, C26, C27 and C28
- The transport equipment represents the NACE groups: C29 and C30
- The other manufacturing represents the NACE groups: C31 and C32

As we can see the NACE groups C13, C14, C15 and C16 are not represented in this graph for the simple reason that these sectors are almost not existing in the EU. These groups deal with textile, cloth, leather (C13, C14, C15) and wood products (C16).

This division of the manufacturing sector shows that it is not equitably divided, some represent between one to five NACE groups. Unfortunately, the group division the most interesting for our analysis is the most divided, the fabricated metal products. Regarding EU-MERCI (2020, p.29) this designation represents four NACE divisions C25, C26, C27 and C28 and this graph added another one with the designation of basics metals (C24) which increases the complexity to determine the exact amount of GHG that the MEI generates in the EU (which is under the NACE group C28).

Despite this constraint it appears clearly that the direct GHG emission of the MEI is quite low regarding that the fabricated metal products and basic metals represent 5.9% of the total emission, or 241 million tonnes CO_2 of the 4,094 million tonnes CO_2 of the total amount generated by the industries in the EU. If we assume that each sector within this 5.9% participates equally to the GHG emission, therefore the MEI would only represent a bit more than 1% of the total direct emission, 81 million tonnes CO_2.

If we consider that the MEI is the European non-financial industry that makes the most of exportation and generates the most of turnover, it can be argued that with only 1% of direct emission, the MEI is a relatively clean industry in terms of GHG emissions.

4.2.3 The other emissions of the MEI in the atmosphere

It is interesting to look at other sources of emissions in order to complete the general picture of the pollution generated by the MEI in the form of particles released in the atmosphere. The Figure 20 of Watson et al. (2013, p.35) shows the "direct emissions of acidifying gases by domestic economic sectors" in the EU. In other words, the Figure 20 looks at the direct emission of Sulphur Dioxide (SO_2) of each industry in the EU.

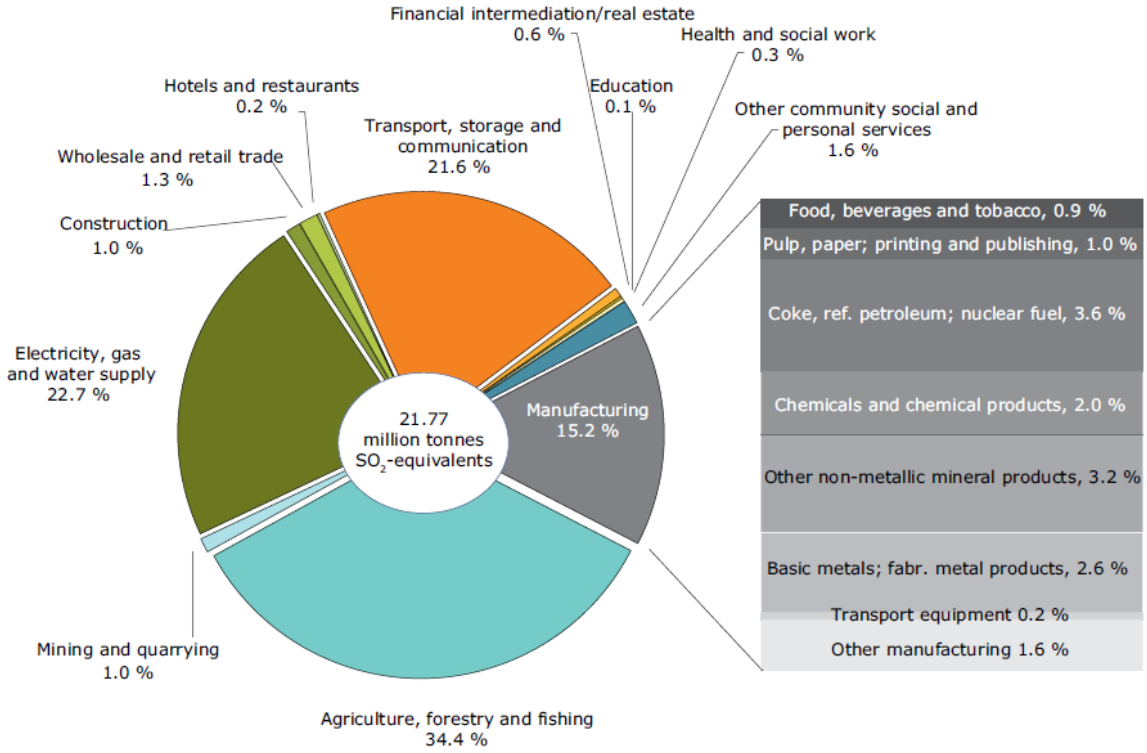


Figure 20: Direct emissions of acidifying gases by domestic economic sectors for the EU-25, 2006 (Source: Watson et al. 2013, p.35)

The first thing that has to be noticed in the Figure20 is the significant difference of total quantity emitted by the European industries between SO_2 with 21.77 million tonnes and CO_2 4,094 million tonnes. High concentration of SO_2 in the atmosphere exists due to acid rainfall and has been a serious public health and environmental problem between the 70th and 80th for the population of industrialised countries. Since then, required policies were conducted to drastically reduce the total emission of SO_2 by the industries (Menz & Seip, 2004).

The large difference between CO_2 and SO_2 is the result of these policies. As we can see on the Figure 20, the manufacturing sector represents only 15.2% of the total SO_2 emission in the EU. Within manufacturing, basic metals and fabricated metal products only represent 2.6% of the total direct emission. By keeping the same assumption as in the previous part, the MEI would only represent 0.5% of the direct emission of SO_2 in the EU, which is 109,000 tonnes of SO_2.

The Figure 21 of Watson et al. (2013, p.36) shows the "direct emissions of ground-level ozone precursor gases by economic sector" in the EU. In other words, the Figure 21 shows the Non-Methane Volatile Organic Compounds (NMVOC) released by the European industries. According to the European Environment Agency (2014, p.06) the NMVOC can be emitted by a large panel of sources and have a similar effect on the ozone layer and the atmosphere as a whole. The NMVOC are mostly emitted by the combustion of different matters, European Environment Agency (2014, p.15) shows that aerosols and the combustion of solvent and used products generate the most of NMVOC.

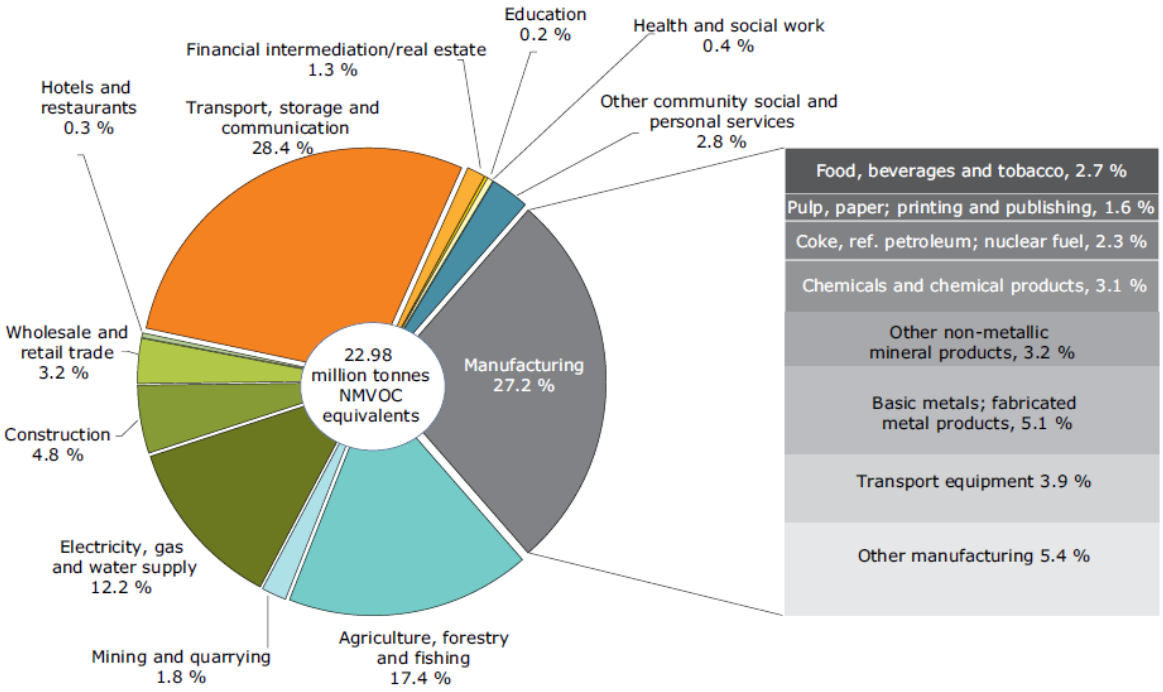


Figure 21: Direct emissions of ground-level ozone precursor gases by economic sector for the EU-25, 2006 (Source: Watson et al. 2013, p.36)

As we can see, the 22.98 million tonnes of NMVOC emission is a similar quantity to the SO_2 emission (21.77 million tonnes), then much lower than the emission of CO_2. However, in contrary to the SO_2 emission, the manufacturing sector represents an important part of the NMVOC emission with 27.2% or 6.25 million tonnes. Moreover, the basic metals and fabricated metal products are one of the highest emitters of NMVOC (5.1%) with other manufacturing (5.4%). By keeping the same assumption as before, the MEI should represent 1% of the total emission of NMVOC. With such a score a similar observation previously made for the CO_2 can be made for the NMVOC. Regarding the high ability of MEI to export and too generate turnover into non-financial industries, this amount of emission seems quite low.

The place of the MEI within the industries emitting particles can be understood by looking at Europa (2020). All of the other sectors of activity in the global market are represented into NACE

codes that represent the specificities or sectors of each industry. In average, each industry is composed of one to five sectors except the manufacturing industry which is composed of 23 sectors of activity and the MEI is one of them. It is for this reason that the emission of the MEI looks so small compared to other economic activities.

4.2.4 The place of MEI in the whole economy and decoupling

The high diversity of the manufacturing industry places this industry as an exception among the others. This is why the manufacturing industry is considered as a different market and often classified into the non-financial activity to distinguish it from the other industry such as transport, accommodation, finance and insurance, information and communication and so on. Therefore, it is interesting to see which place the MEI take in the whole industry to compare it with the whole economic ecosystem.

As decoupling is the goal of the CE it is interesting to look at it within the industry ecosystem as proposed by Cohen, Jalles, Loungani & Marto (2018, p.04-06) in order to determine the performance of each industry towards decoupling policy. Usually the decoupling compares the trend of GDP with the CO_2 emissions, yet other gas of pollution can also be used. However, the GDP cannot be applied to industries, only to countries. This is why the GDP can be replaced by the economic output that each industry generates. Then, comparing the economic output of each industry with their emissions helps to determine the environmental degradation caused by the economic activities of each industry.

The Figure 22 of Watson et al. (2013, p.38) shows the contribution of economic sectors to total economic output, employment and environmental pressures. The Figure 22 compares the industries around five indicators but for this thesis a focus will be made on four of them, the gross economic output, the GHG emissions, the acidify emissions (or SO_2) and the ground ozone precursors (or NMVOC) in order to determine the environmental degradation caused by the economic activities of each industry.

Firstly, the comparison of the MEI (machinery and equipment n.e.c. in the Figure 22) with the other industries in terms of economic output shows that the MEI cannot compete with the industry of services such as the seven first industrial sectors on the Figure 22 (public administration and services; renting, research, business activities; real estate and so on.). Despite this important

difference with the financial activities, as expected and mentioned previously, the MEI generates one of the highest economic output among the industries of production.

Secondly, the GHG emission of the MEI is one of the lowest among the industries, even lower that most of the service industries. The MEI performs well by proposing an economic output of 3% of the global industry for less than 1% of the GHG emissions; this in contrary to industries such as the transport industry which generates more economic output (6%) than the MEI but also emits much more GHG (12% of the total emission) or even more with the production of electricity and gas that generates 34% of the CO_2 emissions for only 3% of the total economic output. Additionally, some of the non-financial sectors such as the chemicals, the coke, refined petroleum and the non-metallics mineral products industries which are competing in the manufacturing sector like the MEI, emit more $C0_2$ than their economic output.

Thirdly, the acidify emission (SO_2) of the MEI is almost not existing such as some service industries like telecommunication, hotels and restauration and financial activities. It is in contrast once again to the transport and the electricity, gas industry but particularly to the agriculture industry that emits 34% of the SO_2 for only contributing with 2% of the total economic output. In general, the rest of the industries have a lower acidify emission compared to their economic output.

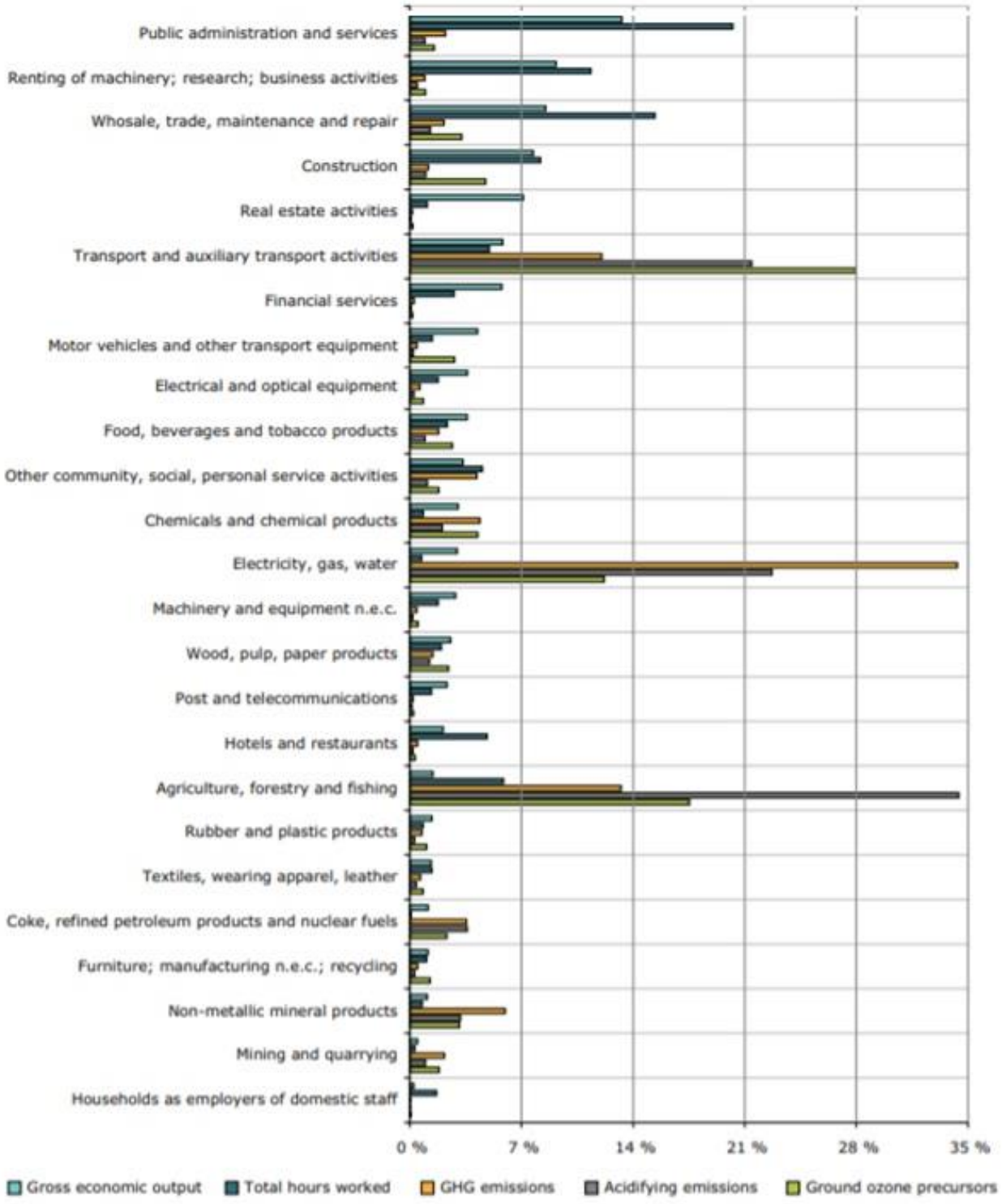


Figure 22: Contribution of economic sectors to total economic output, employment and environmental pressures, EU-25, 2006 (Source: Watson et al. 2013, p.38)

Fourthly, the ground ozone precursors (NMVOC) of the MEI represent a tiny portion of the total emission. Despite this low portion, the emission of NMVOC is the highest category of emission of the MEI compared to the GHG and SO_2 emissions. This observation allows to assume that the MEI uses important quantities and various sorts of solvent and chemical products in the production process. Based on it, it is likely that if the MEI wants to applicate the strategy of C2C in its process

of production, the three first steps of the C2C which mostly consist of detoxify and purify the process of production by analysing, replacing and choosing better products should already be challenging for the MEI.

In contrary to the MEI, the transport industry generates the most of NMVOC with 28% of the total emission followed by the agricultural sector with 16% and the production of energy with 13% of the total emission.

4.2.5 The energy consumption of the MEI in the EU

It is also interesting too look at the energetic needs of an industry to improve the comprehension that the MEI can have on the environment. To understand the effect of the production of energy on the environment it is necessary to look how the energy is provided worldwide. The Figure 23 shows the Total Primary Energy Supply (TPES) in the world between 1900 to 2017. Firstly, the Figure 23 shows that the total of energy has only increased during the past 30 years except after 2008 during the economic crisis. Secondly, the three largest sources of energy are the coal, the natural gas and the oil are the main source of energy.

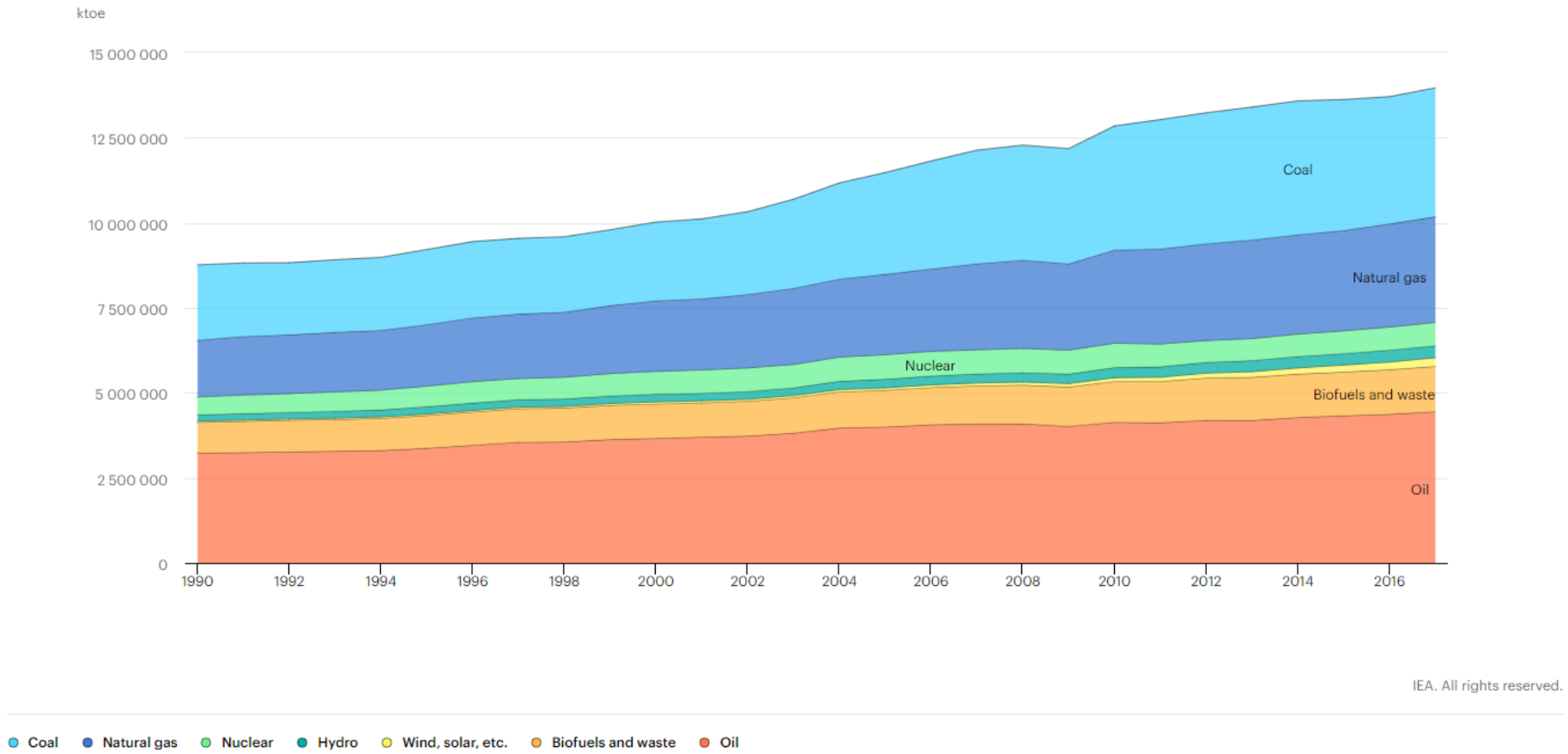


Figure 23: Total primary energy supply (TPES) by source, World 1990-2017 (Source: IEA, 2019)

By adding the nuclear to the three main energy sources previously mentionned, the total of energy provided by non-renewable energy source reaches 88% of the total energy. Thirdly, in opposition to the non-renewable energy sources, the hydor, the wind, solar and the biofuels and waste constitute the renewable energy sources. Unfortunatly the reneawable energy source which does not harm the environment only represents 12% of the total

energy (IEA, 2019). Therefore, when people of corporation use energy, they mostly use energy coming from non-renewable sources. The extraction of such energy damages the environment where it is extracted and the consumtion of such energy generates GHG that is the main source of global warming.

Now that the environmental impacts of the production and consumption of energy have been clarified it is interresting to look at the MEI's energy consumption. The Figure 24 shows the energy consumption of the main non-financial industries in the EU.

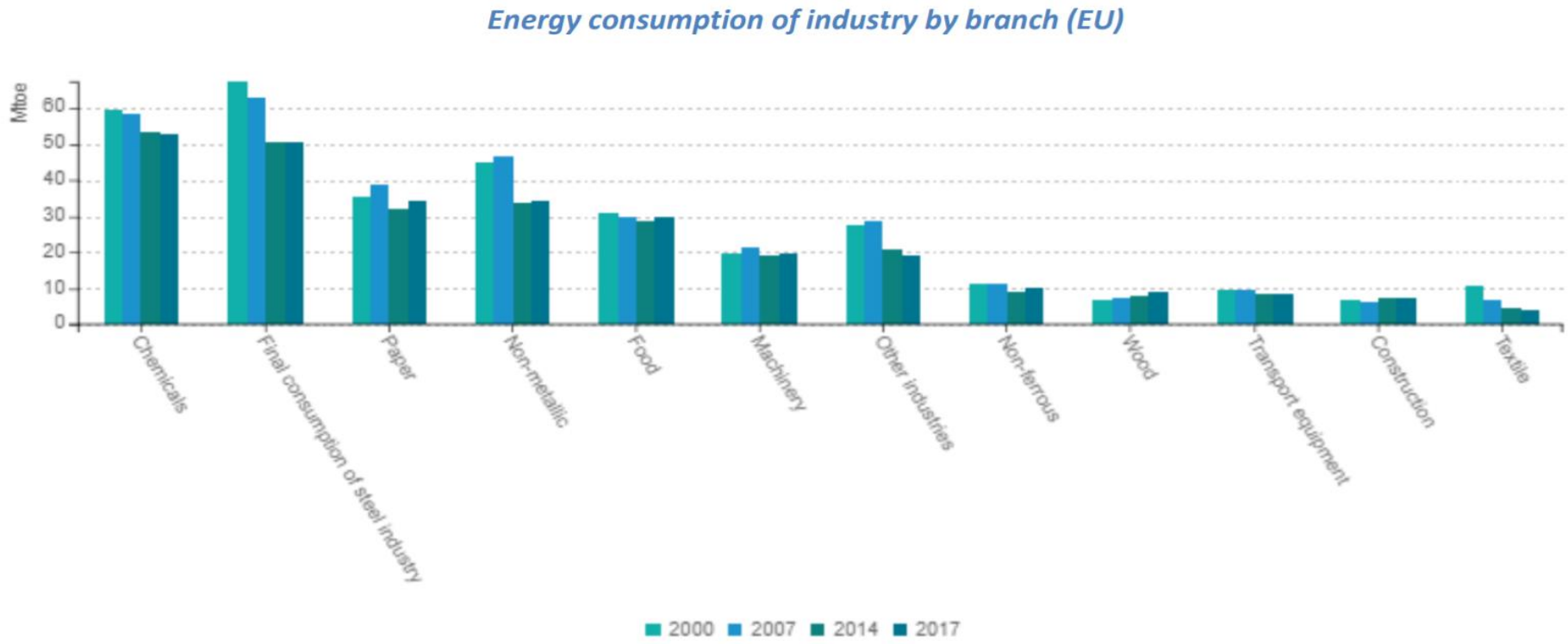


Figure 24: Energy consumption of industry by branch (EU) (Source: European Environment Agency, 2017, p.03)

The four main manufacturing industries that consume the most of energy in the EU are the chemical industry, the steel industry, the paper industry and the non-metallic industry. The Figure 24 also shows that the MEI has an average consumption of energy by consuming a bit less than 20 Million tonnes of oil equivalent (Mtoe) in 2017. The MEI is followed by couple of industries that consume less than 10 Mtoe such as the non-ferous industry, the wood industry, the transport equipment industry, the construction industry and the textile industry. It is interesting to notice that some industries were able to reduce their consumtion of energy overtime such as the chemical industry but most particularly the steel industry that reduced its consumtion of energy by 25% and the non-metallic industry that reduced its consumption of energy by 28%. Even greater but in smaller amout, the textil industry could reduce its consumption of energy by 60% in the last 17 years. However, the majority of the industries such as the MEI did not change their consumption of energy during the past 17 years, therefore the energy consumption stays stable in most cases.
This observation raises the question why the MEI could not reduce its consumtion of energy whereas others could and if the CE could be a strategy for the MEI to start to reduce its consumtion of energy.

4.2.6 Focus on the energetic consumtion of Austrian industries

Regarding that this thesis focus on the EU and that Austria has a special role in this research, this section takes a special look on the overall EU and Austria in specific to examine the energy consumption of every industrial sector within the EU members with Austria in the center. The Figure 25 shows the repartition of the energy consumption of the industrial sector in every EU country. The Figure 25 clearly demonstatres that the consumtion of energy of industry within the EU countries is not perfectly balanced which indicates a form of specialisation for some EU members. For instance, it clearly appears that the Netherlands is highly specialised in the chemical industry due to the fact that this industry uses 50% of the energy of all manufacturing industries there. Lituania and Bulgaria could also be considered as specialised in the chemicals industry. Other very high specialisation can be seen such as the wood industry in Latvia, the non-ferous industry in Norway and Greece, the non-metalic industry in Cyprus and Croatia, the transport industry in Slovenia and Luxembourg or the paper industry in Portugal, Finland and Sweden. However, none of the EU members seems to be specialised in the MEI based on the consumption on energy except in a certain extent to Italy.

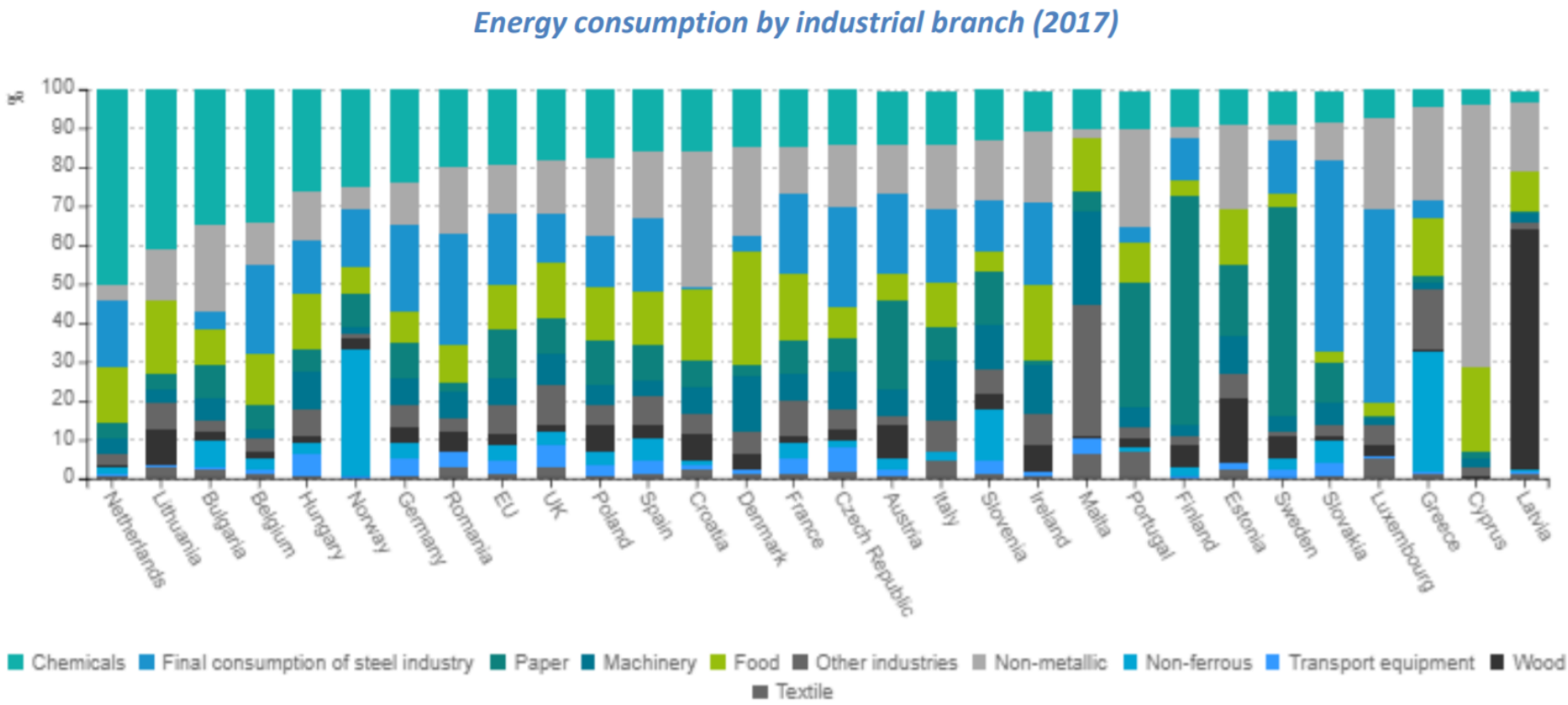


Figure 25: Energy consumption by industrial branch (2017) (Source: European Environment Agency, 2017, p.03.)

Concerning Austria, it is possible to argue that Austria is one of the EU members that has a quite good balance of energy in their manufacturing industry. Austria has a higher consumption of energy in the paper and steel industry which can easily be explained by the high demand of energy needed as mentioned previously. The level of energy that the MEI consumes in Austria corresponds to the average number presented in the previous section. Europewide, based on the energetic consumption, the MEI is well balanced which can be surprising regarding the domination of Germany in this sector.

There are two possible explanations: First the manufacture industry is so large in Germany that the MEI cannot be represented in this vast market particularly regarding energetic consumption due to the fact that the MEI does not need so much energy compared to other industries. Second, investment has been made in Germany in the MEI that allows this industry to make large energy saving which would not be the case for others EU members.
Further research is needed to answer this question. The next section of case study analysis and the expert interview could give some information to answer this question.

4.2.7 Intermediate results

The goal of this section is to correlate the findings of this secondary data analysis with the thesis' research questions.
Firstly, the analysis of secondary data concerning the MEI in the EU showed that the MEI is the first non-financial industry that exports the most, thus generates the most of turnover. This observation has to be coupled with the fact that half of the MEI businesses in the EU are SMEs. By assuming that the generation of value is relatively well divided between all the MEI businesses it is possible to argue, each of these businesses should have the financial capacities to initiate a transition towards CE if they wanted or were aware of it. The next parts of the thesis dedicated to a case study analysis and expert interviews will determine if the main barrier is really financial or more likely technical, strategic and/or behavioural.

Secondly, the secondary data analysis showed that the environmental impact of the MEI in the EU is relatively low, particularly compared to other non-financial industries. Without talking of decoupling, the low rate of emission of different gases compared to the economic growth of the MEI in the EU, places this industry as one of the most effective (not efficient) among the non-financial industries. This is why it is understandable that the decision makers in the MEI would not see the environmental impact of their business as being a key issue for them. Based on this observation, I suppose that the culture of the circularity and being environmentally friendly within MEI businesses should be quiet low. This assumption would answer the research question 4 negatively. The RQ4 asks: Are the MEI's decision-makers afraid to change their production model due to cultural habits? The next parts of the thesis dedicated to a case study analysis and expert interviews will determine the importance of the culture of decision makers in the transition to a CE model.

Thirdly, the previous section dedicated to the energetic consumption of the MEI in the EU showed that the energetic consumption of the MEI remains quite stable overtime. However, in the same time scale other non-financial industries could greatly reduce their energetic consumption. Regarding that CE models are supposed to save energy, it is possible to assume that very few MEI businesses implemented CE technics.

On the other hand, the total energetic consumption of the MEI in the EU is relatively low. It is possible to compare this low energetic consumption with the high turnover that the MEI is able to generate. This observation suggests that the EROI of most of the MEI businesses should be already high, which means that a potential implementation of CE will have to generate an even higher EROI. The next parts will answer if the CE within the MEI is able to improve that much the EROI in order to answer the first research question (RQ1) which asks: Does the use of circular technologies and methods in the MEI generate a sufficient EROI?

5 Case Study Analysis Caterpillar Inc.

5.1 History

Caterpillar Inc. (in the following: Caterpillar) is a manufacturing company founded in 1925 by a fusion of the Holt Manufacturing Company and the C. L. Best Tractor Co. At that time the company just proposed five different kinds of tractors to its consumers that competed in the forestry industry and the road construction industry. Later in 1931, Caterpillar switched its equipment to its typical yellow colour and developed more tractors equipped with the first diesel motors. Caterpillar also started to provide the mining industry at this period due to the high performance of Caterpillar's equipment. In 1937 the machines of Caterpillar helped to complete the construction of the Golden Gate Bridge of San Francisco in the USA. This participation greatly improved the reputation of Caterpillar particularly in the public. From 1945, after the Second World War, Caterpillar created branches that designed and built bulldozers and scraper engines which allowed Caterpillar to completely control the production process of these machines. Between 1945 and 1967, Caterpillar developed new tractors and machines, opened manufactories in Europe and participated in many construction projects all around the world. In 1967, Caterpillar opened its worldwide headquarter in Peoria, Illinois, USA. In 1972 (Stahel, 1995), Caterpillar started to remanufacture its diesel engines at the demand of one of its new and influent customers, Ford Motor Co. Due to the expertise of Caterpillar the group Ford selected Caterpillar to become its Original Equipment Manufacturer (OEM) supplier of diesel engines with the request of remanufacturing the equipment in order to save substantial costs. The remanufacturing activities were current for the car and truck businesses at that time in the USA. In order to fulfil Ford's request, Caterpillar opened a dedicated remanufacturing plant close to its headquarter and officially became a remanufacturer and an OEM. Then in 1979, by following a market study, Caterpillar extended its remanufacturing activities to every engine of its catalogue. Between 1982 and 1985 Caterpillar opened two new facilities dedicated to the remanufacturing activity. Ten years later (1995), Caterpillar gained a substantial share of the US market mainly due to its strategy of diversification, internationalisation and remanufacturing. In 2008, Caterpillar acquired Shandong SEM Machinery Co., Ltd, in China that allowed Caterpillar to enter the Chinese market. Then Caterpillar continued its expansion by acquiring other groups and developing new technologies until today (Reuters, 2020 & Caterpillar, 2020a).

5.2 Caterpillar today

According to Caterpillar (2020b), Caterpillar is actually "the world's leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives" such as presented in the Figure 26:

Figure 26: Product Line (Source: Caterpillar, 2020b)

Today, the sales and revenues represent $53.8 billion and the company employs 104,000 people. The sales and revenues are generated by 5 market segments which are (Forbes, 2019; Caterpillar, 2020b & Reuters, 2020):

- The Construction segment, which is engaged in supporting customers using machinery in infrastructure, forestry and building construction,
- The Resource segment, which is engaged in supporting customers using machinery in mining, quarry, waste and material handling applications,
- The Energy & Transportation segment, which supports customers in oil and gas, power generation, marine, rail and industrial applications, including Cat machines,
- The Financial Products segment, which provides financing and related services, and
- All Other operating segments, which include activities, such as product management and development, manufacturing of filters and fluids, undercarriage, tires and rims, ground engaging tools, fluid transfer products, and sealing and connecting components for Cat products.

The participation of each of this market segments to the turnover of Caterpillar is divided as the Figure 27 suggests:

Figure 27: 2019 total sales and revenues by segment (Source: Caterpillar, 2019, p.2)

The Figure 27 shows that Caterpillar creates most of its value with its construction and mining equipment which is used by the construction industry ($22.6 billion), the energy & transport industry ($22.1 billion) and the resource industry ($10.3 billion) mostly represented by the mining industry. The rest of the turnover is made by financial transaction and the services that Caterpillar proposes to its customers.

As briefly mentioned in the historical part Caterpillar makes 58% of its sale worldwide, as a result the company is present all around the world in every continent as the Figure 28 shows:

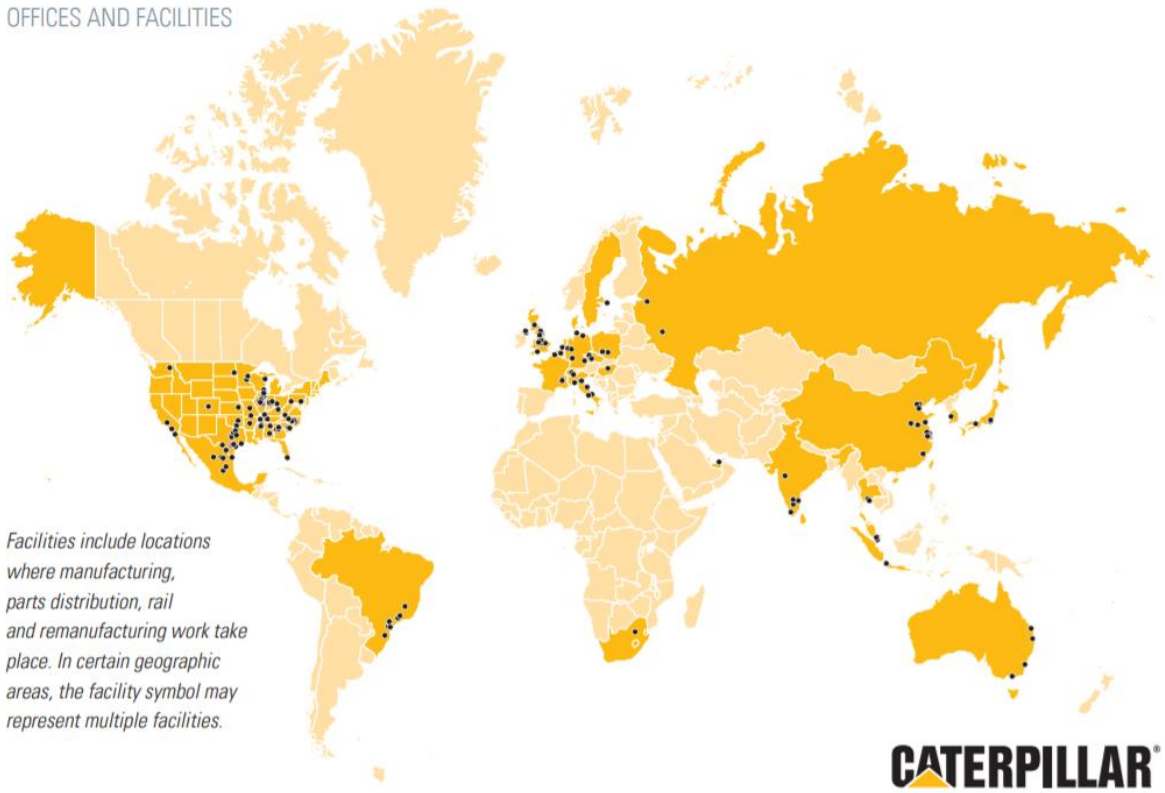


Figure 28: Offices and facilities (Source: Caterpillar, 2019, p.1)

Regarding, the previous information it appears clear that Caterpillar competes mostly in the MEI and can be classified as manufacturer of other special-purpose machinery which corresponds to the NACE group C28.9. By looking closely at Europa (2020) it is possible to argue that Caterpillar is classified as manufacturer of machinery for mining, quarrying and construction: C28.9.2 and as manufacturer of engines and turbines, except aircraft, vehicle and cycle engines: C28.1.1. However, the other minor activities of finance and services are more difficult to classify and do not correspond directly to the MEI.

5.3 The remanufacturing of Caterpillar

As mentioned in the historical section, Caterpillar started in 1972 its remanufacturing activity, however the remanufacturing activity alone does not necessarily guarantee the circularity of the business. Caterpillar developed over time a long experience as a manufacturer and remanufacturer until being able to propose a strategy that fits to the CE principles. Most of Caterpillar's CE is based on the "Cat Reman" program launched in 2006 (Callan & Thomas,2012, p.523).

Before going into the analysis of Caterpillar's circularity it is important to distinguish the remanufacturing activity of a classic and independent company specialised on remanufacturing and the remanufacturing activity that Caterpillar implemented, called "Cat Reman", which is a key factor of Caterpillar's circularity. According to Stahel (1995), most of the classic remanufacturing activities consist of rehabilitating a product to its previous function or similar. For instance, companies receive old products from different corporations and processes by inspecting the products to identify the elements that must be replaced, the ones that can be kept and the ones that can be repaired. Then, they extract the elements of the machines that they identified in order to replace them with new or functional ones. After that, the engines are tested and certified to be sold at a lower price.

However, Caterpillar has another process of remanufacturing. According to Caterpillar (2020c), the first step of Caterpillar's remanufacturing activity consists on disassembling the machines that come to them in order to treat each component of the machines.

The second step consists of cleaning the different components, which involves the use of chemical products to get rid of the years of use that affect the components in order to get the raw material as pure as possible.

The third step consists on inspecting the components in order to determine which treatment the component has to receive next.

Then, the fourth step is influenced by the result of the previous step, the components could just need a treatment of the remaining metal deposition or to pass by a refurbishing process which involves adapted machines and skilled employees.

The fifth step consists on machining and gaging the components, by submitting the components to a variety of adapted tests to validate the quality of the components. Once, the quality of the components has been certificated, the components can be reused in any machine or engine that needs it, in other words they would not necessarily come back in the same type of machine where they were in their previous life.

Then the last step of Caterpillar remanufacturing process is to assemble the components to create a new product, this product is tested with the same standards as a fresh manufactured product. This machine or engine is finally painted to be sold to the customer at a discounted price but with the same guarantee as a new product (Caterpillar, 2020c & Ellen MacArthur Foundation, 2017b).

This important differences between the classic way of remanufacturing and Cat Reman is possible for several reasons.
Firstly, before being a remanufacturer Caterpillar is also a manufacturer which means that it has the control on how they build their machines. This control allows Caterpillar to improve and adapt the design of its machines to make Cat Reman possible.
Secondly, the use of and the investment in new technologies allows the refurbishing of any component of Caterpillar machines. Therefore, any component can be reused which is possible only because the equipment in charge of recycling, refurbishing, cleaning and testing the components is designed only for a certain number of components that belongs to Caterpillar. That is not the case for classic remanufacturers who must deal with many references of components coming from different firms that have different forms and characteristics.
Thirdly, Caterpillar has the position of OEM. Therefore, being a manufacturer and remanufacturer does not limit the interest for remanufacturing activity which in other circumstances could have reduced the volume made by the manufacturing activity and further exposed or disclosed the production knowledge (Stahel, 1995 & Ellen MacArthur Foundation, 2017b).

5.4 The circularity of Caterpillar

As previously explained Caterpillar can potentially make a complete remanufacture of its machines proposing it at a high-quality level. In order to maximise the capacity of Caterpillar's remanufacturing activity, Cat Reman proposes a full strategy in order to create a CE model within Caterpillar. The strategy is centralised on maximising the total life cycle of Caterpillar's products. To do it Caterpillar improved in a first time the basic quality of its metallic components in order to become more resistant and to get their adequate and polyvalent forms. This task could easily be done by Caterpillar due to the fact that its metal providers are also its clients, particularly in the mining industry (Caterpillar, 2018).

The second criterium of Caterpillar's circularity is the design, as mentioned previously Caterpillar is also an OEM, thus it can design its machines to be easily disassembled in order to extract every component. The design of the components is important to facilitate a use in a maximum of

Caterpillar's machines. Such approach also reduces the number of elements involved in the production process which allows financial, energetic and material saving for Caterpillar. Moreover, the low number of elements and the adapted design permit the creation of machines specialised in refurbishing the components. In classic remanufacturing activity, refurbishing has often a low ROI and EROI due to the fact that refurbishing machines can only take in charge a limited number of components' references (Caterpillar, 2020c & Stahel, 1995).

The third criterium of Caterpillar's circularity is the service proposed to the customer. The main objective for Caterpillar towards their customer is to provide the best economic propositions which are mainly based on the performance and the longevity. In order to reach its objective Caterpillar proposes to its customers a variety of contracts to repair or replace (take back) the damaged or just old machines. By getting the old machines back of every customer the Cat Reman of Caterpillar can work at its full potential. Due to the performance of Caterpillar's remanufacturing process Cat Reman is able to propose to its customers the same machines and equipment with the same performance as a freshly manufactured, but 50% to 60% cheaper.
The main reason for Caterpillar to get its machines back to be remanufactured is because 65% of Caterpillar's costs lies on material costs while the general costs such as human resources, electricity and renting only represent 35% of Caterpillar's costs. The material cost is so high because the manufacture of original equipment is very expensive due to their size, their complexity, the small market and the high quantity of natural resources that it needs (mostly coming from the mining industry and steel industry). This is why Caterpillar proposes the maximum of offers to its customer to get back their machines in order to remanufacture it.
To stay on the same strategic idea to get back their materials before they break and to save cost, Caterpillar implemented in 2010 the Cat Product Link system that allows Caterpillar and its customers to follow the location, utilization and condition of the equipment. The use of this new technology improves the relationship between Caterpillar and its customer which also enables the chance of getting back the material before they break (Caterpillar, 2020c; Ellen MacArthur Foundation, 2017b & Caterpillar, 2018).

All the presented elements allowed Caterpillar to participate to the preservation of the environment by different aspects. On one side the expansion of the lifecycle of Caterpillar's products reduce the need for further natural resources extraction. On another side the toxicology of the remanufacturing activity has been greatly improved during the past years. Today it can be argued that a descent amount of harmful chemicals is used during the cleaning process of Cat Reman which is a low price to pay compared to all the advantages and resource savings that it procures.

Another side is that Cat Reman prevents the waste of its materials in the ecosystem by returning the old equipment to its remanufacturing facilities. To emphasis the ecological and financial benefits of the Cat Reman activity Caterpillar compares it to its manufacture plants. Therefore, for the same machine Cat Reman saves on average 85% of energy, 86% of water and 85% of materials compared to the manufacturing facilities.

On the opposite, Cat Reman admits using in average 40% of new elements when assembling machines and equipment. There are still many ways of improvement in this domain, this is why Cat Reman has the objective to reduce the portion of new elements to only 25% of its machines and equipment which would improve the ecological and financial benefits of Caterpillar's CE (Caterpillar, 2018; Ellen MacArthur Foundation, 2017b & Stahel, 1995).

5.5 SWOT Analysis of Caterpillar's CE

The Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of Caterpillar's CE based on the literature used so far will allow to clarify the reasons of Caterpillar's CE implementation and the elements that any company competing in the MEI must consider.

Firstly, Caterpillar's strengths are mostly based on the ability to have a full control of its production process with the consequence and the ability to propose equipment at a discounted price.

Caterpillar is an OEM that manufactures its own engines which is the base for the strong and healthy remanufacturing activity (Cat Reman). This position allows Caterpillar to deal directly with its main customers who are also its suppliers, this unique position in the MEI allowed Caterpillar to be an OEM and a manufacturer. As mentioned before this advantage allows to adapt the design of the equipment to be used for both the manufacture and remanufacture activities. This strength allows Caterpillar to theoretically remanufacture any component which is not the case for conventional remanufacturers. The Cat Reman program of Caterpillar also increases the life cycle of their products which is one of the key factors for Caterpillar's customers to purchase.

Caterpillar's CE proved that remanufacturing activity is the best option for MEI to reduce its costs. Caterpillar is able to propose a machine with the same certification as a new one at half the price, because it has been remanufactured. It proved the power that remanufacturing activities possess to reduce the costs of production in the MEI, mostly due to the high costs to get virgin products. All these elements allowed Caterpillar to increase its market share.

Secondly, Caterpillar's CE weaknesses concern the disadvantages that the remanufacturing facilities generate and the customer perception of the remanufactured products. Remanufacturing activity is a totally different activity than manufacturing, it cannot be implemented in existing

manufacturing facilities. The first reason is that the remanufacturing facilities needs much more space than a manufacturing one for the variety of engines and steps of production and for the storage of the equipment and components. Caterpillar's remanufacturing facilities must dedicate much of their space to the storage of the new and old components, most of the space is taken by the old engines that wait to be remanufactured. Therefore, the space and costs of Caterpillar's remanufacturing facilities are high, particularly because most of the storage place is taken by low value materials such as the old engines and components. Moreover, Caterpillar's remanufacturing activity needs to be close to the customers in order to be efficient, this proximity is a key factor to answer the demand of the customers. However, it implies that remanufacturing facilities have to cover the largest geographic area possible. In other words, the more customers Cat Reman has the more manufacturing facilities have to be opened and operational where the customers are. Each of the new remanufacturing facilities that will be opened suffers from the reluctance among decision makers due to the place, space and storage costs that it creates. Furthermore, Caterpillar's remanufacturing facilities generate wastes during the disassembling and cleaning processes which are difficult to treat. These wastes are sent to specialised waste treatment companies that do not recycle or regenerate these wastes; therefore, they exit the CE system.

Additionally, to the problematic caused by Caterpillar's remanufacturing facilities themselves, Cat Reman faces the reluctance of some customers to believe and purchase remanufactured products. As said Bulley (2019, cited by Ellen MacArthur Foundation, 2017b) "People think it means washed, painted, repaired, second hand and so on. It's a challenge to convince and educate the consumer that they're getting the same performance at 50-60% of the cost of new." Thus, many Cat Reman's potential and/or actual customers are ignorant to the remanufacturing processes and their improvements; this is why they believe that if the price is low the quality of the equipment is necessary lower despite the guarantees.

Thirdly, Caterpillar's CE opportunities are mostly the ability to increase the market share, the global quality improvement of Caterpillar's Catalogue and the research and development of new remanufacturing technics.

Caterpillar's CE strategy may diminish the volume of manufactured machines due to the remanufacturing activity but it is compensated by the ability of the Cat Reman program to propose cheap reparation, replacement and close relationship with the customer which increase Caterpillar's market share.

Another factor to increase the market share is that the remanufacturing activity increases the proximity with the customers and the quality of Caterpillar's products. The goal of Cat Reman is to save costs which is also the objective of Caterpillar's customers when purchasing engines and

machines. By having similar objectives as its customers, Cat Reman works for customer wealth which is to match their needs and increase the quality of the proposed products and services.
Moreover, the use of new technologies and processes within the remanufacturing activities is recent which lets space for many improvements. One of them is that new technics are in development to reduce the portion of virgin elements/components that compose every remanufactured equipment. The other is that researches can create total new concepts of remanufacture which have the potential to open economic opportunities for remanufacturing businesses.

Fourthly, Caterpillar's CE threats concern mostly for the employees and by the determinism of Caterpillar's decision makers.
Concerning the threats for the employees, the work in remanufacturing facilities necessitates many manipulations and manual work with heavy or sharp metallic pieces. Thus, Caterpillars' employees working in the remanufacturing facilities are exposed to many risks which have an influence on their longevity within the company and the attractiveness of such jobs for the new generations. Despite that many young engineers are attracted to work in the remanufacturing activity, it is difficult for Caterpillar to regenerate workforce that is in charge of the manual work. Unfortunately, the manual workers are one of the key factors of the Cat Reman success and progress. It is the skilled manual workers that are able to efficiently remanufacture machines, but even more importantly: it is them who have to choose which components will be kept or not. These employees face visual difficulties to pass through the impression of dealing with dirty old machines and pieces of scraps when it is the moment to choose what to keep or not. A long education is necessary to overcome this difficulty, unfortunately the work aging that faces the MEI constitutes a serious threat for Caterpillar's CE and its ability to progress.
Concerning Caterpillar's decision makers, it appears that the impressive growth of Caterpillar in its strategic sectors is mostly due to the strategy to create a CE model. This strategy allowed Caterpillar to increase its market share, protect its brand, increase the trust of its customers and to save substantial costs. Despite this observation most of the R&D budget is dedicated to the manufacturing facilities rather than the remanufacturing activities of Cat Reman. This decision proves the attractiveness of decision makers to maximise short term profit rather than long term strategy which proves their efficiency to create economic growth.

The following table resumes the SWOT analysis:

Strengths	Weaknesses
➢ It is a Manufacturer (OEM) and a Remanufacturer that allows a global control of the production process ➢ It is the world leader of construction and mining equipment ➢ Its suppliers are also its customers (it is a strength only because of the previous points) ➢ Has a strong relationship with its customers ➢ Is able to restore any components of its equipment ➢ Proposes machines at half the price for the same quality ➢ Remanufacturing saves resources and energy (sustainability) ➢ Remanufacturing is less toxic than manufacturing	➢ The remanufacturing plants take much more space than the manufacturing plants ➢ The remanufacturing plants have to be close to the customers ➢ The storage of old engines demands a high investment to store low value products that wait to be remanufactured ➢ The remanufacturing plants waste (from old engines during disassembling and cleaning) are hardly treatable ➢ Despite the certification, most of the customers think that remanufactured products are more fragile
Opportunities	**Threats**
➢ Increase the market share ➢ Increase the quality of the products to match the customer's needs ➢ Research in remanufacturing technics can reduce the need of virgin products in any remanufactured equipment to save even more costs ➢ Research in remanufacturing can open new economic feasibility in remanufacturing	➢ Work in remanufacturing plants involves physical work that exposes the skilled workers to accidents ➢ Visual difficulties for employees to pass through impression of dealing with dirty old machines and pieces of scraps ➢ Predominant management philosophy for growth that still prioritises and optimises the manufacturing activity which limits the remanufacturing full potential

5.6 Assumptions

The goal of this section is to make the first assumptions concerning the thesis variables and hypotheses based on the findings of this document analysis.

The document analysis focused on Caterpillar showed that a CE implementation in the MEI is primarily articulated around a remanufacturing strategy. The implementation of CE within the Caterpillar demonstrates an ability to generate substantial cost savings particularly on material costs which gives a high ROI to the CE model. Similar results are observed concerning the ability to save energy and other resources which generates a high EROI for the CE model of Caterpillar based on remanufacturing activity. Therefore, regarding the Caterpillar context it is possible to assume that CE technics and C2C are more cost efficient than conventional methods which correspond to the three first secondary research questions. These first findings will have to be tested in the next section based on primary data in order to validate these assumptions of the whole MEI or not.

The document analysis also showed that Caterpillar used some CE technics for a long time, since 1972 when they were forced to do remanufacturing activities. Caterpillar made and continued its remanufacturing technics because it was profitable, so it became over time one of their core activities. As presented in the document analysis the culture of Caterpillar's decision makers is to maximise short term profit, this is why they do not invest in CE and remanufacturing activities despite being the principal reason of Caterpillar's success in the past years. Based on this observations Caterpillar might not have switched to a CE model if they were not already applying the CE strategies. Regarding the advantageous position and results of Caterpillar toward remanufacturing activity it is quite surprising that Caterpillar's decision-makers are still reluctant to the CE and sustainable questions. Based on this observation it is likely that the other businesses competing in the MEI also face this situation of unwillingness to move or change of their decision-makers. The next section of the thesis will help to confirm or not this observation.

The document analysis of Caterpillar also showed that many of the Cat Reman's customers are reluctant or have doubts concerning the quality of the remanufactured products despite the quality guaranteed. It will be interesting to see with the next analysis if other sectors of the MEI also face this reluctance or if their communication or services changed the mindset of their customers towards remanufactured and repaired machines and equipment.

Concerning the variables of better regulation, financial support and institutional support, the document analysis could not show an important need for any of them. This can be explained for two main reasons: Firstly, Caterpillar already implemented a remanufacturing strategy and CE technics in the past, thus, it did not need external help to make this change possible which might not be the case of other businesses competing in the MEI. Secondly, Caterpillar is not under the regulation of the EU but of the US which are quite different. The next section focused on Austrian businesses will certainly be able to bring more information concerning theses variables.

The document analysis of Caterpillar also puts into light that another key factor has to be considered by this thesis to accurately answer the research question which asks: Why would the MEI within the European Union switch to a CE regarding biophysical, economic, cultural and environmental limits? This important factor exposed by the document analysis of Caterpillar consists in the positioning of the MEI businesses towards their providers/suppliers.

The providers of MEI businesses are mostly involved in the steel industry, this industry could be threatened by the remanufacturing activities of their customers (the MEI). Remanufacturing is indeed reducing the demand in virgin materials and components that the steel industry provides to the MEI. In other words, the steel industry businesses and/or OEM do not have incentives to design components that would allow their customers to remanufacture their production. On the other side MEI businesses need a good control over their suppliers in order to have the desired designs to implement remanufacturing activities and to complete the circularity of their production. On one side, the MEI businesses that manufacture engines and have OEM activities can design their own component to apply a remanufacturing activity. On the other side, the business that produce few of their components need a good control over their providers in order to design their components as they desire which allows remanufacturing activity. Having few numbers of providers and being important for them is also a solution to control the quality and the design of components for the MEI businesses.

In order to consider this important aspect in this research a new secondary research question with its hypotheses has to be added and implemented in the conceptual framework as in the mathematical model. Therefore, the new secondary research question, RQ8 is: Does the company have a good control over its providers or is it an OEM in order to get the desired quality and design for its components?

The hypotheses of this new secondary research question are the following:

H15: The position and activity of the company allows a good control over the providers to have the desired quality and design.

H16: The position and activity of the company does not allow a sufficient control over the providers to implement remanufacturing activity or similar in the production process.

This document analysis showed that MEI businesses do not have to fulfil positively all the research question criteria or variables in order to implement the CE, however a certain number of these criteria have to be fulfilled to make the transition happening. The next part of this thesis is dedicated on expert interviews. The goal of the expert interviews is to determine which variables exposed by research questions are the most present and determinant for the transition of MEI businesses to CE.

6 The case studies

6.1 Presentation of the interviewees' companies

6.1.1 Engel Austria GmbH

Engel Austria GmbH (in the following: Engel) is a plastic injection moulding machines manufacturer founded in 1945 by Ludwig Engel. Today Engel is the world market leader of the manufacture of plastic injection machines with its production sites located in Austria (headquarter), Czech Republic, Germany, Korea, USA and most recently in China and in Shanghai. The European facilities of production are complementary and located around Engel's headquarter in Schwertberg (close to Linz) to facilitate the transport and connections (Engel, 2016).

Engel's machines have different purposes depending of the customer. For instance, Engel's plastic injection machines can create automotive components for the automobile industry, they create caps and closures for the packaging industry or they also create components for medical purposes. Engel's machines look as on the Figure 29:

Figure 29: Injection molding machine: e-cap (Source: Engel, 2020)

Regarding Engel's activity it is clear that Engel competes in the MEI and belongs to the NACE group C28.9: Manufacture of other special-purpose machinery and more especially to the subgroup C28.9.6: Manufacture of plastics and rubber machinery (Europa, 2020).

The first interview was made with the Vice President of the department Global Quality and Environment of Engel, Martin Weger. Due to his position he could also share his expertise concerning Engel's circular model.

The circular model of Engel is divided in two parts respectively inspired from the era of R and D of the EMF's CE. Engel builds its success on its ability to propose to its customers machines that are able to save large quantity of plastics during the production process and more importantly allows Engel's purchasers to reuse and recycle plastics.

By investing in R&D Engel is able to propose the best offer on the market that allows plastic recovery at the lowest cost. Recycling, reusing or recovering plastic usually involves important amounts of additional virgin material and energy to be feasible. By its innovation Engel can offer machines that reduce matter and energy that have to be involved in recycling processes. According to Engel (2019), by its action within the era of D of the EMF's CE, Engel signed in 2019 the global commitment for the "New Plastics Economy" of the EMF. This commitment involves more than 350 actors such as companies, universities, NGO's and so on to create a global treatment of plastics in every stage of economy in order to avoid plastics becoming wastes (Engel, 2019; Weger, 2020).

On the other side of the EMF'CE model, the era of R is also developed in Engel despite still being in an early stage. Engel has a policy to prolong at the maximum its product life by involving the most robust materials as possible in their machines. In addition to propose the best quality as possible, Engel disassembles, remanufactures and refurbishes parts and components of its machines. The proportion of material that Engel can remanufacture is still minor but Engel makes improvements to increase its catalogue of components that can be remanufactured. To fit with this strategy Engel also proposes a payback system and different services to their customers to organise the return of machines and components and/or the maintenance of their machines and components (Engel, 2019; Weger, 2020).

By applying all of those strategies, Engel could build its circular model that the Figure 30 represents:

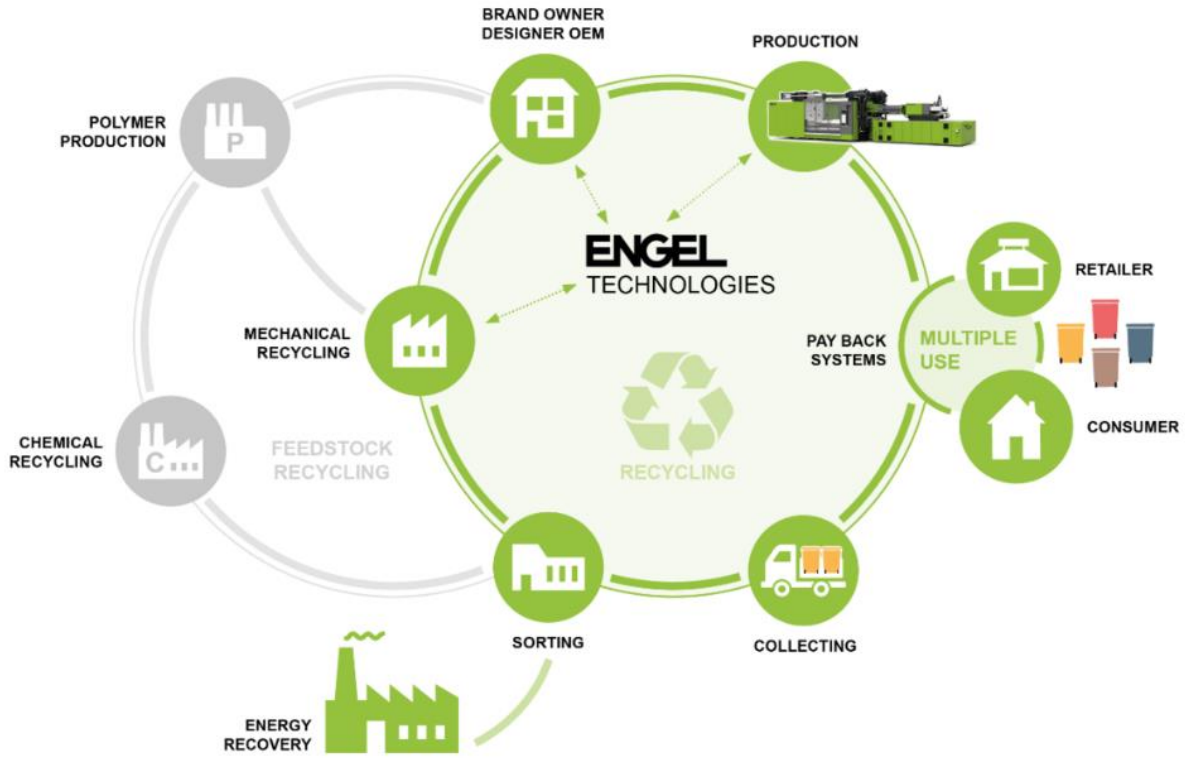


Figure 30: Showing our colours – closing material cycles (Source: Engel, 2019)

As we can see on the Figure 30, Engel's machines are delivered to retailers to be used multiple times. Then, the damaged components or wastes are collected and transported to the adapted actors. The damaged components that Engel refurbishes or remanufactures are sent back to Engel's facilities and the other components to metal recycler and/or OEM businesses that work with Engel. The material that cannot be directly recycled is sent to external recyclers depending of their nature to produce energy, polymer, new metal or to be detoxified.

6.1.2 Pöttinger Landtechnik GmbH

Pöttinger Landtechnik GmbH (in the following: Pöttinger) is a manufacturer of agricultural equipment founded in 1871. Pöttinger is a 150 years old Austrian familial company which is present worldwide such as in Europe (Austria, Belgium, Germany, France, Italy, Denmark, Ireland, Switzerland), Australia, Canada, China and Russia. Pöttinger employs 1.900 persons in total, mostly in Pöttinger's center of production located in Austria which counts 1000 employees, in Czech Republic with 500 employees and in Germany with 200 employees. The rest is dispatched in worldwide offices in the countries previously mentioned. Most of Pöttinger's sales are made in Europe (88%) to reach € 380 million turnover in 2019 (Pöttinger, 2020a; Lechner, 2020).

Pöttinger is a specialist of equipment adapted for treating grassland, for tillage activities and seed drilling. Therefore, Pöttinger's equipment takes many different forms to answer the farmer's needs, the Figure 31 helps to visualise this diversity:

Figure 31: Grassland, Tillage (Source: Pöttinger, 2020b)

Regarding Pöttinger's activity it is clear that it competes within the MEI and belongs to the NACE group C28.3: Manufacture of agricultural and forestry machinery (Europa, 2020).

The second interview for this thesis was made with the Chief Operational Officer of Pöttinger, Jörg Lechner. Due to his position he could share his expertise concerning Pöttinger's activity with its circular actions and its vision of sustainability.

First of all, Pöttinger's equipment is designed to preserve the earth fertility in order to reduce at the maximum the need of pesticides and chemicals. All the equipment is designed to consume the less energy as possible and allows a maximum regeneration of the soil which permits the farmers to save costs and preserves the quality of their lands. Thus, Pöttinger competes in a niche of the market which involves farmers with environmental awareness and/or specialised in the biologic & organic production. It is the participation of Pöttinger to the era of D of the EMF's CE, by developing equipment with a long life allowing organic and biologic agriculture.

Secondly, Pöttinger does not have a real era of R strategy, which means that they do not reuse, recycle of remanufacture the components of their machines; apart from refurbishing the damaged components supported by an efficient maintenance service and of a spare parts supply. Despite the few solutions within the era of R and D in Pöttinger's production process and its matter, Pöttinger developed a real circularity to save the maximum of energy during its production process. In order to build their equipment, the production facility needs high temperature to melt and assemble the machines, this heat circulates in all the production facility in a complex pipe network. After the first uses at high temperature for building equipment, the temperature decreases around 100°C and it is used in another part of the production facility for cleaning the components. Then, after this operation, the temperature decreased further to 50°C and it is used to heat the production facility itself. In complement to this saving system of energy, Pöttinger cooperates with the municipality to deliver the extra energy that Pöttinger generates all over the year except in winter to the city. This smart and circular model of energy use saved sufficient amount of energy to have a ROI after only five years. This system is a good example of EI (Ecological Industry) mentioned in the theoretical section, little energy is lost and all the actors participating to this system benefit from it. The policy of Pöttinger is to apply circular and sustainable systems such as this one as far as the ROI can be reached within eight years (Pöttinger, 2020a; Lechner, 2020).

6.1.3 Wittmann Group

The Wittmann Group (in the following: Wittmann) is an Austrian manufacturer of robots, peripheral equipment and injection moulding machines for the plastics processing industry. Wittman was founded in 1976, at that time the company produced water flow regulators. From 1998 Wittman acquired European, Canadian and American companies to focus itself on the plastic market. Wittman could then produce robots, granulators, handing systems and cooling systems for the plastic industry. On April 1st, 2008 Wittman did its most important acquisition by taking over Battenfeld Kunststoffmaschinen Ges.m.b.H which was specialised in the injection moulding technologies and produced injection moulding machines. From that date the Wittman-group is able to supply the plastic industry with all the necessary equipment that they need in their production process (Wittman Group, 2019; Geyer, 2020; Wittmann, 2019).

The Wittmann Group is now a worldwide company with its headquarter located in Vienna. The company is present in 34 countries and possesses 8 production facilities, respectively located in Austria, Hungary, France, USA and China (Wittmann, 2019; Geyer, 2020).

Wittmann's machines and equipment according to Wittmann (2019) “include robots and automation systems, automatic material handling with dryers and plastics recycling, temperature controllers and chillers for machine tools and volumetric and gravimetric blenders.” All of these machines and equipment are specifically designed to meet the needs of the plastic industry to create tools and components in plastic. Therefore, Wittmann proposes a very large variety of machines and equipment like the following main categories which give an idea of the Wittmann catalogue and activity extracted from Wittmann (2019):

The Figure 32 shows one of the injection moulding machines adapted for every size of plastic components:

Figure 32: Smart Power (Source: Wittmann, 2019)

The Figure 33 shows a robotic bra to form, prepare and cut plastic:

Figure 33: Robot Technology (Source: Wittmann, 2019)

The Figure 34 shows some automation machines typically used to insert and remove elements, it is mostly used in complement to the injection moulding process:

Figure 34: Automation (Source: Wittmann, 2019)

Last but not least, the Figure 35 shows some of the flow and temperature control machines and equipment that Wittmann propose:

Figure 35: Flow Control and Temperature Control (Source: Wittmann, 2019)

Regarding Wittmann's activity it is clear that Wittmann competes in the MEI and belongs to the NACE group C28.9: Manufacture of other special-purpose machinery and more especially to the subgroup C28.9.6: Manufacture of plastics and rubber machinery. Wittmann also competes within the NACE group C28.2: Manufacture of other general-purpose machinery and more especially in the subgroups C28.2.5: Manufacture of non-domestic cooling and ventilation equipment and C28.2.9: Manufacture of other general-purpose machinery n.e.c. (Europa, 2020).

The third interview for this thesis was made with the Production Director Material Handling of Wittmann Kunststoffgeräte GmbH, Markus Geyer. Due to his position he could share his expertise concerning Wittmann's activity and production process, as well as Wittmann's vision of circularity and sustainability.

In a general point of view Wittmann does not have any circularity policy and behaves in accordance to mainstream businesses. Wittmann's actions are driven by customer's demand. Wittmann built its success on the vision to cover all the needs of the plastic industry which means to be as close as possible to its customers. Therefore, Wittmann's customers have the power to influence the production process of Wittmann for more circularity, but the lack of environmental awareness of Wittmann's customers inhibit this possibility so far.

Moreover, regarding the size and the influence of Wittmann, the company considers itself as too big to change its production process or innovate in circularity. In other words, Wittmann considers the necessary investment too high, so high that the ROI is even not considered by Wittmann's decision makers.

Despite its lack of circularity, Wittmann proposes some services that are in accordance with CE. Firstly, Wittmann wants to prolong the product life of its offers due to the fact that it is a main point for Wittmann's customers to purchase or not.

Secondly, for the same reason as the previous point, Wittmann's machines and equipment are designed to reduce the amount of energy and matter that the customers have to involve in their production process. The reduction of the costs is a focus for Wittmann and its R&D strategy.

Thirdly, Wittmann proposes components for their injection moulding machines that allow to recycle a portion of the plastics used during the precedent production. This vision is in line with the eco-efficiency explained in the theoretical framework.

Last but not least Wittmann provides a special service to its customers: In addition to the advice provided to its customers to prolong the product life, Wittmann proposes a variety of training seminars to its customers' employees in its production facilities or the customers production site. The goal of such seminars is to train the maximum of people on the good use of the injection moulding machines, the robots and automate processes. By increasing the knowledge about its machines and equipment, Wittmann increases the life expectancy of their products and optimises the capacity of its products to save energy and matter (Geyer, 2020; Wittmann, 2019).

6.1.4 The coding table

The coding scheme of the three expert interviews that supports the case study analysis of Engel, Pöttinger and Wittmann is resumed in a coding table. The Table 9 and 10 apply the thematic content analysis as described in the methodology. The coding table represented under the Table 9 for the first part and the Table 10 for the second part is composed in three different categories, the themes, the time scale and the interviewees.

The themes are the rows of the coding table (Table 9 and 10), as expressed in the methodology, the themes are either the hypotheses of the thesis themselves or the prompts and topics mentioned during the interviews that fall under each hypothesis.

The time scale is shown in the columns of the coding table (Table 9 and 10), it represents the time line of the interviews. Each interview did not run longer than 50 minutes, therefore, in order to be easier to read, each columns of time scale of the coding table (Table 9 and 10) represent two minutes of each interview. For instance, the second column with the number two represent the time scale 0 to 2 minutes of each interview (the introduction), the next column with the number four represents any themes that have been mentioned between the second minute and the fourth minute of each interview and so on until the end of each interview.

The interviewees are represented in the coding table (Table 9 and 10) by numbers with a different colour in order to differentiate them more easily. The number **1** has a blue colour in the coding table (Table 9 and 10) and represents the first interview conducted with Martin Weger from Engel Austria GmbH, this interview lasted forty minutes. The number **2** has a green colour in the coding table (Table 9 and 10) and represents the second interview conducted with Jörg Lechner from Pöttinger Landtechnik GmbH, this interview lasted fifty minutes. The number **3** has an orange colour in the coding table (Table 9 and 10) and represents the third interview conducted with Markus Geyer form the Wittmann Group, this interview lasted forty-nine minutes.

Themes/Time scale (min)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
H1: The EROI of circular methods is as high or higher than the classic processes								3	3		1 2	2	2												
Good at saving energy								3	3	2 3	2	2	2 3												
Good at saving mattter								3	3	3	1		3												
H2: Implementation of circular methods has a low EROI or decrease the EROI of MEI businesses																									
Lacking of performance of some circular methods							3	3				2	2												
Do not save enought energy																									
Do not save enought mattter																									
H3a: Implementation of era of R strategies are profitable for MEI									1		2	1													
Prolong product life		2				2		2	1			1 3	3	3	2	2	3								
Reusing									1	1	2	2													
Maintenance service											1	1			2	2	3	3							
Product back policy										1				2											
Recommendation and teaching of the good use of material												1						3	3	3					
Renting solution or banking to get meterial back												1													
H3b: Implementation of era of D strategies are profitable for MEI			2	2	2				1	1															
Repairing										1															
Remanufacturing									1																
Refurbushing									1	1	2														
Dissasembling										1															
Receycling			2		2				2 3	3			3	3											
Detoxifying			2		2				2																
H4: Implementation of era of R and D strategies are not profitable or not enough for the MEI																									
Does not use era of R							2																		
H5: The ROI of the C2C design implementation is beneficial for the MEI's businesses											1							1							
Adapted design efficient											1														
R&D investmment profitable																									
H6: The ROI of the C2C design implementation is negative or high enough for the MEI's businesses																									
C2C design have a low ROI																									
H7: As long as the new model is profitable business are willing to change		3		3		1												2							
Employee involved in the circular culture																									
CE drive business sucess							1																		
H8: MEI's business are not used to these new processes and prefer to continue the business as usual		3	3	3		3	1								3	3			2						
The business mentality		3	3	3			1	1							3			2	2						
Lack of understanding of what the CE is doing					3	3	3								3										
Employee do not believe and understand circularity							1																		
Afraid of the concurrence																		2	2						
Unwillingness to change something that "work"				3		3	1								3			2	2						
The change of strategy represent a too high cost due to the size of the company																3						3			

Table 9: Coding of the expert interviews, part 1 (Source: Danjou, 2020d)

Themes/Time scale (min)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
H9: As long as the price is low enough and the performance guarantee the customers are willing to pay		1	1																						
Demand of the customers for more circularity		1 3	1 2 3		2			3	3		1														
Willingness to purchase		1	1	2	2				2		1														
Circularity awarness is improving			1	2	2	2		3	3											2					
H10: Customers emit doubts about the certifications and do not believe that the product can have a similar quality as a virgin product, therefore they do not purchase.																									
No customer interest of custormer in circularity or sustainability			1 3	2 3	2 3	2		3	3								2			2			2		
Less than half of customers have environmental awarness		1	1	2																2					
Mistrust within remanufactured products																									
H11: Financial or better regulations constitute a key factor for MEI's businesses to switch in a CE model													1								2 3	2 3		2	
EU's regulation limits the possibilities for more circularity													1							2	2 3	3	2		
Need of financial suppport for transition																						3		2	
H12: Adapted regulation or financial support are not determinant for the MEI in the EU to switch in a CE model																									
Financial support are often unadapted																					3	3		2	
H13: An institution bringing knowledge and advise to MEI's businesses is essential for the MEI to switch in a CE model													1									2 3	2		
Better knowledge would help													1									2 3	2		
Ingnorance of CE is a key problem																							2		
H14: An external institution is not necessary for the MEI's business to switch in a CE model																									
The market and customer influence how companies make business,not the institutions																						3			
Mistrust in external institutions																							2	2	
H15: The position and activity of the company allows a good control over the providers to have the desired quality and design.																		1	1				3	3	
The company has a good control over its providers, OEM businesses																		1					3		
Coohoperate with other designers																		1	1						
The company is somewhat an OEM																		1							
H16: The position and activity of the company does not allow a sufficient control over the providers to implement remanufacturing activity or similar in the production process.														2	2	2									
The company does not have control over its providers, OEM businesses														2	2	2									
The company not doing OEM activity								2						2	2	2							3		

Table 10: Coding of the expert interviews, part 2 (Source: Danjou, 2020d)

Therefore, each time that a theme (row) has been mentioned and confirmed by an interviewee (number), the number of the interviewee is attributed in the time scale (column). It happened that an interviewee confirmed a theme in the same time scale as another interviewee did which was predictable regarding the fact that each interview was based on the same interview guideline. When it happens the cell will have each number included which gives a bigger cell than the others, for instance in the time scale six with the theme "demand of the customer for more circularity" which

falls under the topic of the nineth hypothesis “As long as the price is low enough and the performance guarantee the customers are willing to pay”, the three interviewees confirmed this theme in the same time which gives a large cell within the coding table including “123”.

6.1.5 Analysis of the interviews, RQ1

Whereas this research and the interview guideline are driven by answering the research questions, this section has the objective to test the hypotheses, this is why this section focusses on the answers that the interviewees gave concerning each hypothesis. In other words, this section is guided by the rows of the coding table previously presented.

The first research question asks (RQ1) if the use of circular technologies and methods in the MEI generates a sufficient EROI. Its related hypotheses want to know if (H1) the EROI of circular methods is as high as or higher than the classic processes or if (H2) the implementation of circular methods has a low EROI or decreases the EROI of MEI businesses.
The interviewees have unanimously confirmed in many occasions that CE technics and methods are able to save matter and energy and are also worth of the investment. As shown in the coding table Mr. Geyer (3) was the earliest at confirming that CE methods save matter and energy. Geyer (2020) insisted on the fact that energy and matter saving of the machines are important reasons for Wittmann’s customers to purchase. He stated that “energy and material saving take an important place during the development of our machines” (Geyer, 2020). At this moment of the interview, between the 15th and the 20th minute, he explained the importance of saving costs for Wittmann’s customers and that the design of its machines was made for this purpose. He also said that certain components were made to collect and recycle plastics (Geyer, 2020).

Mr. Lechner (2) also mentioned it but insisted particularly on the ability of CE methods to save energy. Lechner (2020) described in detail how the energy saving system of Pöttinger’s facility works. Inspired from the ecological industry a system of pipelines in the whole facility distributes the energy from different purposes. After the most consuming operation in energy of the facility such as melting metal pieces, the remaining energy is transferred for another operation in the facility, then the remaining energy is used to heat the facility itself. With such methods Pöttinger can save energy cost with a very interesting EROI.

Mr. Weger (1) also confirmed that CE methods have a satisfying EROI for saving energy and more particularly matter. Weger (2020) explained that the biggest saving for Engel occurs on matter saving. By applying diverse technics, the EROI was very high for their production process.

To summarise the findings concerning the first hypothesis, Engel uses CE technics to generate an important matter saving during its production process. In the same time its machines are designed to allow its customers to also save energy and matter when using Engel's machines. Pöttinger uses CE methods and technics to save energy in its facilities, but regarding the machines, Pöttinger does not propose energetic and matter saving solutions for its machines. The products participate to the circularity in agriculture in other ways. Then, Wittmann uses CE technics to allow the maximum of energy and matter saving for its customers, however Wittmann does not use such technics to produce its machines.

On the other hand, Lechner (2020) and Geyer (2020) mentioned a theme inherent to the second hypothesis which puts limits on the ability of CE technics to generate sufficient EROI but without saying that CE technics do not generate sufficient EROI in general. Both of them mentioned the fact that some CE technics that their own company studied were lacking in term of performance. In other words, they could not generate an EROI high enough. On this direction Lechner (2020) states "the policy of Pöttinger is to consider and implement such technics only if in less than 8 years the ROI is reached, higher than 8 years Pöttinger does not consider that it is worth to invest". Therefore, some of the approaches that Pöttinger studied to improve its circularity were not worth the investment. It is also interesting to notice a time limit that Pöttinger chose for the ROI of its circularity projects. It is likely that every company would choose different time limits for circularity projects to be worth of investment. Unfortunately, Mr. Geyer (3) did not communicate such policy within Wittmann. Further research is necessary to determine the average time limits to reach a profitable EROI in the MEI.

6.1.6 Analysis of the interviews, RQ2

The second research question asks (RQ2): Does the investment in circular methods such as the era of R and D generate enough profit and cost saving to be profitable for MEI? Its related hypotheses want to know if (H3) the implementation of the era of R and D strategies are profitable for MEI or if (H4) the implementation of the era of R and D strategies are not or not enough profitable for the MEI.

Regarding the density of information that composes this research question the coding table divided this research question in two parts, one dedicated to the era of R and the other to the era of D of

the CE. An additional reason is that the Austrian companies chosen as case studies have each a different focus and strategies. Therefore, some would more likely implement era of R strategies than era of D strategies or vice-versa.

As we can see in the coding table the earliest in the interview who discussed the era of R and D strategies was Mr. Lechner (2). He explained that the strategy of prolonging the product life is a priority for Pöttinger regarding the expectations of their customers. This is why they build the most robust equipment possible using the best quality they can afford. Then, he explained and confirmed that Pöttinger applies era of D strategies by the special proprieties that their equipment proposes to their customers. Lechner (2020) states that "our blades and tires are specially designed to preserve the quality of the soil […], the idea is to limit the need of chemicals […], for example, our tillage equipment has a form that keeps the regenerative ability of the soil […]. The weight of our machines and their tires also preserve the soil quality." Pöttinger plays in a niche of the agricultural market that counts on the environmental awareness of farmers who want to limit their use of chemicals. By applying such design in their machines, Pöttinger helps indirectly with detoxifying the soils and regenerating them. The strategy of Pöttinger is to propose equipment that regenerates the soil, helps to reuse biomass and preserve it; these are era of D strategies. Pöttinger proves that focusing on era of D strategies is a feasible corporation strategy and it is profitable either for the environment and the viability of the group. Lechner (2020) also states that "our customer can keep the quality and fertility of their land longer; it is our vision of sustainability […]. We communicate a lot on the benefit of such methods because it is a big sale argument from us". With those words, Mr. Lechner (2) emphasises the importance of the era of D technics in the group strategy.

Later in the interview Mr. Lechner (2) talked again about the product life strategy of Pöttinger which is important for Pöttinger to stay competitive, he also mentioned the maintenance service and the repairing service that Pöttinger provides. They propose a refurbishing of the damaged components in order to keep the satisfaction of their customers as high as possible. Unfortunately, this maintenance and repairing service passes by tier companies and dealers, not by Pöttinger itself which limits the efficiency and circularity of this service. In other words, so far, the era of R strategies do not seem to be particularly used by Pöttinger. But it was without counting a reusing system of their powder used during the painting of their machines: Lechner (2020) states that "during our cataphoretic coating, our new system allows us to use 98% of the powder, with that we almost don't have any waste that can affect the environment." Usual and large cataphoresis facilities which use their processes have normally to deal with very high waste costs due to the large loss of matter during the process. According to FAI (2018) "Cataphoresis is an organic

coating method that uses electrical current to deposit paint onto a part or assembled product." Pöttinger created its own cataphoric local which is able to save most of the powder involved during the process. This case showed that despite that the era of R strategies are not the priority of Pöttinger, they implemented such methods simply because it was profitable.

Mr. Weger (1) from Engel also mentioned many of the era R and D strategies that Engel uses. He explained that the primary concern of Engel was to create machines that are able to save the maximum of plastics during the injection moulding process in order to reuse and recycle the plastics which is a demand of their customers. Weger (2020) states "our customers and suppliers push us more and more in this direction, and that is an indirect economic value because if they tell you I will not buy from you if you do not do anything else in this field it does not generate money but you could lose a lot of money, that is how circularity in our topics are right now working in our industry." Therefore, Engel proposes in a first step to its customers machines that are in phase with the circular principles to follow a growing demand. Pushed by the success on being focussed on circular service that their machines procure, Engel also started to apply circular technics for the conception and production of its machines which are more inherent to the era of D of the CE.
By following the interview guideline and reaching the fourth section asking for the production processes and strategies that Engel uses, Weger (2020) states "What we are doing is remanufacture, we have a quiet big business in retrofitting our machines and upgrading our machines, prolonging the life time of the machines […]. We have quite a big service and organisation that remanufacture the machines and upgrade the machines […]. We are not doing reuse for all the parts, for the whole machines but we are doing it for certain specific parts. Some parts of the machine, like mechanical components, the electric components that outdate after some years like a processor […], we disassemble motors and it returns to our suppliers to check if it is good as new, if yes we use it again." Therefore, most of the potential CE technics of production are today applied by Engel, which are primary oriented on remanufacturing strategies as we could have seen with Caterpillar in the document analysis. However, Engel cannot control by itself the entire remanufacturing process. Weger (2020) admits "some components like motors and dryers we do not produce it ourselves, we are not technical experts for that. So, for that we return it to our supplier and they check it for us, the other components like the mechanical components, like steel components we do remanufacture those ourselves, so for those components we do not need a supplier to bring them back in our machines. We check it ourselves and put them back in our machines to be good as new or we refurbish them to make it good as new." Despite not being able to have a full control over the remanufacturing processes, Engel was able to implement what looks like to be the most interesting CE technics for the MEI. Weger (2020) confirms the benefits of

such strategies: “Actually it is about cost efficiency; if you use a more once again you do not have to buy a new one which are very expensive […], also for the steel components if I do not have to produce a new tile bar and stuff like that actually we save money, that’s why we do that actually. It is also about customer satisfaction, because if you prolong the machine’s life time, if you can update machines and they do not have to buy a new machine, that is a reason why they buy from Engel, it is about customer satisfaction as well.” Here Mr. Weger (1) confirms the third hypothesis (H3) concerning the advantages of CE strategies for the MEI but also contradict the findings that have been found in the document analysis of Caterpillar. Caterpillar was facing difficulties to convince its customers of advantages for them to get remanufactured machines due to the fact that they assimilated it at a lower quality. In the case of Engel, prolonging the life product seems to be an absolute priority for the customers which welcomes the services and advantages that provides the remanufacture of components.

Mr. Geyer (3) also mentioned some of the CE technics inherent to the era of R and D despite not having a remanufacturing policy. Firstly, Mr. Geyer (3) insisted on the importance for Wittmann to propose machines with a long-life expectancy. Geyer (2020) states “The durability and the robustness of our machines is our priority because it is the priority of our customers. Our customers want to use their machines as long as possible […]. The basic to make our machines run longer is to build them as robust as possible, for that we use components of good quality and use the best melting technics for them, this is why our customer buys from us.” Mr. Geyer (3) confirms the statements of Mr. Lechner (2) and Mr. Weger (1) that the robustness and the ability of a long-life duration of the machines is a priority for the customers of the MEI or at least in the markets where the three case studies compete. Therefore, all the strategies that can extend the product life are at least studied by the case studies and CE technics are among them.

Proposing robust products is inherent to the era of R strategy and Wittmann applies it. Wittmann also proposes another era of R technic, the maintenance service. Geyer (2020) confirms “Yes, we do have a maintenance service, the intervention is managed by our partners. If a customer has a motor problem our maintenance service will contact our partner specialised for that.” Therefore, Wittmann does not manage by itself a maintenance service directly with its customers, mostly because most of the components of their machines come from partners of the steel industry and OEM.

However, Wittmann proposes an era of R strategy which helps at prolonging their products life, they frequently propose trainings to their customer on the good use of their machines. Geyer (2020) says “We are quite proud in Wittmann to propose seminars about the best utilisations of our machines […]. Our training service became quite a big service and our customer likes it, we

explain how our machines work, we give advises to make them run longer, the product that should be used, how to clean the machines and so on […]. For me the training service is complementary of my department, it is like supporting and showing the good quality of our machines to our customers […] and it also makes a kind of special relationship with our customer, they come to us to learn or we move to them to teach them." These seminars proposed by Wittmann contribute to extending the life expectancy of the machines in many ways. If the users care about the machine it is likely that it will run longer, if a customer understands the importance to clean and check frequently a machine, the machine will run longer. As said Mr. Geyer (3) this service supports the products and rises the trust between Wittmann and its customers. Therefore, these era of R technics bring different advantages to Wittmann. The training service also helps Wittmann to differentiate itself from its concurrent in addition to extend the life expectancy of its machines.

Concerning the era of D technics, Wittmann does not use any for the production of its machines, therefore no remanufacturing policy, reusing or refurbishing. However, they propose recycling solutions to their customers. Geyer (2020) states that "we developed for our customers new technics and components that make it possible to reuse plastic elements […] like after an injection some plastics go outside of the mould, usually this plastics were lost but we made special granulators that grind the plastics, make it in small pieces, and then the regrind matter can be reused in the machine for another injection." Therefore, influenced by its customer's needs Wittmann developed a variety of components to recycle plastics for their injection moulding machines. By proposing recycling technics, Wittmann allows its customers to have more cost-efficient machines and rises its customer satisfaction.

Based on the findings concerning the second hypothesis, none of the interviewees denies the benefits of the CE technics and the fourth hypothesis (H4). All of the companies implemented era of R and D technics either in their production process or regarding the service provided to their customer, also if some do not have the official objective to build a CE business. The case studies implemented CE technics because they are cost efficient in the MEI and their customers asked for such services. For instance, Wittmann and Engel allow recycling and prolonging the life of their product by different methods and Pöttinger participates to preserve the soil quality of its customers. It is interesting to notice that so far in the interview analysis, the main driver for implementing era of R and D methods mentioned by the interviewees is by far the customers. In other words, the demand guides the actions of the companies.

6.1.7 Analysis of the interviews, RQ3

The third research question asks (RQ3) "Does the implementation of C2C design in the MEI processes have an ROI high enough for the MEI? Its related hypotheses want to know if (H5) the ROI of the C2C design implementation is beneficial for the MEI businesses or if (H6) the ROI of the C2C design implementation is negative or not high enough for the MEI businesses.
Regarding that Pöttinger and Wittmann do not implement circular technics in their production process Mr. Lechner (2) and Mr. Geyer (3) were not aware and did not mention the C2C.
On the other side Mr. Weger (1) confirmed the utilisation of the C2C principles in Engel, "Yes, we know and apply C2C" (Weger, 2020). After this confirmation Mr. Weger (1) explains later on in the interview how and on which kind of components they apply C2C principles. Weger (2020) explains that "we design and produce a lot of our components, we do a lot, steel manufacturing, steel metal, steel bridging, turning milling […], so everything that has to do with steel, we do that." In other words, Engel applies C2C design when they manufacture steel components which represent the largest proportion of components within an injection moulding machine.
For the other kind of material that Engel does not manufacture itself such as electronic components, Engel uses suppliers. Thus, Engel might not be able to apply C2C design to products that come from tiers companies. Surprisingly Weger (2020) states that "for our suppliers we are in design cooperation, we do cooperation design, we do it together […], we can dictate quite well the quality and design." Thus, Engel seems to be able to apply a coherent C2C design in these machines despite not having a direct control over the production of all the components. Mr. Weger (1) also confirmed that applying the C2C design to heir components made the performant remanufacturing policy of Engel possible. This case study confirms the findings of the documented analysis focussed on Caterpillar about the importance of design such as C2C for remanufacturing activities.

The Engel case study agrees on the hypothesis five (H5) which confirms that C2C is beneficial for MEI businesses. Unfortunately, the fact that only one case study could talk about the C2C might not be sufficient to officially confirm the hypothesis five or six (H5, H6). Further research is needed to confirm one of these hypotheses. It would be interesting to focus particularly on companies that apply a remanufacturing activity to determine whether they use the C2C. As explained in the methodology, the context of this research did not allow the interview of other companies which could have helped to answer this research question more substantiated (RQ3).

6.1.8 Analysis of the interviews, RQ4

The fourth research question asks (RQ4) “Are the MEI’s decision-makers afraid to change their production model due to cultural habits?” Its related hypotheses want to know if (H7) as long as the new model is profitable, businesses are willing to change, or if (H8) MEI businesses are not used to these new processes and prefer to continue the business as usual.

As shown in the coding table, Mr. Geyer (3) was the first to mention the current state of circular culture during his interview. Geyer (2020) states in the beginning of the interview that “I think we look at these solutions and we do it when they generate money, sufficient money.” Mr. Geyer (3) mentions a similar sentence a second time later in this interview without going further into the circular culture within Wittmann. Instead he talked about the recycling service that Wittmann proposes to its customers as previously mentioned. Therefore, at this stage of this interview, he mostly mentioned themes inherent to the seventh hypothesis. However, later in the interview and for the rest of the interview he mentioned different aspects of the eighth hypothesis. Geyer (2020) says “Business is business, the boss and the shareholders want to make the most money as possible, it is how it works […], the more money they get the happier they are […]. We are very business oriented so I don’t think that sustainability stuff is a big concern for us.” These kinds of sentences came back regularly during the interview which confirms the business mentality or corporate culture within Wittmann. Geyer (2020) refers to another aspect of the eighth hypothesis by stating that “in the same time we do not really know how the CE and all this stuff works, how it can bring money, I mean sufficient money […], if you do not know how something works no business would go for it, it is just too much risks […], in the same time what we are doing brings money and works pretty well so why would they change something that works well, [...]. We do not have a reason to change.” Here Mr. Geyer (3) exposes the fact that some MEI businesses simply do not have the knowledge about CE or circular technics and how to implement it. Thus, his argument to not operate a change was simply that the actual model works well enough for them and that CE has too many uncertainties. Geyer (2020) also mentioned another reason for MEI businesses to not change their habits: “Wittmann is quite big now, we have many facilities and we produce a lot of different machines, I think it would be just too expensive for Wittmann to do a transition, we would have to adapt our equipment for all our products in all our facilities, I do not find that realistic to be honest.” Mr. Geyer (3) mentioned this argument a second time during the interview. He means that the total investment necessary to make a transition of the production model of Wittmann would frighten decision makers or any MEI businesses, particularly if their offer is diversified and involves many facilities. Almost all the arguments exposed by Mr. Geyer (3) show that Wittmann

supports the eighth hypothesis (H8) saying MEI businesses are not used to these new processes and prefer to continue the business as usual.

As it is possible to see in the coding table the next interviewee that mentioned the circularity culture within its company is Mr. Weger (1). He mentioned first how he and its department perceive CE. Weger (2020) explicates that "CE is part of our strategy and most of us believe that it will be the reason of our future success […], it drives business success but we have to improve our communication about CE […]. We know and we see that it is not just important for business success and our leaders but also for the employees satisfaction […], when you work for Engel you are somehow working for the plastic industry and the image of plastic is actually not that good […]. If I have to give a grade from zero to ten [of Engel's circular culture] I would give a three maybe." Mr. Weger (1) clearly shows that despite the importance of the CE in Engel's strategy, the circular culture is hardly rising neither among the employees themselves nor within the decisions-makers. Weger (2020) perceives the actual culture of the Engel's decision-makers as follows "it is the corporate culture […], we are family owned business, now the new generation is in house and are improving, but there is still the old culture in place. The old culture was very business-oriented […], actually the main issue is business focussed, [...] it is not very clear for everybody how we generate money from that (the CE)." Here Mr. Weger (1) confirms the statements of Mr. Geyer (3), that businesses are used to do what they always did and are not necessarily ready to change. Moreover, the ignorance towards what CE is doing and how it can generate money seems to be a key factor to this unwillingness to change among MEI businesses.

Then, Mr. Lechner (2) refers the latest to the circular culture of its company. His statements concerning Pöttinger support what the other interviewees already said and tend to confirm the eighth hypothesis. Regarding that Lechner (2020) states "We are a family business but we try to change, but most of the people here just do what they are used to do in business, because it is safe and it works, it brings money. Business is business." Once again, the concept of business mentality seems to block the actions of Pöttinger towards the CE which is coupled with the unwillingness to change something that works for the MEI's decision-makers.
In addition, Mr. Lechner (2) brings another reason to continue the business as usual that the other interviewees did not mention. Lechner (2020) states "we are a family business, then the notion of sustainability is very important for us, we want to make Pöttinger live longer. It is really the mentality here […], but our concurrent are very powerful, we are very small compared to them so we have to be careful, it is business. If we can do something sustainable, we will do it only if it is possible […]. It is a balance between being environmentally friendly and making money. Most of

our concurrent don't care about that, they are aggressive against us." Here Mr. Lechner (2) emphasises the importance of the concurrent behaviour, the situation and the position of a company in the market. If a powerful opponent in the market becomes aggressive, the priority of a small company would be to resist to those attack at any cost. Therefore, sustainability and long-term strategies are not the priority anymore.

Despite that each of the interviewees mentioned the CE technics as profitable and that business could be willing to change, what agrees on a certain extend on the seventh hypothesis, the interviewees largely mentioned the cultural limitations of such a change. Therefore, the business mentality or corporate culture, the lack of comprehension of the CE, the unwillingness to change something that already brings money and aggressive concurrence are the reasons why MEI businesses are not used to the CE and would prefer to continue the business as usual. All of the interviewees mentioned as the biggest barrier, the business or corporate culture which is quite difficult to define but that all employees might have already felt. This results confirm the findings of the document analysis of Caterpillar concerning the fourth research question (RQ4) that asked: Are the MEI's decision-makers afraid to change their production model due to cultural habits? In light to the research findings, the answer of this question is the eighth hypothesis (H8), MEI businesses are not used to these new processes and prefer to continue the business as usual.

6.1.9 Analysis of the interviews, RQ5

The fifth research question asks (RQ5) "Are the MEI's consumers willing to purchase a remanufactured or repaired product with guarantee of quality as if it was a regular product?" Its related hypotheses want to know if (H9) as long as the price is low enough and the performance is guaranteed the customers are willing to pay or if (H10) customers emit doubts about the certifications and do not believe that the product can have a similar quality as a virgin product, therefore they do not purchase.

On one side, Pöttinger and Wittmann do not implement circular technics in their production process to propose to their customers remanufactured or repaired products Mr. Lechner (2) and Mr. Geyer (3) could not answer properly the research question five. However, they could give insight about the behaviour of their customers towards the growing environmental awareness and CE.
Mr. Lechner (2) shared that farmers that had initially no concern with sustainable questions now ask Pöttinger how to preserve their land and reduce their dependence on chemicals particularly in

the EU. He also said that this growing awareness and demand remain low in other countries, particularly in the USA where Pöttinger has difficulties to find customers on this large market. Mr. Lechner (2) also mentioned that their future customers are willing to purchase only when Pöttinger takes time to explain how their equipment and machines work and how helping the land to regenerate is more beneficial for their business on the long term. In other words, Pöttinger teaches how sustainable strategy works in order to get new customers.
Mr. Geyer (3) also mentioned the growing demand of their customers for circular solutions and particularly for recycling solutions. He affirms that Wittmann's actions are driven by the demand, therefore, the growing number of their customers that ask for recycling solutions in order to be more cost efficient pushed Wittmann for creating such components and machines.
However, Mr. Geyer (3) also mentioned that it is for a similar reason that Wittman does not implement circular technics in their product process, simply because their customers do not care about Wittmann's production methods and its environmental impact. Mr. Lechner (2) also stated similar statements concerning the low concern of most of their customers towards CE and sustainability. Lechner (2020) states "I would say that the half of our customers do not really care about these questions, they purchase from us simply for cost efficiency reasons." Therefore, the economic reasons seem to be the dominant factor for MEI's customers to purchase. Mr. Lechner (2) and Mr. Geyer (3) reveal that the willingness of purchasing circular services are eclectic among MEI's customers, some look for it whereas others do not care.

On the other side Engel implemented circular technics in their production process to propose to their customers remanufactured, repaired and refurbished components and machines. This is why Mr. Weger (1) was the only interviewee that was able to properly answer the fifth research question. Straight to the point Weger (2020) states "It is also about customer satisfaction, because if you prolong the machine life time, if you can update machines and they (the customers) do not have to buy a new machine that is a reason why they buy from Engel, it is about customer satisfaction as well." For Mr. Weger (1) remanufacturing services improve the main concern of their customers, the life expectancy which makes them even more willing to purchase. Engel's customers are willing to purchase remanufactured products to use their machine longer. Regarding the statements of the other interviewees, one of the key questions is to know which proportion of the customers look for circularity. Weger (2020) states that "we conducted a questionnaire about our service, there are 100 questions, they tell on an index of zero to ten how they will rate us depending on how important this topic is for them. In most of the rating they are somewhere between seven and eight, or six and nine, this is more or less the range where customers rate us […]. If we ask them, if CE is it part of their daily business, we have an average of 6.8 or 6.0, so

this is lower compared to the other categories, so this is not the most important topic right now, but what we can see is from the last time when we asked them, it is now 0.4 more important for our customers and that is quite significant because when you answer a questionnaire yourself, normally people don't use numbers from 0 to 4 and they don't use the number 10 so frequently, so an answer that improves 0.4 points is a major improvement. So that actually tells us that got a bigger importance." Then, despite the high interest for the remanufactured services that Engel provides, a lower number of their customers considers the CE question. Mr. Weger (1) also confirms with numbers the growing interest on CE for Engel's customers.
Then, he brings some numbers about the proportion of Engel's customers that care or not about CE services. Weger (2020) states that "40% of the customers did not answer this question (about interest in circularity), they did not consider it, they did not care about it. Then, 33% of our customer say it is very important and give a 10, 20% told us like medium importance and 8% it is not important. So actually, one third of our customer have a high awareness of CE."

As Mr. Weger (1) shows, one third of their customers highly care about the CE services that Engel provides, the others do not care or are not aware of it. He also shows that customers are willing to purchase remanufactured and repaired products also if they do not care about CE or have environmental awareness which represent the majority of the Engel's customers. These findings tend to confirm the ninth hypothesis (H9) that states that as long as the price is low enough and the performance is guaranteed the customers are willing to pay. Unfortunately, due to the facts that the other interviewees could not answer the fifth research question, it is impossible for this thesis to be sure of the veracity of Mr. Weger's opinions for the rest of the MEI. In addition to that all of the interviewees mentioned that a part of their customers is willing to purchase CE services when they are profitable and on the other side, they also mentioned that most of the customers simply do not care about the circularity. As it is possible to see in the coding table, the arguments are uniformly divided between the themes supporting the ninth and the tenth hypothesis. Such disparity makes the confirmation of any of these hypotheses impossible.

6.1.10 Analysis of the interviews, RQ6

The sixth research question asks (RQ6) "Are the not adapted EU regulations and the lack of financial support to the CE transition key factors for the European MEI businesses to not switch towards CE?" Its related hypotheses want to know if (H11) financial or better regulations constitute a key factor for MEI businesses to switch to a CE model or if (H12) adapted regulations or financial support are not determinant for the MEI in the EU to switch to a CE model.

As shown in the coding table, Mr. Weger (1) was the first who mentioned the importance of a regulation of the CE. His opinion was short but likeminded towards regulations. Weger (2020) states "I strongly believe that for circularity and sustainability, one of the main drivers, one of the main incentives would be legal regulations, for example if we talk about carbon dioxide and the same is true for circular economy you have to make it interesting for the company. For most of the companies the best push is that it costs something if you don't do it, regulations I think it is a major point." As we can see Mr. Weger (1) considers legal regulation as a key factor to force the switch towards CE. He also does not believe in the EU to be able to make a change of the actual situation, which might be unfortunate. A certain level of mistrust towards the EU to answer this key question for the switch to CE exists obviously within the MEI.

Mr. Lechner (2) also actively supports the idea of a modification and improvement of the actual regulations. Lechner (2020) states "the European regulations limit too much our action towards sustainability. They are not adapted, too complex, too restricting […], not only these regulation for the CE but also the one that affect our business, other companies from other countries are much less regulated and restricted, they have a competitive advantage on us, it is not a fair competition like this." Here Mr. Lechner (2) confirms that regulations are an important factor for the transition to the CE, he also adds that other regulations that affect their business are too restricting compared to the regulations in other countries. He particularly mentioned the pressure of US companies that benefit of a much more flexible regulation system and are bigger than Pöttinger. Mr. Lechner (2) also mentions the direct financing to switch for CE. Lechner (2020) states "Money is every time welcome and will help for the transition […], it also depends of the criteria of this financing, quite often these financing measures are not adapted to our specific needs and force us to do things that we would have done differently." Here Mr. Lechner (2) exposes the need of financial support for companies such as Pöttinger that do not have an advantaged position in their market and a strong treasury. He is also worried about the criteria of such a support system that might put too many limitations on the companies. Constraining companies with too strict duties might frighten them to apply for such financial support system. Therefore, such a solution has to be adapted to each industry to be efficient or being global and giving large freedom to companies which would on the other hand increase the risk of not achieving the goal of such measure.
Mr. Geyer (3) has similar statements as Mr. Lechner (2), he strongly supports the idea that the actual regulations are not adapted for the CE and that there are no real incentives for Wittmann to switch for a CE model. He also mentions the interest into financial support but is also suspicious about their real effectiveness. He is more in favour of incentives by the regulations to switch to a CE model.

All the interviewees agree on the fact that a better regulation system is necessary for a switch to CE or helping the companies that already operated such a change. They consider better regulation as a necessity for the CE and their business as a whole. This confirms the eleventh hypothesis that states that financial or better regulations constitute a key factor for MEI businesses to switch to a CE model. The twelfth hypothesis is almost not mentioned except concerning the financial support that faces a certain level of mistrust among the interviewees. In other terms they want a better regulation system that gives them incentives to move for CE but no restriction or obligation coming from eventual financial support.

6.1.11 Analysis of the interviews, RQ7

The seventh research question asks (RQ7) "Would an institution supported by the EU to increase the knowledge and the comprehension of CE be a determinant factor for the implementation of CE within the MEI?" Its related hypotheses want to know if (H13) an institution bringing knowledge and advise to MEI businesses is essential for the MEI to switch to a CE model or if (H14) an external institution is not necessary for the MEI businesses to switch to a CE model.

Mr. Weger (1) mentions an eventual help of institutions soon after mentioning regulations. Weger (2020) admits "I agree that if an institution would have supported us, we would have switched earlier to CE." As Engel has already made the switch, he completes his opinion with the following "I'm sure that there will be some possibility but no from the EU's side but on a bigger level, it could be the regulation side" (Weger, 2020). Therefore, for MEI businesses that already implemented CE, their priority needs and requests end up in the legal regulation, either European or national.

Mr. Lechner (2) also emphasises the potential benefits of such institution or organisation. Lechner (2020) states "It depends what kind of institution, but I think that if people could explain us what is the CE and how it works it could help […]. I guess the most challenging is to convince our leaders, but if they can, it would be a big step for the CE and sustainability; if they can understand, it will be a big step". Here Mr. Lechner (2) goes further and sees the potential and the interest of such organisation in teaching and convincing the MEI's decision makers of the interest in CE. Therefore, overcoming the ignorance of many business would be the major interest for such organisation according to Mr. Lechner (2).

Mr. Geyer (3) confirms the previous points of views. Geyer (2020) states "The final decision belongs to our company, but if people can explain clearly what is the CE and how they can apply

it […], so they could at least consider it which would be already a big change. Honestly, I do not really know what is the CE and my boss also I think, so for that an organisation could help, at least it will give a chance to the CE." Here Mr. Geyer (3) confirms that if an organisation could at least meet and interact with the MEI's decision makers to explain them what is the CE, it would increase the chance that a company switches to CE. Organisation would have the potential to do it, because it can clarify what is the CE and overcome the ignorance of this topic in the MEI.

All the interviewees agree on the potential benefits of an institution or organisation specialised in rising the awareness among businesses for the transition of the MEI to the CE. Particularly, companies that did not yet implement a CE in order to increase their knowledge about the CE. The ignorance of this new model is an important factor to overcome to make a large switch for the CE to happen. Of course, the success of such organisation depends of the presenters and their persuasive abilities. It is also uncertain which proportion of MEI businesses would be convinced and initiate a change this would deserve a specific study. In every case the interviewees unanimously support the thirteenth hypothesis that states that an institution bringing knowledge and advise to MEI businesses is essential for the MEI to switch to a CE model.

6.1.12 Analysis of the interviews, RQ8

The seventh research question asks (RQ8) "Does the company have a good control over its providers or is it an OEM in order to get the desired quality and design for its components?
Its related hypotheses want to know if (H15) the position and activity of the company allows a good control over the providers to have the desired quality and design or if (H16) the position and activity of the company does not allow a sufficient control over the providers to implement remanufacturing activity or similar in the production process.
Mr. Lechner (2) was the first during the interview who explained the relationship to their providers. Lechner (2020) states "Our suppliers are the steel industry and it is quite difficult for us to put pressure on them. We are not what we can call a big customer for them, so our influence on them is quite small. Despite this situation we negotiate the best quality of components that they can provide to us […]. To make it simple, our factory assembles the components together to create our machines and then we paint it and condition it. We do not produce our components ourselves; we are dependent of our suppliers for that." As we can see Pöttinger is not an OEM, they do not produce their own components or at least the most strategic ones. In other words, they are dependent of their suppliers. Unfortunately, it seems that Pöttinger lacks of influence on their suppliers, they are almost in conflict. When asking how this relationship impacts Pöttinger,

Lechner (2020) answers “It is quite a pity that we do not have a high control over our suppliers, I think it is restricting our possibilities, but it is a very complex question. I think we will have to rethink our strategy about our suppliers.” Mr. Lechner (2) shared his disappointment over Pöttinger’s relationship with its suppliers. Regarding the statements of Mr. Lechner (2) it is clear that Pöttinger has a low influence on their suppliers and the material that they would like to receive. This situation does not allow Pöttinger to even think about conducting a remanufacturing activity regarding the presented elements. Therefore, Pöttinger falls under the sixteenth hypothesis that states that the position and activity of the company does not allow a sufficient control over the providers to implement remanufacturing activity or similar in the production process.

Mr. Weger (1) also mentions the relationship that Engel has with its suppliers. And it is relatively different than the previous case. Weger (2020) states “Actually, we are in the lucky situation that for most of our suppliers, not for all of those, we are at least in the top three customers, so we have quite a big influence on our supplier. That is a big plus, for the core components we have quite a big influence on our suppliers, we can dictate quite well our demand in quality and design, actually for those suppliers we are in design cooperation, we do it together.” Here we can see that Engel has a good relationship with its suppliers and a certain degree of power and influence. As we saw in the previous parts of this section that analysed the third research question, Engel is an OEM that produces its own components made of steel and orders the electronic components. This situation is a good basis to eventually conduct a remanufacturing activity.
When asking how this control over the suppliers was possible and helps the remanufacturing activity, Weger (2020) answers “actually it is because it is a strategy topic, our strategy with our supplier is ‘partnership not cheap buying’. We are also price sensitive like any other company but actually our strategy is the cooperation over a lot of years, most of our suppliers we have them for a long time and we do cooperation and development projects […] It is a good cooperation.” Here Mr. Weger (1) explains that the strategy of cooperation with the suppliers implies that Engel accepts to buy components at an interesting price for the suppliers in order to conduct a partnership and cooperation. This strategy over their suppliers is at the origin of the close relationship between Engel and its suppliers. Due to this relationship, Engel is able to get the needed components with the design and quality wanted which is ideal for their manufacturing and remanufacturing activity. Therefore, Engel with its status of OEM for steel components and its pro-active relationship with its suppliers to get the desired electronics components is able to propose a coherent remanufacturing activity and CE. This confirms the findings of the document analysis of Caterpillar, in the sense that a good control over the supplier and/or being an OEM is a basis to operate a remanufacturing activity in the MEI. Thus, the Engel case study confirms the fifteenth

hypothesis that states that the position and activity of the company allows a good control over the providers to have the desired quality and design.

Mr. Geyer (3) exposes another vision and relationship with suppliers that have to be considered in order to understand and apprehend the eighth research question (RQ8). Geyer (2020) states "I would say that we have quite a good power over our providers, I mean we are quite a big customer for them, so they cannot ignore us, that gives us a certain power. We use that to negotiate the best price for all kind of material. It is part of our strategy to find the best suppliers that will do what we want at the lowest price […] it is like we test the market; we get good quality material at a quite low price; we receive it and we assemble our machines. This is for my department; in some other departments they command the machine that interests them from small manufacturers and sell it under our name in our plastic network." As we can see Wittmann applies a total other strategy concerning suppliers compared to the previous case study (Engel). Wittmann applies an aggressive negotiation over their suppliers in order to reduce the price of their components. Wittmann is able to do it regarding its strategy to look after the supplier that would be in this situation. However, this strategy is possible only for materials that are produced in mass. Therefore, ordering specific components and design is almost impossible for Wittmann despite the apparent powerful control that it has over its suppliers. This impossibility to ask for specific design makes the implementation of a remanufacturing activity difficult. Remanufacturing activity become even impossible regarding the fact that Wittmann does not produce any components themselves, as it is not an OEM.

The Wittmann case study contradicts both the fifteenth and the sixteenth hypothesis due to the fact that despite having a good control and power over the suppliers, Wittmann is not able to get the design that it needs and wants to conduct a remanufacturing activity. This is mostly due to the price aggressive strategy that Wittmann applies.

The analysis of the three case studies proved the importance of the supply control or OEM activity for a remanufacturing activity, however it also showed the necessity to rephrase and specify the eighth research question to make it totally applicable with the limitations of this research. The notion of strategy of the MEI has to be considered and has a major importance towards the ability for MEI businesses to get the desired design of components to apply remanufacturing activity. Therefore, the eight-research question would be (RQ8) "Does the company have a good control and strategy over its providers or is it an OEM in order to get the desired quality and design for its components?" Under this question, the case studies analysis showed that the companies that did not have sufficient power and/or an adapted strategy could not get or negotiate components' design

that would allow remanufacturing activities. On the other hand, the company which applies an adapted strategy and had sufficient power over its providers could get well designed components to conduct a remanufacturing activity.

6.1.13 The research results

The case study analysis of Engel, Pöttinger and Wittmann allowed to test the conceptual framework and mathematical model with their variables. The variables were determined based on the theoretical model and were presented in the methodology. The predetermined variables were: High ROI and EROI, cost saving by era of R technics, cost saving by era of D technics, implementation of C2C design in the production process, better EU regulation or funding in favour of the CE, creation of institutions of CE in the EU, culture change of the businesses and cultural change of the customers. The variables were translated into seven secondary research questions with their hypotheses. After having made some assumptions on some hypotheses in the document analysis of Caterpillar, an eighth variable was determined which is the status of OEM and/or the relationship and strategy over the supplier of MEI businesses. Secondary research question and hypotheses have been made to cover this new variable. This section tested the veracity of each hypotheses and the eight secondary research questions in order to answer the research question of this thesis: Why would the MEI within the EU switch to a CE regarding biophysical, economic, cultural and environmental limits? This section has the objective to quickly resume the findings of the test of the hypotheses just made previously in order to present a model that answers the research question according to the research results and limitations.

The implementation of CE within the MEI demonstrates an ability to generate substantial cost savings particularly on material costs which gives the CE model a high ROI in the MEI. Similar results are observed concerning the ability to save energy and other resources which generates a high EROI for the CE model in the MEI. Therefore, the first research question (RQ1) that asks "Does the use of circular technologies and methods in the MEI generate a sufficient EROI?" can be answered positively regarding the results which correspond to the first hypothesis (H1): The EROI of circular methods is as high as or higher than the classic processes.

Regarding the variety and appliance of the technics of the era of R and D found in the case studies and the document analysis, it appears clear that these technics are profitable for MEI businesses. Some interviewees exposed that some technics might not be appropriate or effective enough for technical or technological reasons. But all of them could find and implement CE technics that are

profitable for them. The overall results confirm the second research question (RQ2) that asks "Does the investment in circular methods such as the era of R and D generate enough profit and cost saving to be profitable for MEI?" and its third hypothesis (H3). The implementation of the era of R and D strategies are profitable for the MEI.

Concerning the variable of the C2C covered in the third research question (RQ3): "Does the implementation of C2C design in the MEI processes have an ROI high enough for the MEI" the information provided by the case studies is unfortunately not sufficient to answer it. Despite the valuable information provided by Lechner (2020) in the Engel case study, the other case studies (Pöttinger and Wittmann) could not answer the third research question due to the fact that they do not use or even know the C2C technics. This inability to answer the RQ3 is directly linked to the limitations inherent to this thesis as exposed previously in the methodology. Thus, the C2C variable should not be considered in the final model of this research.

Concerning the variable of the decision-makers' culture in the MEI covered in the fourth research (RQ4): "Are the MEI's decision-makers afraid to change their production model due to cultural habits?" the interviewees confirmed the assumptions found in the document analysis that MEI's decision makers are not used to the CE and are not willing to change their business habits. Many different cultural barriers have been found in the case studies analysis that limit the possibility for a switch to a CE model such as the corporate culture, the lack of comprehension of the CE, the unwillingness to change something that already brings money and the aggressive concurrence. In the light of the research findings, the fourth research question (RQ4) has to be answered positively which corresponds to the hypothesis 8. MEI businesses are not used to these new processes and prefer to continue the business as usual. Regarding the importance of limitation that the business culture has for the switch to the CE in the MEI, every solution to reduce this influence is welcome to make a switch towards a CE model possible. Thus, bringing incentives, increasing the CE knowledge and having new generations more open-minded among decision makers are important elements to overcome the cultural barrier among the MEI's decision makers.

The variable of the customers' culture or more precisely their willingness to purchase or ask for products that come from CE technics is covered in the fifth research question (RQ5): "Are the MEI's consumers willing to purchase a remanufactured or repaired product with guarantee of quality as if it was a regular product?" Unfortunately, for similar reasons as in the third research question (RQ3) it is impossible to answer the fifth research question (RQ5) due to the fact that most of the interviewees could not answer it. In the same time, the interviewee Mr. Weger (1),

who strongly confirms that consumers are willing to purchase remanufactured products is in opposition with the findings of the document analysis of Caterpillar where the company struggles to convince consumers of the good quality of their products. Thus, due to the lack of information quantity and the eclectic results among the confirmed information, the customer willingness to purchase remanufactured goods variable should not be considered in the final model of this research.

Concerning the regulation variable covered in the research question (RQ6): "Are the not adapted EU regulations and the lack of financial support to the CE transition key factors for the European MEI businesses to not switch towards CE?" there are certain doubts among the interviewees concerning the efficiency of direct financial support being a good method for switching to CE, an opinion also confirmed in the document analysis of Caterpillar. However, all the findings support the importance of regulations. The experts of the MEI unanimously confirm the limitations of the actual regulation system for their businesses to implement the CE. They also ask for an adaptation of regulations, either in the EU or by the Austrian government. Regarding the research findings, the sixth research question (RQ6) has to be answered positively which corresponds to the hypothesis 11. Financial or better regulations constitute a key factor for MEI businesses to switch to a CE model. Thus, a better regulation will be an important factor for the MEI to switch to a CE model and will be implemented in the final model of this thesis. However, the financial support will not be considered in the final model.

Concerning the institutional support variable covered in the seventh research question (RQ7): "Would an institution supported by the EU to increase the knowledge and the comprehension of CE be a determinant factor for the implementation of CE within the MEI?" as for the previous research question the interviewees unanimously agreed that the support of an institution in charge of promoting and explaining the CE to the MEI businesses has a great potential to make MEI businesses switch to a CE model. Companies that already implemented CE would have switched earlier and the companies reluctant at making this change could be convinced to make the change happen. According to the research findings, the main interest of such institution is to increase the knowledge of decision makers of MEI businesses about CE. With a better comprehension of the CE, the experts believe that it is an important factor to make a switch to the CE feasible. This supports the thirteenth hypothesis 13. An institution bringing knowledge and advise to MEI businesses is essential for the MEI to switch to a CE model. Thus, an institution specialised on teaching, promoting and explaining the CE is a key factor for a switch to a CE model for the MEI. This variable will also be implemented in the final model.

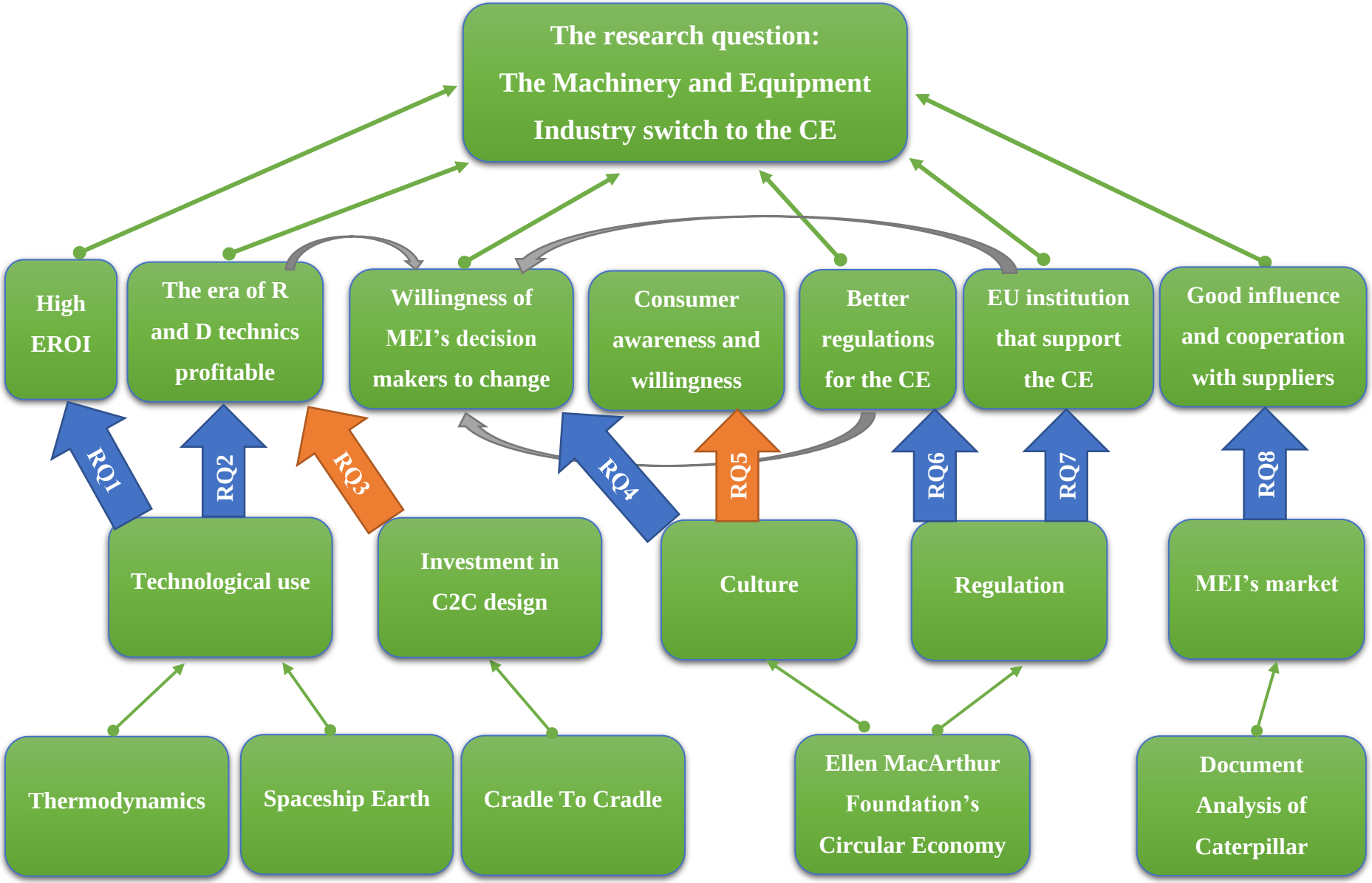
Last but not least, the eighth-research question (RQ8) enriched with the document analysis of Caterpillar and rephrased after the interview analysis asks: “Does the company have a good control and strategy over its providers or is it an OEM in order to get the desired quality and design for its components?” This research question covers a variable that can be called supplier relationship. The results provided by the interview analysis showed that the research question was quite inexact as were its hypotheses. However, the new phrasing of the eighth research question considers the strategy that the MEI uses over their suppliers. The case studies analysis could show that companies that apply a good strategy of cooperation and gain a good level of control over their suppliers are able to conduct a remanufacturing activity and have a CE model. While the companies with a weak control of their suppliers or without a strategy of cooperation are not able to get the design of components that they would need to conduct a remanufacturing activity and a coherent CE model. The research could show that the strategy and influence over the supplier is a key factor for MEI businesses to conduct a remanufacturing activity. Therefore, it is also an important factor for MEI businesses to consider, in order to be able to switch to a CE model. This variable will also be implemented in the final model.

Based on these results, the mathematical model presented in the methodology can be corrected regarding the variables that have been confirmed by the study.
The Machinery and Equipment Industry (MEI) switch to CE = Y
Higher ROI and EROI than classic methods = a_i
The implementation of the era of R technics are profitable = b_i
The implementation of the era of D technics are profitable = c_i
Open minded decision-makers in the MEI towards new ways of making business = d_i
More adapted and coherent EU’s regulation in favour of the CE = e_i
Creation of an institution of CE in the EU to rise the CE understanding among MEI’s decision makers = f_i
Strategy of cooperation and good influence over the suppliers = g_i

$$Y = a_0 + \sum_{i=0}^{n} a_i + b_i + c_i + d_i + e_i + f_i + g_i$$

In order to have a better visual representation of what has been confirmed by this research the following graph represents those findings based on the conceptual framework proposed in the methodology.

The bottom boxes represent the theories or analysis where the variables of the thesis have been determined and confirmed.
The green arrows make the links between the theories used by the thesis and the extracted important concepts for the MEI.
The concepts important for the MEI are the boxes in the third row, they constituted the focus points to determine and choose variables, secondary research questions and their hypotheses.
The blue arrows represent the research questions and their hypotheses that have been tested and confirmed by this thesis and the orange arrows are the research questions and their hypotheses that could not be tested properly by the research and therefore falsified.
The variables that have been confirmed by the thesis research are the boxes in the second row. The grey arrows represent the influence that the variables have among each other's. As the business culture is an important factor to overcome, other variables have the goal to facilitate the transition towards the CE.
The green arrows make the links between the confirmed variables and the research question of this thesis which is on the top row of this graph.


The research question:
The Machinery and Equipment Industry switch to the CE
High EROI
The era of R and D technics profitable
Willingness of MEI's decision makers to change
Consumer awareness and willingness
Better regulations for the CE
EU institution that support the CE
Good influence and cooperation with suppliers
RQ1
RQ2
RQ3
RQ4
RQ5
RQ6
RQ7
RQ8
Technological use
Investment in C2C design
Culture
Regulation
MEI's market
Thermodynamics
Spaceship Earth
Cradle To Cradle
Ellen MacArthur Foundation's Circular Economy
Document Analysis of Caterpillar

Therefore, according to the research findings and limitations, MEI businesses will largely operate a switch to the CE in the EU under the following conditions: when they experience the better profitability and ability of saving matter and energy by the CE technics; when parts of MEI's decision-makers have a greater knowledge about what the CE does or is about; when EU regulations will be more adapted overall for the CE in order to give incentives to the MEI's decisions makers; when an organism raises the awareness of and the understanding about the benefits of the CE in the MEI; and when MEI businesses have good influence and build a strategy of cooperation with their suppliers to make remanufacturing activity possible.

7 Conclusion

The concept of CE is growing in importance in the EU and has been chosen as a solution in answer to the environmental crisis. The action plan for the CE proposed by the EC is at the center of the EU strategy to make the transition to the CE (European Commission, 2015). However, few businesses and industries made this transition so far; this is also true for the MEI. The goal of this thesis was to understand this specific industry and explain how and why the MEI would operate a transition towards CE.

The study took as a base a theoretical framework that wanted to define the concept of CE due to its recent appearance in the literature. The concept of thermodynamics, of Spaceship Earth, of C2C and the EMF vision were studied. Based on it, variables to answer the research question: "Why would the MEI within the EU switch to Circular Economy regarding biophysical, economic, cultural and environmental limits?" were defined. Those variables were high ROI and EROI, cost saving by era of R technics, cost saving by era of D technics, implementation of C2C design in the production process, better EU's regulation and funding in favour of the CE, creation of institutions of CE in the EU, culture change of the businesses, cultural change of the customers. Each of these variables was developed and presented in a methodological section where secondary research questions with their hypotheses were found. The rest of the thesis focused on testing these hypotheses in order to verify the variables and answer the research question.

Before focusing deeply on the secondary research questions and their hypotheses, the thesis used secondary data to understand the MEI in the EU. It showed that Germany and Italy are the most important actors of this industry and that the exportation of the MEI is very high, higher than the automobile sector for instance. By convenience for the primary data collection, the thesis focussed on MEI businesses in Austria. The secondary data analysis could show that Austria is specialised

in two sectors of the MEI, the agricultural and forestry sector and the industry processing machinery sector. In addition, this section also showed that the region of Upper-Austria hosts the most of MEI businesses in Austria which is where most of the studied companies by this thesis come from.

Then, a document analysis has been conducted on one of the best practice firms of the MEI, Caterpillar Inc., to increase the understanding and challenges that the CE faces in the MEI. This study showed that the most interesting and effective CE strategy for MEI businesses is remanufacturing, regarding its profitability and sustainability. This document analysis also reveals another important variable that could not be found in the theoretical framework, but which is necessary to conduct a remanufacturing activity for the MEI. This new variable is the status of OEM and/or the relationship with and control over the suppliers of MEI businesses. This variable has been translated into a secondary research question and hypotheses to be tested in the next section focussed on primary data collection.

Then, a case studies analysis of three Austrian businesses operating in the MEI has been conducted. This analysis was mostly based on primary data coming from the interview of a representant of each of the Austrian businesses, Engel, Pöttinger and Wittmann. This analysis focused on testing the secondary research questions and their hypotheses. Some could have been confirmed and others not. The variables that concerned the implementation of C2C design in the production process and cultural change of the customers with their willingness to purchase remanufactured products or their desire for CE services could not have been tested properly mostly due to the research limitations of this thesis. The interviews were planned in February and March, but due to the corona crisis, most of the interview partners cancelled or stopped the contact what limited the number of interview partners for this study. The fact is that the variable of C2C and customer behaviour towards remanufactured products could only have been tested with companies which operate remanufacturing activity. Due to the facts that less companies answered and that the thesis focussed on Austria have limited the chance to interview and analyse companies that have a manufactory activity. Therefore, to complete this thesis, future research should focus on MEI businesses that already have a remanufacturing activity and not necessary only in Austria but all-around Europe.

Despite these difficulties faced by the thesis, most of the variables could have been tested and confirmed by the expert interviews. Therefore, according to the research findings and limitations, MEI businesses will largely operate a switch to the CE in the EU under the following conditions: when they experience the better profitability and ability of saving matter and energy by the CE

technics; when parts of MEI's decision-makers have a greater knowledge about what the CE does or is about; when EU regulations will be more adapted overall for the CE in order to give incentives to the MEI's decisions makers; when an organism raises the awareness and the understanding of the benefits of the CE in the MEI; and when MEI businesses have good influence and build a strategy of cooperation with their suppliers to make remanufacturing activity possible.

As the environmental awareness grows, more people and leaders realise the impact of current models of production and consumption on the environment. The EU called for a more circular way of doing business, but it was barely followed in Europe until now. Every industry has specific challenges and needs that the EU cannot address by proposing a broad program to switch to the CE. This is why this thesis looked at the specificities of the MEI in order to make it switch to the CE. In light of the thesis results and under the thesis limitations, conducting a remanufacturing activity as the main CE technique should be the absolute priority of MEI businesses regarding its high EROI, ROI and capacity at preserving resources and energy. To be possible, MEI businesses should be their own OEM or being in close cooperation with their suppliers in order to get the design of components that allows remanufacturing activity. The business culture and the old habits are an important barrier to switch to the CE. To overcome this barrier the EU regulation has to be adapted to CE which would give incentives to MEI's decision makers to switch to the CE. In addition, and complement, an organism should be in charge of promoting the CE among MEI businesses and more specifically explaining and teaching to MEI's decision-makers what the CE is about. The goal is to overcome the ignorance of the CE among MEI's decision-makers.

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9 Annexes

Interview guideline

Name of the company
Interviewee name
Interviewee position

Presentation of myself

Good morning / afternoon / evening. My name is Quentin DANJOU, I'm a MSc Sustainable Development, Management and Policy *student at Modul University Vienna. This interview is related to my master thesis research to answer the question of "Why the Machinery and Equipment Industry in the European Union would switch to circular economy". (brief description of purpose of the research). The questions I would like to ask are related to the research that I briefly described and the interview will take no longer than 50 minutes. Do you have any question related to my person or my research? If not, we could start the interview.*

1. What is your personal perception and belief of the Circular Economy?

1.1. Is this perception applied within ***(company's name)***? On which proportion?

2. How would you grade the culture of the circularity within your company?

1:	2:	3:	4:	5:	6:	7:
Excellent	Very good	Good	Reasonable	Somewhat satisfying	Not satisfying	None

2.1. If the culture of CE is not satisfying within *(company's name)*, what do you think is the reason for such a low interest?

- Unawareness of CE
- Unwillingness to change something that already works
- Doubts concerning the ability of CE to generate profit
- Lack of support (EU or state)
- No adapted regulations
- ROI (return on investment) not high enough
- CE technics (era of R) cannot save enough resources
- Other reasons: …

2.2. If the culture of CE is satisfying within *(company's name)*, what do you think are the reasons of such a high culture?

3. What about the environmental awareness of *(company's name)*'s customers? What is their knowledge and their awareness about circularity?

3.1. How would you grade the impact that has the awareness of *(company's name)*'s customers on *(company's name)*'s activities?

1:	2:	3:	4:	5:	6:	7:
Very high	High	Quite high	Some	Quite small	Small	Not at all

3.2. Does *(company's name)* communicate to its customers about its circularity or its environmentally friendly side?

3.3. How would you grade the importance of such communication in the strategy of *(company's name)*?

1:	2:	3:	4:	5:	6:	7:
Very high	High	Quite high	Some	Quite small	Small	Not at all

4. Which technics inherent to the CE does *(company's name)* use in its production process?

- C2C (designing its product to be reusable in the production process)
- Detoxify/Purify the product and the production process
- Prolong the product life (against planned obsolescence)
- Reusing old products or matters
- Repairing products or components
- Remanufacturing damaged products
- Re-refining matters
- Others: …

4.1. Why did *(company's name)* implement such processes?

- These technics are much more cost efficient than buying virgin products
- Mostly save matters
- Mostly save energy
- Demand of the customers
- Demand of the EU or Austria
- For the image of the company
- By convictions/beliefs of the directive board
- Others: …

4.2. Or the reasons of none implementation within the production process?

- Unwillingness to change
- Insufficient Return On Investment
- Technical constrains
- Lack of knowledge
- Lack of incentives coming from the EU or Austria
- Customer unwillingness to purchase repaired, remanufactured goods
- Lack of partnership with organisations specialised in the CE's implementation
- Others: …

5. **Does *(company's name)* have an after-life policy for its products? Such as:**

- Proposing a maintenance service to the clients
- Proposing a take back service to the clients
- Advising the clients on the good utilisation of the products
- Proposing to the client to rent the product instead of being the owner
- Others:

5.1. Which form does it take concretely within *(company's name)*'s production process?

6. If an institution specialised in the implementation of the CE (bringing knowledge) mandated by the EU was existing, *(company's name)* would have switched earlier or would have increased its circularity; Do you:

1: Strongly agree	2: Agree	3: Slight agree	4: Uncertain	5: Slightly disagree	6: Disagree	7: Strongly disagree

6.1. Explain your answer please.

7. **The global transition of the MEI towards the CE model would only happen with a large involvement of the EU? Do you:**

1:	2:	3:	4:	5:	6:	7:
Strongly agree	Agree	Slight agree	Uncertain	Slightly disagree	Disagree	Strongly disagree

7.1. **Explain your answer please.**

8. **Does *(company's name)* manufacture its own components or has a good control over its providers to choose the design and quality that *(company's name*) wants?**

8.1. How would you grade this control?

1:	2:	3:	4:	5:	6:	7:
Very high	High	Quite high	Some	Quite small	Small	Not at all