Chair of Industrial Logistics

Master's Thesis

Investigation of the relationship between circular economy practices and circular economy outcomes in the manufacturing sector

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May 2024

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Acknowledgments

I would like to express my deepest gratitude to my supervisor Priv.-Doz. Dr. Manuel Woschank MSc. for his support and encouragement throughout the entire duration of my master thesis. Due to the know-how and honesty, he provided me with in several meetings over the last months, I was able to undertake my studies on a very high scientific level. Additionally, without his help, I would not have had the opportunity to fulfill my dream of writing my master thesis in the United States of America at the WPI.

I am also very grateful for the help of my second supervisor Professor Joseph Sarkis, who supported me throughout my five months stay in Worcester at the WPI. In each and every conversation we had, I was able to benefit from the decades of scientific experience of one of the most renowned researchers in the fields of circular economy.

Abstract

The circular economy has gained increasing academic and industrial interest over the last years and especially in the manufacturing sector it is seen as an effective strategy to lower the environmental burden and still be able to be competitive through new opportunities the circular economy brings with it. However, due to the great extent of research performed in this field of study, the practices, policies and outcomes get mixed up with other environmental or ecological approaches. This study investigates the relationship between certain circular economy practices and circular economy outcomes. Through a systematic literature review, the most commonly mentioned practices and outcomes, which qualify as circular, have been identified. Based on the resource-based view (RBV) two hypotheses were formulated regarding the relationship between recycling and redesign with five circular economy outcomes. Multiple linear regression analysis was used to indicate significant correlations between the practices and the outcomes. The data used in the regression analysis derives from the EIKON database and contains data regarding circular economy practices, firm size and location and several quantitative outcome variables of 447 manufacturing companies all over the world. The results show that recycling has a significant relation with the reduction of energy consumption and the increase of the recycling ratio. While the redesign strategy shares this positive significance regarding the recycling ratio, further results also indicate that redesign leads to a significant reduction of waste and CO_2 emissions. This is due to the reason that, unlike recycling, redesign is a prevention strategy, so the generation of waste and emissions is already prohibited in the design phase of the products. These findings suggest that circular economy practices can be an effective method to target certain indicators and benefit from the increase of circularity. This study contributes to the circular economy theory by providing evidence for a significant relationship between circular economy practices and circular economy outcomes, which can be used by manufacturers to implement in their operations or policymakers to introduce new rules based on well-grounded scientific research.

Kurzfassung

Die Kreislaufwirtschaft hat in den letzten Jahren zunehmend akademisches und industrielles Interesse geweckt. Vor allem in der produzierenden Industrie wird die Kreislaufwirtschaft als wirksame Strategie angesehen, um die Umweltbelastung zu verringern und dennoch durch die neuen Möglichkeiten, die die Kreislaufwirtschaft mit sich bringt, Wettbewerbsfähigkeit aufzubauen. Aufgrund der großen Anzahl an veröffentlichten Studien in diesem Bereich werden jedoch Praktiken, Strategien und Auswirkungen mit anderen ökologischen Ansätzen vermischt. In dieser Studie wird die Beziehung zwischen bestimmten Praktiken der Kreislaufwirtschaft und den Auswirkungen der Kreislaufwirtschaft untersucht. Durch eine systematische Literaturrecherche wurden die am häufigsten genannten Praktiken und Auswirkungen ermittelt, die als zirkulär gelten. Auf der Grundlage der ressourcenbasierten Sichtweise (RBV) wurden zwei Hypothesen über die Beziehung von Recycling und ökologischen Design (Redesign) mit fünf Auswirkungen der Kreislaufwirtschaft aufgestellt. Mit Hilfe einer mehrfachen linearen Regressionsanalyse wurden signifikante Korrelationen zwischen den Praktiken und den Auswirkungen ermittelt. Die für die Regressionsanalyse verwendeten Daten stammen aus der EIKON-Datenbank und enthalten Daten zu den Praktiken der Kreislaufwirtschaft, der Unternehmensgröße, dem Standort sowie verschiedenen quantitativen Indikatoren von 447 Fertigungsunternehmen aus der ganzen Welt. Die Ergebnisse zeigen, dass Recycling einen signifikanten Zusammenhang mit der Verringerung des Energieverbrauchs und der Erhöhung der Recyclingquote hat. Während die Redesign Strategie diese positive Wirkung in Bezug auf die Recyclingquote teilt, zeigen weitere Ergebnisse, dass die Redesign Strategie auch zu einer signifikanten Verringerung von Abfall und CO_2 Emissionen führt. Der Grund dafür ist, dass Redesign im Gegensatz zum Recycling eine Vermeidungsstrategie ist, so dass die Entstehung von Abfällen und Emissionen bereits in der Entwicklungsphase der Produkte umgesetzt wird. Diese Ergebnisse deuten darauf hin, dass Praktiken der Kreislaufwirtschaft eine wirksame Methode sein können, um bestimmte Verbesserungen zu erreichen und von der Implementierung von Praktiken der Kreislaufwirtschaft zu profitieren. Diese Studie leistet einen Beitrag zur Forschung über die Kreislaufwirtschaft, indem sie Beweise für einen signifikanten Zusammenhang zwischen den Praktiken der Kreislaufwirtschaft und den Auswirkungen der Kreislaufwirtschaft liefert, die von Industrieunternehmen für die Umsetzung in ihren Betrieben oder von den politischen Entscheidungsträgern für die Einführung neuer

Regelungen auf Grundlage dieser fundierten wissenschaftlichen Untersuchungen genutzt werden können.

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1 Introduction

The relationship between industry and the environment is pivotal for industrial business performance, and the significant increase in environmental impacts has intensified the pressure on manufacturing companies. Going back to the beginning of the industrial revolution, facilitated by new manufacturing methods, the mass production of goods led to products with high availability and low costs. However, the consequence of this progress included high emissions of greenhouse gases, water pollution, solid waste generation and landfill usage, pushed by the growth of the new middle class consumer society and an increase in industrial activity. Additionally, the world population is growing, which leads to a rapidly rising demand for resources and thereby increasing consumption of natural resources. Since we only have one planet and its resources are limited, the current path of exponential economic and population growth cannot be continued forever.[1] So in this scenario, not only the challenge of environmental pollution is becoming more and more acute, but also resource scarcity will cause severe problems in the future if not tackled now. Manufacturing companies get confronted to simultaneously cope with environmental regulations and laws, risks in resource supply, price volatility of scarce resources and increasing competition for critical resources. This leads to additional economic challenges, such as supply chain risk, deregulated markets and financial instabilities, as well as social problems, like high unemployment rate and poor working conditions.[2] In light of these challenges for the industry and the underlying limitations of the linear take-make-use-dispose economy, there is a pressing need for a paradigm shift. Addressing the three dimensions of the sustainability paradigm (ecologic, economic, social), the circular economy (CE) has recently gained more and more importance. Aligning with the eco-industrial development circular economy is described as a closed loop material flow through the whole economic system.[3] Yuan et al. describe the circular economy in association with the 3R principles (reduction, reuse and recycling) as the closed flow of materials and using raw materials and energy through multiple life cycles.[4]

[1] Meadows et al. (1972), p. 45 ff.
[2] EC (2015), p. 5 ff.; Geissdoerfer et al. (2017), p. 757 ff.
[3] Geng; Doberstein (2008), p. 37 ff.; Geissdoerfer et al. (2017), p. 758.
[4] Yuan et al. (2006), p. 5 f.

1.1 Problem statement

Although the term circular economy is not a new one and has been the subject of research work for several decades, the concept of it and its practice have almost exclusively been led and developed by business consultants, policymakers and theoretical researchers. Although the number of publications is rising (especially over the last few years) the field of circular economy is still very scattered and some content is unexplored.[5] In particular the practical implementation worldwide is mostly at a very early stage, and although the "reuse" part of the 3R is always mentioned as the most effective one, most implementations focus on recycling.[6] Manufacturers are confronted with increasingly strict environmental regulations, pressured by the growing awareness of the ecological effects of the manufacturing industry. While trying to reduce the environmental harm their products are inflicting, the expectation for producers to achieve a continuous growth of their economic value and contribute to their home countries financial development is also gradually increasing. Thus, the general consensus developed is that management practices need to find a balance between commercial development and damaging the environment and also taking in consideration the social aspects, such as job creation and working conditions.[7] Circular economy practices and policies are exactly the tool which can function as the bridge to unite and achieve these crucial goals of the future. But there is still a lack of awareness of the term CE and most of the research is focusing only on a single industrial sector or only one dimension of the benefits of circular economy.[8] Apparently, most of the studies still see the circular economy paradigm only as an economic opportunity and focus on the financial impacts of its practices.[9] Meanwhile, other researchers keep their focus on the environmental aspects of the circular economy, which makes it difficult to evaluate the practical implementation of the practices and policies, as it could lead to negative financial impacts on the firms performance and would therefore be irrelevant for a company to consider.[10] These mixed results could lead to a confusion about the circular economy theory and there

[5] Korhonen et al. (2018), p. 37.
[6] Ghisellini et al. (2016), p. 11 f.
[7] Yin et al. (2023), p. 1.
[8] Kumar et al. (2019), p. 2 ff.
[9] Oliveira Rosa; Oliveira Paula (2023), p. 421 ff.; Yu et al. (2022a), p. 1 ff.; Rodríguez-González et al. (2022), p. 1 ff.
[10] Birat (2015), p. 3 ff.; Yang et al. (2023), p. 1 ff.

is an urgent need to combine all the dimensions of sustainability as the circular economy has initially intended to.[11]

1.2 Aims of the study

This study aims to close this research gap of the scattered influences of circular economy practices and policies and their outcomes. The intention is to find out how strongly the different circular economy practices are correlated with the different outcome dimensions of the circular economy. As the manufacturing industry is the main cause for greenhouse gas emissions, water pollution, electricity usage and other environmental damages, the focus will be set on this sector, to achieve the aim of this study of analyzing the input and output dimension of the circular economy, directly at the roots of the problem. Based on the findings of a systematic literature review, hypotheses will be formulated regarding which practices or policies implemented by manufacturers lead to which benefits. The literature review´s target is to identify among the wide variety of circular economy practices and policies which one are the most common and if they are really classified as circular. The same procedure is performed regarding the outcomes of the circular economy, as it is important to classify, whether different indicators even qualify as specific circular economy outcomes. This classification provides the possibility to find out how strongly certain circular economy practices are related to circular economy outcomes according to the literature and formulating hypotheses based on these results. Subsequently, after formulating these hypotheses, the EIKON database, filled with data from manufacturers all over the world for decades, will be used to test the correlation of implemented circular economy practices or policies in a manufacturing enterprise and the actual circular economy outcomes.

1.3 Research methodology

Overall, this study can be divided in eight main chapters, each one consisting of several sections. This first chapter provides an introduction to the topic, starting with the relevance of the topic and describing what exactly the concerns and objectives of this study are. Chapter two will provide the theoretical foundational literature of the topic, focusing on the circular economy with its historical development, a concrete definition of circular economy and a description of circular economy practices,

[11] Yin et al. (2023), p. 1 f.

policies and outcomes. In addition, as this work focuses on the manufacturing industry, manufacturing companies will be defined and a classification for manufacturing companies will be presented. Chapter three provides the systematic literature review focusing on the relationship between practices and policies of the circular economy and their outcomes. Based on the literature, the most common practices and outcomes are used to develop the hypotheses in chapter four, which also contains the theory of this study. Chapter five presents the methodology for the database research, including the data of the EIKON database, which is then analyzed with a multiple linear regression. The results and findings of the regression analysis will be presented in chapter six. Chapter seven will consist of a discussion, implications and limitations based on the results of the regression analysis. The last chapter will give a brief conclusion of the study and suggests future directions for further research on this topic.

2 Theoretical foundation

2.1 Circular economy

Despite all the radical changes our industry experienced over nearly three centuries, one thing has not quite changed along the timeline: the linear consumption model, based on the make-take-dispose pattern. Material gets extracted by companies, sold to a manufacturer who increases the value of the raw material by putting in labor and energy and then sells a product to costumers. Through this selling process the ownership and responsibility of the product transfers to a consumer, who discards the product if it is no longer of substantial use. The opposing model of this linear economy is the circular economy, which has been gaining interest dating back to the early 1970s and is especially booming over the last few years with hundreds of publications every year. The idea of this circular economy is to turn products at the end of their life cycles into inputs for other products and thereby closing loops in industrial ecosystems and minimizing the primary resource input and generated waste. Additional targets of circular economy are, but not limited to, long-term value preservation, more jobs through shifting the focus to unlimited resources like labor instead of natural resources, and less greenhouse gas emissions.[12]

2.1.1 Historical background

There is no exact date or a single originator of the circular economy concept, but rather a few contributors who made serious impact to the development of the CE concept over a certain period. Some authors attribute the introduction to Pearce and Turner (1989), who investigated the linear characteristics of the present economy and developed a conceptual framework for the circular economy framework. Pearce and Turners idea on the other hand, was influenced by the work of Boulding (1966), which described a coexistence between the economy and the environment, as the earth is a closed and circular system with restricted natural resources. [13] Gallaud and Laperche see the first influences of ecological thinking and thereby the circular economy even earlier, just after the Second World War, as people became aware for the first time of the serious environmental impact of an atomic bomb and then of the extensive use

[12] Geissdoerfer et al. (2017), p. 757 f.; Gallaud; Laperche (2016), p. 2 ff.; World Economic Forum (2014), p. 14.; Stahel (2016), p. 435.
[13] Pearce; Turner (1989), p. 29 ff.; Geissdoerfer et al. (2017), p. 759.; Winans et al. (2017), p. 825 f.

of synthetic herbicides in the Vietnam War.[14] Another early pioneer of the circular economy was W.R. Stahel, who described the concept of a circular economy by substituting energy for manpower. He mentions waste prevention, higher resource efficiency and job creation as impacts of this strategy. In later works Stahel also presents the idea of selling the utilization of goods rather than the ownership as a sustainable business model contributing to a closed loop economy.[15]

How we understand circular economy nowadays and its practical applications to the industry and economic has evolved out of a variety of concepts and ideas that are based on the closed loop theory. The German chemist Michael Braungart along with the American architect Bill McDonough designed the cradle-to-cradle concept and certification process, which considers all technical and biological material involved in industrial and commercial processes as nutrients.[16] Geissdoerfer et al. also mention the laws of ecology, industrial ecology and looped and performance economy as important concepts for the circular economy.[17]

While before the turn of the millennium the interest of circular economy was mostly generated by theoretical research, the first governments started including ideas of the circular economy in their policies in the early 2000s. Japan introduced a law on waste management and one on the efficient use of resources following the 3R approach (reduce, reuse, recycle) to compensate for their lack of natural resources. Germany has been setting the focus in their sustainable development policy on the optimization of material use since the early 2000s, to decouple economic growth from material consumption. In China, circular economy has even been set as a national priority as the government realized, that the economic boom over the last decades has only been realizable at the expense of environmental pollution. China included circular economy in their 11th five-year plan (2006-2010) to establish an energy- and resource-gently society. A law in 2009 promoted the circular economy theory and the position of it was further strengthened in the following 12th five-year plan (2011-2015).[18] As more and more countries included circular economy in their policies, also supranational

[14] Gallaud; Laperche (2016), p. 16 f.
[15] Stahel; Reday-Mulvey (1976), p. 108 ff.; Geissdoerfer et al. (2017), p. 758.
[16] Braungart; McDonough (2009), p. 68 ff.; World Economic Forum (2014), p. 26 f.
[17] Geissdoerfer et al. (2017), p. 759.
[18] Gallaud; Laperche (2016), p. 5 f.

bodies have included it as a priority in their future development – most notably the EU in their Circular Economy Strategy in 2015.[19]

The latest and most renowned definition of the circular economy has been developed by the Ellen McArther Foundation, which describes the circular economy as restorative by intention, relying on renewable energy and minimizing waste through careful design. It draws a sharp line between the consumption and the use of materials and promotes a functional service model, where the manufacturers hold on to the ownership of their goods and sell the use of them, not a one-way consumption. The McArther Foundation describes the circular economy based on just a few simple principles, which are listed and explained in Table 1.[20]

Table 1: The principles of the circular economy[21]

Principle	Explanation
Design out waste	By intentionally designing products to eliminate waste, they fit within biological or technical material cycles to allow for disassembly and refurbishment. This approach is based on non-toxic biological nutrients capable of composting, and reusable technical materials to maintain high quality.
Build resilience through diversity	Enhancing resilience in systems through prioritizing of modularity, adaptivity and versatility. Diverse systems with many connections and scales are more robust in the face of shocks compared to efficiency-driven systems.
Rely on energy from renewable sources	Promoting the use of renewable energy and shifting the taxation from material consumption to labor and energy can promote circular economy business models.
Think in "systems"	Understanding the interdependence of parts within a whole and their relationships with the infrastructure and environment. This principle focuses on feedback and connections leading to regenerative solutions.
Waste is food	Biological nutrients should be reintroduced into biosphere through non-toxic, restorative loops and technical nutrients upcycled to improve quality.

[19] EC (2015), p. 1 ff.
[20] World Economic Forum (2014), p. 22 ff.
[21] World Economic Forum (2014), p. 23 ff.

2.1.2 Definition of circular economy

Apart from the definition of the circular economy by the Ellen McArther Foundation based on the previous five principles, there exist several other definitions of the circular economy theory. Geng and Doberstein understand circular economy as "realization of closed loop material flow in the whole economic system", which is in line with the eco-industrial development.[22] In association with the 3R principle of reduction, reuse and recycling, Yuan et al. define the core of circular economy as the circular (closed) flow of materials and the use of raw materials and energy through multiple phases.[23] Gallaud and Laperche refer to the circular economy definition of the French ADEME (Agence de l'environnement et de la maîtrise de l'énergie, or the French Environment and Energy Management Agency), which describes it as a system with the overall aim of reducing resource waste to decouple their use from the gross domestic product growth while reducing the environmental impact and increasing the social well-being. Thereby, the ADEME also includes a social factor into the circular economy theory.[24] Kirchherr et al. wanted to find a general definition of the circular economy and took a closer look at the countless different definitions in scientific literature. They also found various possibilities for defining circular economy and stated, that those countless definitions could lead to a blurring of the concept. To prevent this, they devoted their work to the creation of a coding framework to analyze the definition of circular economy. They analyzed over 100 definitions according to their compatibility to 17 core principles, for example the 4R (reduce, reuse, recycle, recover) or the level on which the circular economy system takes place (macro, meso and micro level). Based on the result of this coding framework they describe circular economy as follows:[25]

> *"an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity*

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[22] Geng; Doberstein (2008), p. 37 ff.
[23] Yuan et al. (2006), p. 5.
[24] Gallaud; Laperche (2016), p. 8.
[25] Kirchherr et al. (2017), p. 221 ff.

and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers."
(Kirchherr et al. (2017))

As this work is concentrating on the influences of certain practices and policies in companies of the manufacturing sector, circular economy at the core will be defined by the 4R principle, which is also the central principle of the European Union Waste Framework Directive[26], with strong reliance on renewable energy resources, smart product design and the waste is food principle[27]. Additionally, the 9R principle of Pottinger et al., as an extension of the 4R principle, is respected in this work. Furthermore, although circular economy has in general a broader field of influence, the focus of the circular economy in this work will stay mostly at the micro level, as the results will be analyzed on company level.[28]

2.1.3 Importance of the circular economy

Continuing the contemporary demand for resources will lead to a global demand thrice of what we use today, according to forecasts. Humanity is already consuming 1.5 globes worth of resources every single year and, following the scientific estimates, would need more than 4 globes to satisfy the demands in 2050, which is less than 30 years away. But growth is limited, and so is this one planet. Studies show that companies in the European Union are extremely dependent on imported raw materials (>40%), which leads to the conclusion that with raw materials short, European companies are going to be hit hard. But in this challenge also lies a big opportunity. If companies can deliver solutions to use resources more efficiently, they can survive this economic dilemma and prosper from it. Solving the problem is possible by creating more with less – to create more value with less resources. Circular economy is based on this principle and aims to overcome this enormous challenge of resource scarcity, which concerns everyone on our planet, and is getting more significant day by day.[29] Taking Europe as an example: increasing the resource productivity by 30% by 2030 would already bring huge benefits. It would put Europe on the track to a more resource-efficient way of manufacturing and additionally, deliver an estimated 1% of

26 Union (2016), p. 10.
27 World Economic Forum (2014), p. 23 ff.
28 Kirchherr et al. (2017), p. 224.
29 Pietikäinen (2020), p. 43 f.

GDP increase and two million jobs. But to achieve those crucial future goals, circular economy shall be seen in a much wider context than a simple waste legislation as crucial to make companies more competitive and protect the environment. This means intervening in the whole product life cycle: from raw material extraction to product design, distribution, consumption and product end-of-life scenarios.[30]

> *"Accelerating the transition towards a circular economy model is not an option, but a mandatory choice. While we have to face the striking effects —even economically— of climate change with increasing global competition for lacking resources, we cannot pass this opportunity"* (Bonafe (2020))

2.1.4 Circular economy policies

To abandon the linear "take-make-dispose" model and transfer to a circular economy, certain policies are necessary to achieve the circular economy principles. This work will go along with Estrada and Arturo´s definition of a policy, who defines a policy as the following:

> *"a theoretical or technical instrument that is formulated to solve specific problems affecting, directly or indirectly, societies across different periods of times and geographical spaces."*
> (Estrada; Arturo (2011))

Hartley et al. utilized data from 47 in-depth interviews with European CE experts to summarize on a certain set of CE policies, proposed by those experts to facilitate CE transition. The results of the study present eight recommendations for circular economy policies, partly on company level and partly on EU wide level[31]. These eight policy recommendations are following the framework of Milios and are mapped according to his product life cycle (Figure 1).[32]

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30 Bonafe (2020), p. 55 f.
31 Hartley et al. (2020), p. 1 ff.
32 Milios (2018), p. 872.

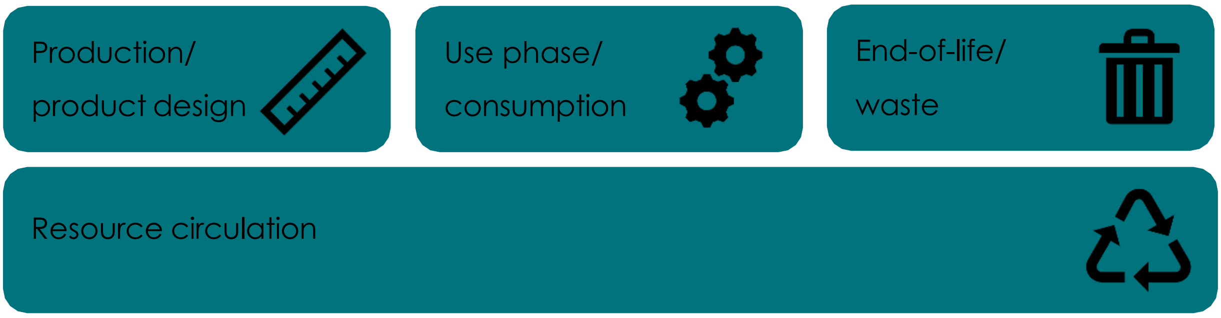

Figure 1: Product life cycle[33]

2.1.4.1 *Production and product design*

For the first life cycle phase (production/product design) a further adoption of circular design standards is described as the key policy in this phase. By rethinking the design of a product and making it more durable and reusable, the primary material consumption can be decoupled form the GDP growth and a huge step towards a more circular economy could be made.[34] Milios includes other additional different policies in this first life cycle phase, for example regarding batteries and their waste or the packaging of products.[35]

2.1.4.2 *Product use and consumption*

Regarding the use phase and consumption, the experts recommend expanding the circular procurement, by favoring circular products over their linear alternatives or initiating thresholds for certain percentages of recycled content, eco-efficiency and reusability. Abad-Segura et al. also suggest an improving efficiency of water usage as an important policy regarding the first two life cycle phases.[36] The EU 2015 Action Plan for the Circular Economy proposed the introduction of product labeling regarding the durability of the product and the promotion of innovative consumption, as leasing, lending or sharing.[37]

2.1.4.3 *End-of-life and waste*

The policies recommended for the end-of-life stage and wastes are for the most part on macro level, regarding national or EU wide policies like reduced taxes for circular economy products, liberalization of waste trading or establishment of eco industrial parks. Policies on company level essential for supporting circular economy practices

[33] Milios (2018), p. 872.
[34] Hartley et al. (2020), p. 3.; Abad-Segura et al. (2020), p. 19.
[35] Milios (2018), p. 870.
[36] Abad-Segura et al. (2020), p. 19.; Hartley et al. (2020), p. 3 f.
[37] EC (2015), p. 5 ff.

are the general decrease of waste generation and the reduction of the emission of greenhouse gases in the waste sector.[38]

2.1.4.4 Resource circulation

The previous three sections represented the most important circular economy policies along the product life cycle. All these policies individually can induce the desired outcome of a circular economy, but despite their impact, by using the synergistic effects of a policy combined with a second one from another life cycle stage, the outcomes could be maximized. For example, it would make sense for a company to combine the goal of decreasing waste generation with a circular product design, which aims to create less or easier sortable waste. Furthermore, could the implementation of a policy tackling only one life cycle stage bring additional negative impacts and neutralize the intended advantages of the policy. Increased marketing of circular economy and the support of a material flow analysis (MFA) between companies could strengthen the resource circulation along the whole life cycle further. For that reason, it is desirable to find a policy mix based on synergies to support the circular economy practices successfully.[39]

2.1.5 Circular economy outcomes and indicators

Literature concerning the circular economy mainly focuses on theoretical systems and outcomes of it. Additionally, it is a relatively new concept and there has been low interest, so far, in measuring the quantitative outcomes of the circular economy through specific ecologic or economic indicators.[40] Another important fact to mention is, that although a lot of studies predicted certain benefits of the circular economy, these expected benefits did not always occur, and sometimes circular economy even worsened the situation further.[41]

2.1.5.1 Definition of circular economy outcomes

Circular economy outcomes are the intended changes in a company or also larger cooperation as countries or the EU, achieved through circular economy policies and practices. While previous research regarding the impact of circular economy typically focused on only one specific strategy, a specific product or only the environmental

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[38] Milios (2018), p. 870 ff.; Abad-Segura et al. (2020), p. 19.
[39] Milios (2018), p. 872 ff.; Hartley et al. (2020), p. 6 f.
[40] Cautitanu et al. (2018), p. 266.
[41] He et al. (2023), p. 2.

dimension, the general definition of circular economy outcomes is broader. In the literature, these outcomes are mainly divided into three sections and follow the UN paradigm of the sustainable development: the economic, environmental and social ones.[42] Examples of economic outcomes are increased revenue and cash flow or reduced costs. The environmental dimension has outcomes like minimizing waste, toxicity, water and electricity use and emissions, facilitating reusability and lower the primary material input, while the social dimension focuses on job creation, workers health and safety and consumer risk. Apart from the outcomes, following the sustainable development paradigm, Sinha also lists value chain enhancement (organizations innovate and craft new processes and strategies, which leads to increased value in the value chain) and consumer value creation (create value through circular economy practices not only for themselves but also for the consumer) as possible additional circular economy outcomes. This work, however, will focus on the three dimensions of sustainable development.[43]

2.1.5.2 Indicators to measure outcomes

To measure the outcomes of the circular economy and therefore the functionality of CE policies and practices, there are a wide range of indicators for each dimension of the outcomes. These indicators allow a quantitative analysis of the circular economy strategy and make comparison possible. So far, unfortunately, there has not been developed an official set of indicators to describe the circular economy outcomes and provide clear information of how the circular economy model is to function exactly. But there have been publications of international institutions for indicators of related topics; The UN, for example, developed ten indicators for sustainable development, the OECD published 25-30 indicators to measure green growth and the World Bank has specified over 50 indicators related to environment and sustainable growth. Cautitanu et al. proposed a reference system for these wide range of indicators, also following the sustainable development structure. Table 2 shows a summary of his proposition, which is based on literature and official institutional indicators. [44]

[42] Griggs et al. (2013), p. 305 f.; Park et al. (2010), p. 1496.
[43] Sinha (2022), p. 237 f.
[44] Pauliuk (2018), p. 82 ff.; Cautitanu et al. (2018), p. 266 ff.

Table 2: Circular economy indicators (adapted from Cautitanu et al. (2018))

Sustainable development dimension	Indicator class	Indicators
Environment	Resource efficiency	• Consumption of natural resources • Energy consumption • The use of renewable energy • Proportion of renewable energy by sources • Domestic material consumption, calculated by material types • The rate of the surfaces occupied by organic farms / total area used in agriculture • Energy consumption calculated in terms of type of transportation • Annual energy consumption / per capita • The rate of energy consumption covered from renewable sources
Environment	Environment and components	• Artificial land • Natural capital • The level of CO_2 emissions • The ratio of total area running the risk of soil erosion
Environment	Waste management	• The production of hazardous waste /economic activities • Solid waste derived from industrial and household consumption • Radioactive waste management • Waste recycling and reuse
Economic	Economic development	• GDP/capita • The rate of GDP growth • The rate of inflation • Net national income (% of GDP) • Total expenditure on research development (% of GDP) • Public expenditure on education (% of GDP)
Social	Population	• Indicators referring to human health • The unemployment rate • The poverty rate • Healthy life expectancy by gender • Expenditure on healthcare (% of GDP)

2.1.6 Influence of circular economy policies on quantitative outcomes

As already described, the aim of circular economy policies is to contribute to the benefits of a circular economy. But there are some problems with this expectation. First, most of the work done regarding circular economy, is scientific research rather than practical implementation. In addition, most of the research does not quantify the outcomes of implemented policies, so there is no indication of how good the policies are. To properly analyze the benefits of circular economy policies, the outcomes must be measured by quantitative indicators or correlations must be identified.

Palea was aware of this lack of evidence and focused on the environmental correlations of CE policies. She developed a CE score for companies, based on eight policies, which aim to achieve circular economy. These policies include water and energy efficiency, reporting on the three R´s and use of renewable energy. This CE score is then tested for correlation with certain economic key values. The study reveals that the circular economy score is significantly positively correlated with the return on assets, return on equity and especially asset turnover. However, the results also showed a significantly negative correlation with the return on sales, which indicates a reduction in operating margins.[45]

Another barrier of the CE policies and their results could be the fact, that companies are obligated to include such policies in their action plans, because international organizations, like the EU, demand it. This could lead to companies seeking to please its stakeholders through pretending to be circular with policies, without even improving its performance.[46] In a study about the motivation of companies in Pakistan´s automobile industry to implement circular economy policies, internal drivers have also been identified. The results show that the greater part of companies are using circular economy policies only for their economic outcomes like higher profit. This strong empathy by the enterprises to increase profitability through circular economy initiatives is ignoring the social and environmental benefits of the circular economy and is rather focusing on only one dimension of sustainable development. Figure 2 summarizes the results of the work of Agyemang et al. regarding the intended outcomes of companies by implementing circular economy policies and initiatives at micro level.[47]

[45] Palea et al. (2023), p. 4 ff.
[46] Marco-Fondevila et al. (2021), p. 1 f.
[47] Agyemang et al. (2019), p. 10.

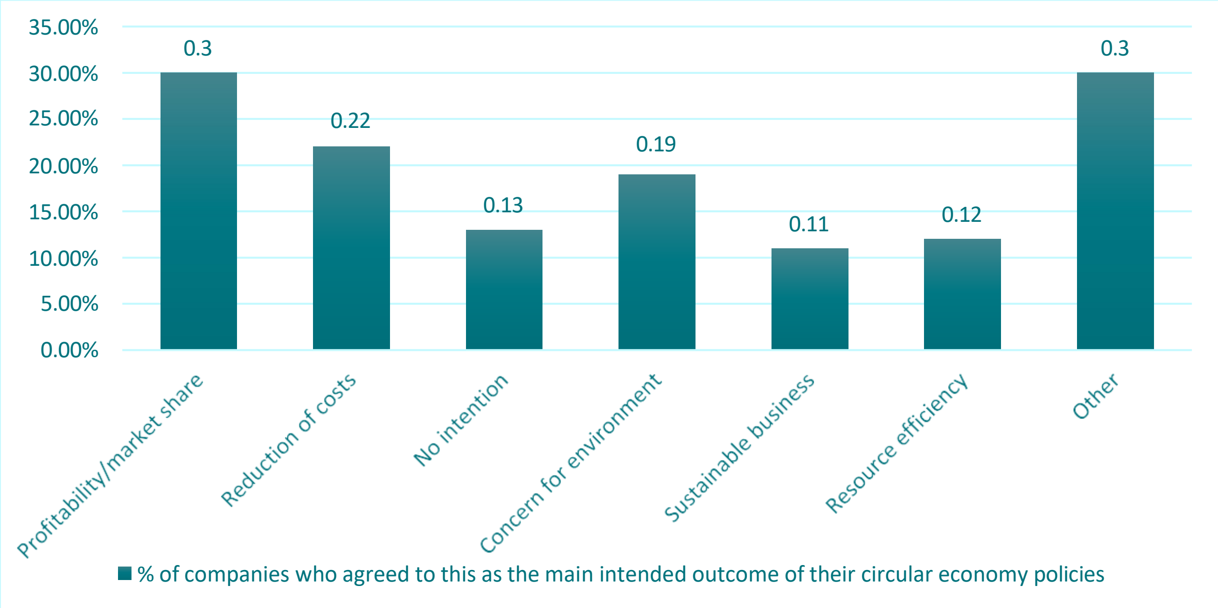

Figure 2: Intended outcomes by introducing circular economy policies/initiatives (adapted from Agyemang et al. (2019))

On the other hand, this demand for circular economy policies on the micro level can also lead to the opposite and encourage companies to strive for new innovations and a more circular design. Taghipour et al. analyzed the correlation of governmental restrictions and reliefs regarding circular economy, and their impact on the circular economy outcomes in steel manufacturers in Thailand. They found a strong correlation between these influences and the circular improvement of the companies regarding less greenhouse gas emissions and customer satisfaction.[48]

2.2 Manufacturing companies

The manufacturing is a crucial part of the economy, as it contributes significantly to the production of goods across various industries. The scope and scale of manufacturing operations can vary widely, from small-scale artisanal production to large-scale industrial facilities.

2.2.1 Definition

Manufacturing companies are organizations, which process raw materials, components or parts into finished goods by human labor, tools, machinery and chemical processing. This processing defines the word "manufacturing" and enables the companies to sell the finished products at a higher cost than the value of the raw materials used. The process of manufacturing starts with the product design and

[48] Taghipour et al. (2022), p. 4 ff.

materials selection, followed by the mechanical, physical or chemical transformation of the materials and substances which adds value to the product to make the sale of it economical beneficial. Apart from the physical transformation, the economic value of a manufactured good may derive from a wide variety of other nonphysical activities. This includes especially business services such as research, marketing, logistics, information technology and software development. These immaterial inputs may be provided in-house or also be purchased from other companies. Some of the key characteristics of manufacturing companies are:

- Production processes: Manufacturing companies use specific processes to create products, which depend on the type of product being manufactured (welding, molding, machining, assembly, …).
- Raw materials: This involves the use of raw materials or components. The choice and quality of these materials can have significant impact on the final product.
- Quality control: Ensuring the quality of products is a critical aspect of manufacturing to meet expectations of costumers and industrial-wide regulations.
- Mass production: Through producing in large scales, manufacturing companies achieve economies of scale and reduce thereby costs per unit.
- Technology and innovation: Enhancing efficiency, improving product quality and staying competitive through successful technology and innovation.
- Job creation: Contribution to employment by creating jobs in various roles.[49]

2.2.2 Historical evolution from Industry 1.0 to Industry 5.0

Manufacturing has existed for millennia and was originally carried out by skilled artisans, who passed skills down through apprenticeships over dozens of generations. These manufacturers may have been part of a guild who protected their trade secret and privileges. In more rural areas, manufacturing took place on a less organized scale by craftspeople through home-based manufacturing, united through joint ups. However, at the end of the eighteenth century the First Industrial Revolution shifted this early understanding of manufacturing systems. With the introduction of factory systems in Britain, enabled by the utilization of water and steam power (Figure 3 shows a design

[49] Marc Levinson (2017), p. 1 f.; Will Kenton (2022).

drawing) in mechanical manufacturing systems, the manufacturing system shifted and took advantage of the new technologies.[50]

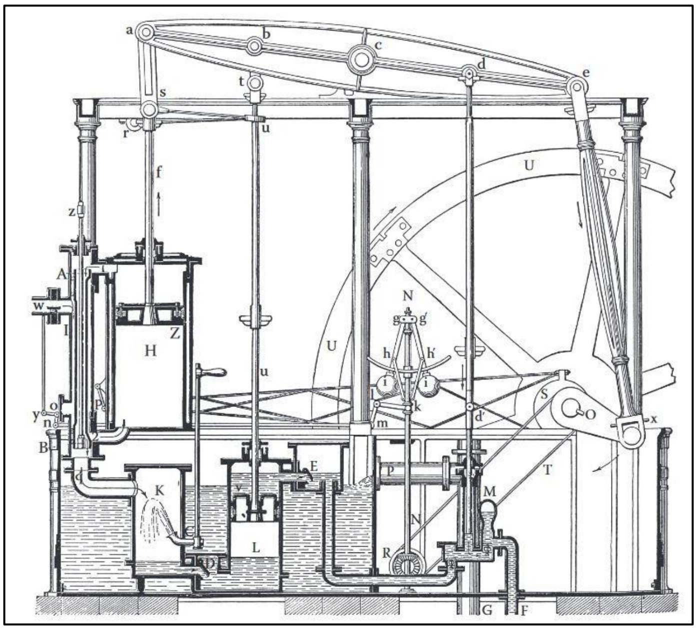

Figure 3: Steam engine by James Watt (by Bibliographischen Institut Leipzig & Wien (1885-1900))

About a hundred years later, at the end of the nineteenth century, the second Industrial Revolution started, symbolized by mass production due to the use of electrical energy. The assembly line method of manufacture was invented and led to the concept of division of labor. This meant that different people would only take part in just one part of the manufacturing process, instead of everything, to transform to a more efficient and cost-effective process.[51] The middle of the twentieth century then brought the third Industrial Revolution with increasing production automation through electronic and information technologies. The current fourth Industrial Revolution is a German initiative and started around the 2010s. In the context of the so-called "Industry 4.0", manufacturing systems are being updated to an intelligent level and the technologies used to manufacture are being significantly transformed by cyber-physical systems (CPS), the Internet of Things (IoT), cloud computing and many more highly modern trends (Figure 4). Nowadays, in the Industry 4.0 age, manufacturing companies take advantage of advanced information levels and manufacturing

[50] Marc Levinson (2017), p. 1 f.; TWI Ltd (2023).
[51] Da Xu et al. (2018), p. 2941 f.; TWI Ltd (2023).

technologies to cope up with the dynamic and challenging demands of the global market and make their production processes smart, reliable and flexible.[52]

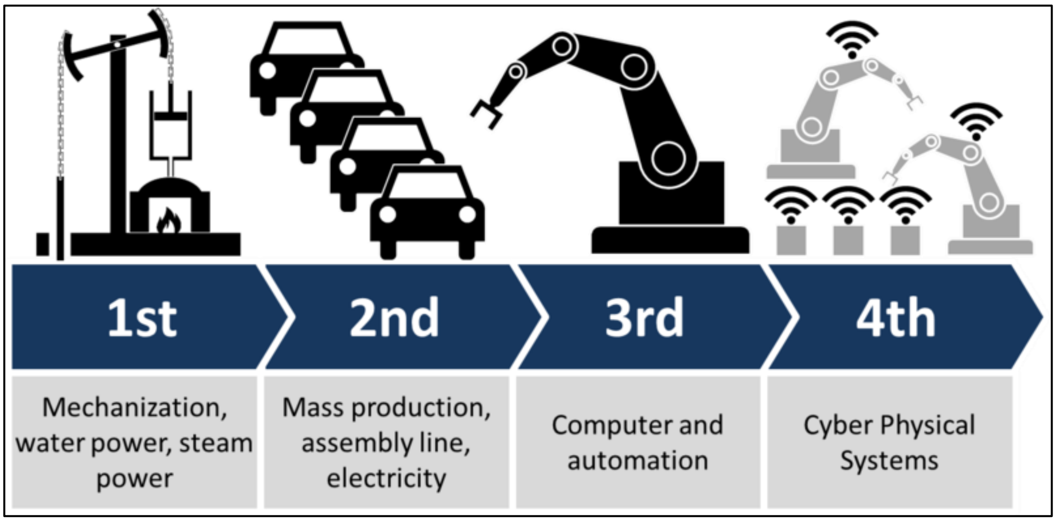

Figure 4: The four industrial revolutions (by Roser (2017))

This model by Roser is extended by the newest publication with a fifth industrial age, the "Industry 5.0". This concept introduces an industry, where robots are intertwined with the human brain and work as collaborator instead of competitor. Unlike Industry 4.0's focus on automation, Industry 5.0 will foster collaboration between humans and autonomous machines. These machines will be intuitive, understanding human intentions and desires, leading to a harmonious work environment where humans and robots collaborate effectively. This collaboration will result in highly efficient production processes, reduced waste and lower costs. Industry 5.0 will redefine the concept of a robot, introducing robots that act as human companions and work alongside humans, ensuring safety and understanding human goals and expectations. These robots learn from human operators and execute tasks accordingly, providing a unique sense of satisfaction to humans working alongside them.[53]

2.2.3 Classification of manufacturing enterprises

Companies in the manufacturing sector are classified according to the categorization of enterprises.

> *"An enterprise is defined as a legal entity possessing the right to conduct business on its own, for example to enter into contracts,*

[52] Zhong et al. (2017), p. 616 ff.
[53] Nahavandi (2019), p. 1 ff.

own property, incur liabilities and establish bank accounts" (OECD (2023))

Enterprises are classified in different categories according to their size and to measure this size, different criteria may be used. The most commonly used is the number of people employed. According to the European Union, small and medium-sized enterprises (SMEs) employ fewer than 250 people and are further subdivided in micro enterprises (fewer than 10 employees), small enterprises (10 to 49 employees) and medium-sized enterprises. Enterprises with more than 250 people employed are categorized as large enterprises (Table 3).[54] Additionally, the European Commission determined certain annual turnover values to classify the different enterprise sizes. This turnover threshold is below 50 million € for medium-size companies, smaller than 10 million € for small enterprises and a maximum of 2 million € for micro sized enterprises.[55]

Table 3: Enterprise size classification (by (OECD (2023))

Category	Employees	Annual turnover
Micro enterprise	1 – 9	<= € 2 m
Small enterprise	10 - 49	<= € 10 m
Medium-sized enterprise	50 - 249	<= € 50 m
Large enterprise	> 250	> € 50 m

Apart from the definition of the European Commission for the sizes of enterprises, there are several other classification guidelines from institutions around the world. The U.S. Small Business Administration for example, classifies businesses into three categories:

- small-sized businesses: annual revenue of less than $38.5 million and no more than 1,500 employees
- medium-sized businesses: annual revenue between $38.5 million and $1 billion and 1,500 to 2,000 employees
- large-sized business: over $1 billion in revenue and over 2,000 employees

Another classification is proposed by the Indonesian Central Statistic Agency which categorizes micro business with less than four workers, small businesses with less than 20 workers, medium-sized enterprises with 20-99 employees and large ones with more

[54] OECD (2023).
[55] European Commission (2003).

than 100 workers. However, within this work, the size classification of the European Union will be used.[56]

[56] Ahmad Nasrudin (2023), p. 1 ff.

3 Systematic literature review

A systematic literature review was performed, to get deeper insights into the state-of-the-art research regarding this topic. The aim of this literature review is on the one hand, to discover every input factor or policy that leads to a circular economy in manufacturing companies, and on the other hand, the impacts and outcomes of the circular economy in those companies. Furthermore, to discover the linkage between those input and outcome factors has been set as another target of this literature review.

3.1 Approach of the systematic literature review

The systematic literature review has the aim to map and evaluate the existing diversity of knowledge for a specific research topic. It is a key tool to highlight boundaries of the current scientific works and identify potential research gaps.[57] The process of a systematic literature review is typically structured in an iterative cycle consisting of different parts. The first step is to find appropriate key words and a database, followed by searching and categorizing the literature to determine the relevant research and lastly, to complete the analysis.[58] In the following, each step of the process is described and the results of them are presented.

3.1.1 Defining the appropriate keywords

As suggested, first a database was chosen. This works relies on the Scopus database to find relevant and qualitative papers. The Scopus database was chosen as it is the largest database of peer-reviewed research literature in the fields of science and technology and other scientific databases like Web of Science showed no significant differences with the identified search results. To obtain comprehensive data for the analysis of this research and avoid the exclusion of relevant scientific evidence, a broad strategy was used, limiting the search terms to four keywords with a variety of synonyms. To get the focus of the overall topic of this work, the first keyword was "circular economy". To find relevant information to the different practices and outcome factors of the circular economy, the second and third keyword were defined through a variety of different synonyms regarding these terms. The fourth and last key word aimed to set the focus on the micro company level of the manufacturing

[57] Tranfield et al. (2003), p. 207 f.
[58] Mark Saunders, Philip Lewis, Adrain Thornhill (2009), p. 2 ff.

industry. Hence, the fouth key word is "manufacturing company" and as synonym the broad term "industry" was used, in order to ensure no unintended exclusion of any research. A full list of all used keywords and the synonyms is presented in Table 4.

Table 4: Set of keywords

Keyword	Synonyms
circular economy	-
practice	• policy
outcome	• output • result • benefit
manufacturing company	• industry

3.1.2 Initial search results

With the use of the defined keywords, the "title, abstract, keywords" search in the Scopus database was used, as it guarantees the inclusion of all relevant research works. The results were further restricted to the relevant field of environmental science, engineering, business and management and economics. The search space was further limited to journal papers in the final publication stage, including the document types of articles, reviews and conference papers. The final search query used in Scopus was formulated as follows:

(TITLE-ABS-KEY(circular economy)) AND (TITLE-ABS-KEY(policy) OR TITLE-ABS-KEY(practice)) AND (TITLE-ABS-KEY(outcome) OR TITLE-ABS-KEY(output) OR TITLE-ABS-KEY(result) OR TITLE-ABS-KEY(benefit) OR TITLE-ABS-KEY(impact)) AND (TITLE-ABS-KEY(industry) OR TITLE-ABS-KEY(manufacturing company)) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"BUSI") OR LIMIT-TO (SUBJAREA,"ECON")) AND (LIMIT-TO (DOCTYPE,"re") OR LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"cp")) AND (LIMIT-TO (LANGUAGE,"English"))

This search string generated a raw data set of 1180 papers, which will be the primary data source of the literature review. To store and consequently analyze the raw data, the search results were downloaded in RIS format, including all important information, like author´s name, title, abstract and publication year. An initial analysis of the raw data shows, that the interest in circular economy increased sharply over the last few years (see Figure 5) and over 80 % of the papers published just over the last 4 years (2020-2023) within the total timeframe of publications from 2003-2023.

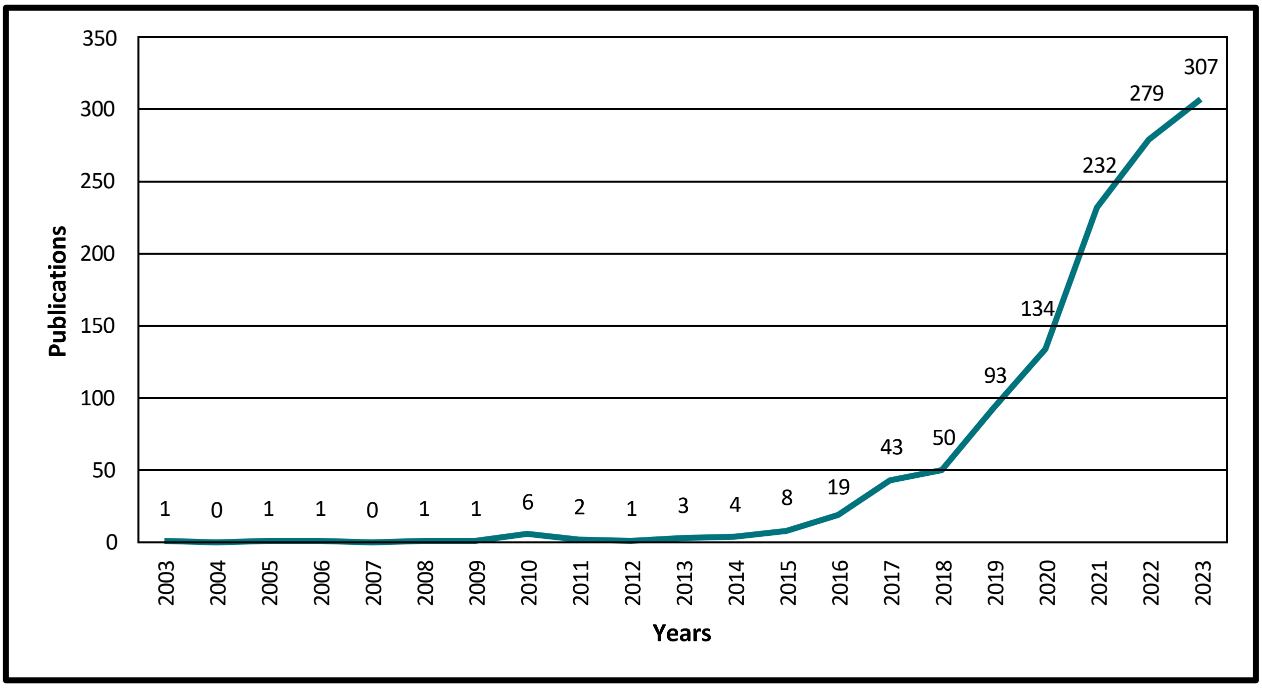

Figure 5: Number of publications of initial search results for each year

3.1.3 Refinement of the search results

The next step of the literature review was the refinement of the primary data and reduction to the essential papers which really focus on the relationship between what is done by a company to achieve circular economy and to what extent these measures influence the performance of the company regarding the different sustainability dimensions. In the first iteration cycle, the titles of all papers were categorized and classified as relevant (fitting/might be fitting for further analysis) or irrelevant. Papers only got categorized as irrelevant in this step, if the title made it clear, that it can´t contribute to this work. Reasons for being categorized as not relevant are for example that the publication won´t be before 2024, that they don´t focus on the manufacturing sector but rather on other economic sectors like the food sector, tourism, construction service, healthcare or municipal waste or also because the focus of the paper was on influences not on micro level, but on macro level, regarding policies and strategies of whole countries. This first screening iteration led to the exclusion of 725 papers, resulting in 455 papers (39%) categorized as relevant for further analysis. In order to be able to fully determine if a paper is relevant for this work or not, a second screening iteration has been performed and the publications were rated based on their abstract and title. This rating matrix consists of three levels: high-, medium- and low-appropriate for this study. Papers which have no focus on circular economy (e.g. only mentioned circular economy in the abstract as an example) or are directed on other industry sectors apart from the manufacturing sector were rated as low-appropriate for this work. Medium-appropriate studies were classified as such because they mentioned circular economy in combination with blockchain or Industry 4.0 and had the focus not on the circular economy itself, but rather on the other topics. Another reason for the categorization as medium-appropriate and not high-appropriate is the lack of relevant focus on the practices and outcomes of the circular economy. Table 5 shows the result of the rating process of the identified records of the first screening iteration. Of these, 42 papers were classified as high-appropriate, while 203 papers classified as medium-appropriate, and 210 publications got a rating of low-appropriation.

Table 5: Results of second screening iteration

Appropriateness	Papers	Papers [%]
High-appropriate papers	42	9.23
Medium-appropriate papers	203	44.62
Low-appropriate papers	210	46.15
Total	455	100.00

3.1.4 Data analysis

As these 42 papers are rated as high-appropriate for this work, they will be analyzed more deeply in the following. Following the upstream trend of the last years, the most publications were made over the last few years (Figure 6).

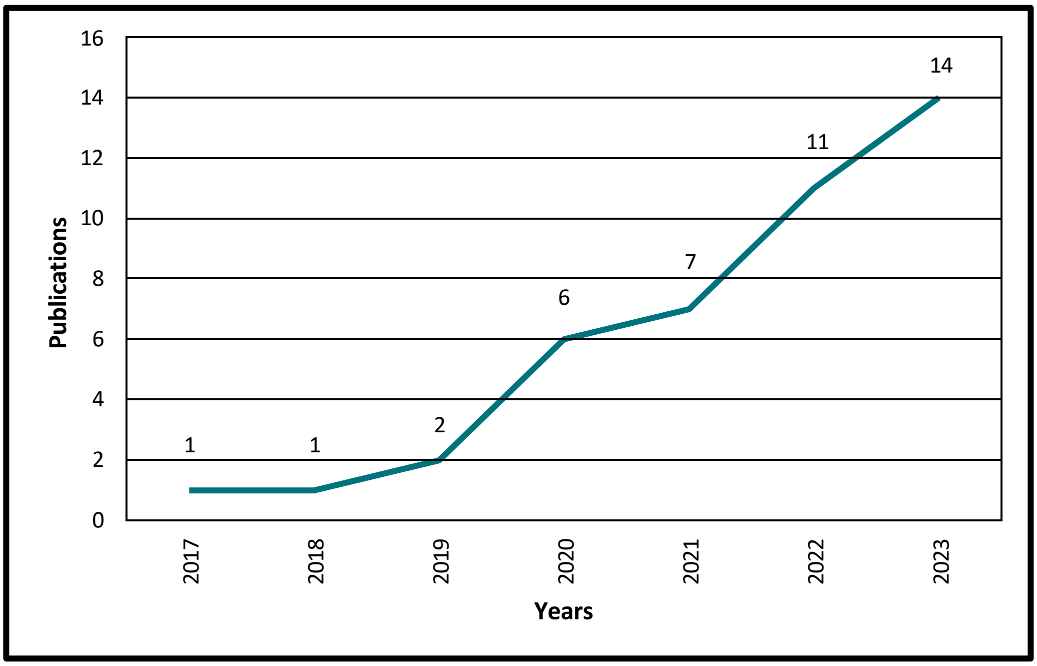

Figure 6: Publications per year of high-appropriate papers

Out of the records, one paper was published (2.4%) in 2017, one paper (2.4%) in 2018, two (4.8%) in 2019, six (14.2%) in 2020, seven (16.7%) in 2021, eleven (26.2%) in 2022 and 16 (33.3%) in 2023. It clearly shows that the interest in the connection of circular economy practices and policies with outcomes is quite modern and the trend is facing upwards. Most often, papers within the defined limitations are published in Business Strategy and the Environment, Journal of Cleaner Production, Procedia CIRP, Resources, Conservation and Recycling, Sustainability (Switzerland) and Sustainable Production and Consumption (Table 6).

Table 6: Top contributing publication sources

Source	Records	Records [%]
Journal of Cleaner Production	7	16.67
Sustainable Production and Consumption	6	14.29
Sustainability (Switzerland)	6	14.29
Business Strategy and Environment	3	7.14
Resources, Conservations and Recycling	3	7.14
Procedia CIRP	2	4.76
Others	15	35.71

3.1.5 Data structuring

In order to be able to perform the analysis of the found literature during the review process, it is important to structure the content analysis. The first part of the content analysis will provide all practices, policies and activities included in the 42 papers rated as high-appropriate for this work, which are considered as "circular". As there exists confusion about what a circular economy practice or policy is, some publications mention practices and policies which do not align with the R concept this paper uses as guideline. Hence, the most common mentioned practices and policies will be listed, and if necessary, additional practices and policies will be added to the R framework this work uses. The second part of the content analysis will concern the outcomes and benefits of these previous determined circular economy practices and policies. The goal is to focus on circular economy outcomes, as again, some literature is mixing up circular economy with other related terms, such as sustainability or green production. Again, the most commonly mentioned outcomes will be selected as circular economy outcomes, as they are supported by enough research.

The last part of the content analysis of this literature review aims to connect the circular economy practices and policies determined in the first part of the analysis with the outcomes and benefits determined in the second part. The target in doing so, is to find patterns of certain practices/policies connected with certain outcomes. Through finding these connections, which are mentioned and supported by multiple studies, later on, hypotheses can be formulated based on these findings.

3.2 Content analysis of the systematic literature review

In the following, the 42 publications declared as high-appropriate will be analyzed regarding the three sections explained previously. The content analysis will summarize the results of each section and give an insight into the state-of-the-art research on this field.

3.2.1 Circular economy practices and policies

This section will give an overview about practices, policies and in general all inputs, which lead to a circular economy mentioned by each of the 42 publications. The purpose of this section is to subsequently obtain a set of practices/policies based on the number of references throughout the selected papers.

Table 7: Circular economy practices/policies mentioned in the studies (Explanation of coding 1-16 see Table 8)

Reference	Methods	Circular economy practices/policies															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(Albertsen et al. (2021))	Case study Interview		x	x	x	x	x										
(Alvarado-Bawab; Villa Marenco (2023))	Interview	x				x		x	x	x					x		
(Barón et al. (2020))	Content analysis		x				x	x	x	x	x	x			x		
(Barreiro-Gen; Lozano (2020))	Survey	x	x	x		x											
(Battesini Teixeira et al. (2023))	Literature review Case study Expert interview	x	x			x		x		x							
(Carvalho Araújo et al. (2019))	Literature review					x				x							
(Khan; Haleem (2021))	Literature review Expert interview	x		x		x	x	x	x	x	x	x	x		x	x	x
(Ramsheva et al. (2020))	Interview Case study	x	x			x		x		x							
(Stewart; Niero (2018))	Literature review	x		x		x		x	x	x	x						
(Bressanelli et al. (2021))	Literature review					x	x	x							x		
(Garcia-Saravia Ortiz-de-Montellano et al. (2023))	Content analysis	x	x	x	x	x				x	x					x	
(Hrdlička; Severová (2022))	Case study			x													
(Keßler et al. (2021))	Content analysis					x				x							
(Liu et al. (2018))	Content analysis				x					x							
(Liu et al. (2023))	Survey Case study							x				x					
(Mansilla-Obando et al. (2022))	Interview Case Study	x				x				x							
(Marrucci et al. (2022))	Content analysis			x						x							
(Padilla-Rivera et al. (2020))	Literature review	x				x				x							
(Russell; Nasr (2023))	Case study		x	x						x							
(Valusyte (2021))	Literature review Case study							x									

Reference	Methods	Circular economy practices/policies															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(Russell; Nasr (2023))	Case study		x	x						x							
(Valusyte (2021))	Literature review Case study							x									
(Walker et al. (2021))	Interview																
(Yu et al. (2022b))	Questionnaire			x		x		x									
(Barón Dorado et al. (2022))	Content analysis			x		x	x	x	x	x	x					x	x
(Baumer-Cardoso et al. (2023a))	Literature review Survey	x								x	x			x	x		
(Baumer-Cardoso et al. (2023b))	Case study	x				x				x	x				x		
(Bracquené et al. (2022))	Sensitivity analysis	x		x		x	x			x						x	
(Saraji; Streimikiene (2022))	Literature review	x		x		x	x	x		x		x	x		x		
(Bressanelli et al. (2020))	Case study					x		x									x
(Chen; Dagestani (2023))	Literature review	x				x				x						x	
(Fernando et al. (2021))	Literature review Survey					x		x									
(Khan et al. (2023))	Literature review					x				x							
(Khan et al. (2022))	Survey	x				x				x							
(Mora-Contreras et al. (2023a))	Content analysis	x		x		x		x									
(Mora-Contreras et al. (2023b))	Literature review			x		x	x	x				x	x				
(Oliveira Rosa; Oliveira Paula (2023))	Literature review	x				x		x	x	x							
(Peter John; Mishra (2023))	Literature review	x	x			x	x	x		x							
(Roci et al. (2022))	Case study			x		x		x		x					x	x	
(Rodríguez-González et al. (2022))	Survey Interview	x		x		x				x							
(Sousa-Zomer et al. (2017))	Literature review Case study	x		x			x			x					x		
(Susanty et al. (2020))	Questionnaires	x						x								x	

References	Methods	Circular economy practices/policies															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(Yin et al. (2023))	Literature review					x	x	x				x					
(Yu et al. (2022a))	Content analysis							x								x	

Table 8: Coding of circular economy practices/policies and how often they are referenced

Code	Circular economy practice/policy	Number of references	Number of references [%]
1	Reduce	21	50.00
2	Repair	8	19.05
3	Refurbish	17	40.48
4	Repurpose	3	7.14
5	Recycle	30	71.43
6	Take-back system	11	26.19
7	Redesign/circular design	22	52.38
8	Using renewable energies	6	14.29
9	Reuse	27	64,29
10	Using biodegradable/renewable materials	7	16.67
11	Make production more environmental efficient	6	14.29
12	Environmental supplier selection	3	7.14
13	Workforce training related to circular economy	1	2.38
14	Make products a service	9	21.43
15	Recovery	8	19.05
16	Product traceability	3	7,14

Table 7 gives a full listing of all the circular economy practices and policies which were mentioned in each of the 42 individual high appropriate papers. Two thirds (28) of the papers mention two to five practices/policies ,which represents the majority across the papers. Another big share of the papers (eleven papers) mentions between six and nine practices and policies, frequently referring to multiple circular economy activities in the same sentence or passage. Only three of all the papers do not fit in one of those categories and represent exceptions, either to their small number (one practice) or very high number (13 practices and policies) of mentioned circular economy practices (see Table 9). On average, 4.33 circular economy practices and policies were mentioned per paper across all the publications. Additionally, also the methods used by the publications are included in the table. Most commonly literature review and case study is used as method across the publications, followed by content analysis and interview. A rather small part of the papers used surveys or questionnaires as their research method.

Table 9: Number of circular economy practices/policies mentioned

Mentioned CE practices/policies	Paper quantity	Paper quantity [%]
1	2	4.76
2	8	19.05
3	7	16.66
4	6	14.28
5	7	16.67
6	5	11.90
7	1	2.38
8	2	4.76
9	2	4.76
10	0	0
11	0	0
12	0	0
13	1	2.38
Total	42	100

Table 8 declares the codes of the different circular economy practices and policies used and demonstrates the total number of mentions in all the papers. As expected, the practices of the R theory are mentioned the most. Redesign, Reduce, Refurbish, Recycle and Reuse were all mentioned in about half or more (except Refurbish in only 40 %) of the papers. Other activities referring to circular economy and frequently mentioned were the introduction of a take-back system, transforming products into a service and two of the less mentioned R strategies, Repair and Recover.

3.2.2 Circular economy outcomes

Following all the practices and policies of the circular economy, this secondary section of the content analysis of the literature review will summarize all the outcomes, which are understood as circular economy outcomes in the literature. The focus of these outcomes will be the direct connection between a circular economy practice or policy and its immanent outcome. The importance of this sharp distinction of outcomes is the smearing of circular economy outcomes with general environmental outcomes or sustainability outcomes. By detecting the most commonly referenced circular economy outcomes, it will be possible to find connections between those outcomes and the circular economy practices and policies which facilitated them.

Table 10: Circular economy outcomes mentioned in the studies (Explanation of coding 1-17 see Table 11)

Reference	Theory	Circular economy outcome																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(Albertsen et al. (2021))	-	x																x
(Alvarado-Bawab; Villa Marenco (2023))	-	x	x	x	x	x												
(Barón et al. (2020))	-		x	x	x	x	x	x	x	x								
(Barreiro-Gen; Lozano (2020))	-		x	x				x										
(Battesini Teixeira et al. (2023))	-		x		x		x	x										
(Carvalho Araújo et al. (2019))	-		x	x			x	x	x									
(Khan; Haleem (2021))	-		x	x	x	x		x										
(Ramsheva et al. (2020))	-		x	x				x	x									
(Stewart; Niero (2018))	-		x		x		x	x	x	x								x
(Bressanelli et al. (2021))	-	x	x	x								x						
(Garcia-Saravia Ortiz-de-Montellano et al. (2023))	-		x		x		x		x				x					
(Hrdlička; Severová (2022))	-		x					x					x					
(Keßler et al. (2021))	-		x	x			x											
(Liu et al. (2018))	-		x		x													
(Liu et al. (2023))	Practice-based		x		x			x				x						x
(Mansilla-Obando et al. (2022))	Stakeholder			x			x	x			x							
(Marrucci et al. (2022))	-		x						x	x								
(Padilla-Rivera et al. (2020))	-												x	x				
(Russell; Nasr (2023))	-		x	x	x					x		x	x					x
(Valusyte (2021))	-		x				x											x
(Walker et al. (2021))	-												x		x			
(Yu et al. (2022b))	-	x														x	x	

Reference	Theory	Circular economy outcome																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(Barón Dorado et al. (2022))	-						x	x	x									
(Baumer-Cardoso et al. (2023a))	-		x	x	x	x			x	x								x
(Baumer-Cardoso et al. (2023b))	-		x		x	x	x	x	x	x				x	x			x
(Bracquené et al. (2022))	-			x			x	x										x
(Saraji; Streimikiene (2022))	-		x	x	x		x	x	x									
(Bressanelli et al. (2020))	-		x	x		x		x		x								
(Chen; Dagestani (2023))	Resource-based Stakeholder		x					x										
(Fernando et al. (2021))	Resource-based									x								
(Khan et al. (2023))	-	x								x								
(Khan et al. (2022))	Resource-based			x														
(Mora-Contreras et al. (2023a))	Resource-based Dynamic capability	x				x							x					x
(Mora-Contreras et al. (2023b))	-			x	x		x	x	x		x				x			
(Oliveira Rosa; Oliveira Paula (2023))	-		x	x	x	x		x	x									
(Peter John; Mishra (2023))	-	x	x							x								x
(Roci et al. (2022))	-									x								
(Rodríguez-González et al. (2022))	Resource-based	x	x	x	x			x				x						
(Sousa-Zomer et al. (2017))	-		x				x											
(Susanty et al. (2020))	-	x		x								x						
(Yin et al. (2023))	-	x		x	x											x		
(Yu et al. (2022a))	Organization capability	x	x							x								

For the analysis of the circular economy outcomes, every outcome which was mentioned in the papers as an outcome induced by a circular economy practice or policy was noted for every single paper (see Appendix). Table 10 gives an overview of all the different outcomes mentioned in the papers with coding for the outcomes provided in Table 11. In addition, the table includes the theory (if there is any) used by the publication. Surprisingly only very few of the publications (19.05 %) even based their work on any theory. Among the used theories, the resource-based view (RBV) was used the most with a total number of five papers. The other used theories, which includes the practice-base view, the stakeholder theory, the dynamic capability theory and the organization theory, were only used by one or two papers.

Table 11: Coding of circular economy outcomes and how often they are referenced

Code	Circular economy outcome	Number of references	Number of references [%]
1	Higher Revenue/Profit	10	23,81
2	Less raw/primary materials used	26	61,90
3	Reducing waste	20	47,62
4	Reduce/Improve energy consumption	16	38,10
5	Reduce/Improve water consumption	8	19,05
6	Extension of life cycle	14	33,33
7	Reuse of waste	19	45,24
8	Use of renewable energy	12	28,57
9	Reduce emissions	11	26,19
10	Customer responsibility for the product	2	4,76
11	Lowering material purchasing/production costs	5	11,90
12	Job creation	6	14,29
13	Social equity	2	4,76
14	Higher hours of training/More trained workforce	3	7,14
15	Market share	2	4,76
16	Product quality	1	2,38
17	Higher recycling ration	11	26,19

Among the outcomes, the result of the content analysis was not as clear as with the circular economy practices and policies, as the results of the mentioned outcomes are more spread across the different papers. The use of less primary or raw material (61.90 %), reducing waste (47.62 %) and the reuse of waste (45,24 %) were mentioned most frequently across the 42 papers. A fairly large number of publications named reduced or improved energy (38.10 %) or water (19.05 %) consumption, the extension of the life cycle (33.33 %), the use of renewable energy sources (28.57 %), reduced emissions (26.19 %) and higher revenue/profit (23.81 %) and recycling rates 26.19 %) as outcomes of circular economy practices/policies. Other outcomes were only mentioned by a very small number of papers, which indicates that they have a lower importance among the different circular economy outcomes.

3.2.3 Links of circular economy practices/policies and outcomes

The concern of this third and final section of the content analysis of the literature review is finding the direct links between circular economy practices/policies and circular economy outcomes. While analyzing the papers, the focus was laid on identifying the concrete impacts of activities, which were identified as circular economy practices or policies. The reason for this is, that on the one hand, a lot of papers limit the outcomes of certain circular economy practices/policies to a general point of view, for example Liu et al. say that circular design leads firms to financial and environmental performance improvement, or Keßler et al. state that recycling leads to a lower environmental burden and reuse has an even lower environmental impact.[59] These general outcomes like financial or environmental improvement can mean a lot of different things and are not very specific and therefore create a lot of uncertainty regarding the impacts of circular economy practices. On the other hand, there are also a lot of papers which mention a concrete outcome of circular economy practices and policies, like Mora-Contreras mentioned increased water reuse and higher revenue and Yin found a connection between circular economy practices and waste reduction, energy consumption and pollution reduction.[60] However, since the outcomes are not connected to a specific practice or policy, these findings do not help in identifying the direct links between practices/policies and their outcomes.

Table 12: Links between circular economy practices/policies and circular economy outcomes

Practice/Policy	Induced outcome	Number of mentions
Recycling	Higher Revenue/Profit	3
Recycling	Reducing waste	9
Recycling	Reuse of waste	2
Recycling	Less primary material	5
Recycling	Product quality	1
Recycling	Customer responsibility for the product	1
Recycling	Lowering purchasing/production costs	2
Recycling	Reduce/Improve energy usage	1
Recycling	Reducing emissions	1
Recycling	Higher recycling ratio	2
Reuse	Less primary material	4
Reuse	Reducing waste	7
Reuse	Extension of life cycle	2
Reuse	Reuse of waste	2
Reuse	Higher Revenue/Profit	3
Reuse	Customer responsibility for the product	1
Reuse	Reduce emissions	2
Reuse	Lowering purchasing/production costs	3

[59] Liu et al. (2023), p. 1 ff.; Keßler et al. (2021), p. 1 ff.
[60] Yin et al. (2023), p. 1 ff.; Mora-Contreras et al. (2023a), p. 77 ff.

Practice/Policy	Induced outcome	Number of mentions
Reuse	Reduce/Improve energy usage	2
Reduce	Reduce/Improve energy usage	2
Reduce	Reduce/Improve water usage	2
Reduce	Customer responsibility for the product	1
Redesign	Reducing waste	3
Redesign	Less primary material	8
Redesign	Reuse of waste	1
Redesign	Extension of life cycle	7
Redesign	Reduce/Improve energy usage	2
Redesign	Higher recycling ratio	1
Repair	Extension of life cycle	2
Repair	Less primary material	1
Repair	Reduce/Improve energy usage	1
Repair	Reduce emissions	1
Repair	Reducing waste	1
Repair	Lowering purchasing/production costs	1
Refurbish	Reducing waste	4
Refurbish	Higher Revenue/Profit	1
Refurbish	Job creation	1
Refurbish	Extension of life cycle	1
Refurbish	Less primary material	3
Refurbish	Reduce/Improve energy usage	2
Refurbish	Lowering purchasing/production costs	1
Refurbish	Reduce emissions	1
Refurbish	Job creation	1
Recovery	Reuse of waste	2
Recovery	Reducing waste	1
Recovery	Less primary material	2
Recovery	Lowering purchasing/production costs	1
Recovery	Higher Revenue/Profit	1
Recovery	Reduce emissions	2
Recovery	Reduce/Improve water	1
Recovery	Customer responsibility for the product	1
Take-back system	Extension of life cycle	1
More environmental-efficient production	Reduce emissions	2
More environmental-efficient production	Reducing waste	4
More environmental-efficient production	Reduce/Improve energy usage	2
More environmental-efficient production	Reduce/Improve water usage	1
CE workforce training	Higher training hours/more trained staff	1

Table 12 gives a full summary of all the identified connections between circular economy activities and outcomes and their frequency of occurrence. Recycling was the practice with the most identified direct outcomes, with a total number of ten different outcomes, mentioned a combined 27 time across the publications. The strongest impacts of recycling regarding the literature are reducing waste, using less primary material and generating a higher revenue/profit. The Reuse strategy was the practice with the second most identified links, just behind Recycling, with nine different outcomes mentioned in 26 time in the papers. The outcomes mentioned the most were the same as the one induced by the Recycling strategy. Redesign is the third most mentioned circular economy practice with direct outcomes and the literature frequently mentions reducing waste and the extension of the product life cycle as impacts of the Redesign strategy. The Repair (six outcomes mentioned seven times), Refurbish (nine outcomes mentioned a combined 15 times) and Recovery (eight outcomes mentioned a total eleven times) strategies have also been mentioned quite frequently in combination with direct impacts. For the Reduce strategy, although it was one of the most referenced circular economy practices overall, the literature provides very little evidence of direct impacts of it. Across all the 42 papers, only five mentioned an outcome directly generated by the Reduce strategy. Apart from the practices included in the R theory, almost no other practice or policy was mentioned with a direct impact. The introduction of a take-back system and workforce training related to circular economy were only linked to one direct outcome each, throughout all publications. The focus on a more environmentally friendly production is the only one worth mentioning, hence it was linked to four different outcomes mentioned nine time in total. For all the other practices and policies identified in the first part of this content analysis of the literature review, no direct links have been found between those circular economy practices/policies and direct circular economy outcomes.

However, there are some research gaps among the studies. A greater part of them focus their research on a specific sector of the manufacturing industry, like Carvalho Araújo et al. on the wood panel production or Battesini Teixeira et al. on the textile industry or on a special geographical region, for example Barón et al. on manufacturing companies in Spain.[61] Furthermore, the connections between circular economy practices or policies and circular economy outcomes, were mostly identified by the studies by literature review or case studies, often just based on a few singular companies like Roci et al. or Bressanelli et al. did.[62] Extensive quantitative analysis with the use of a database was only conducted by two studies, but they again focused on a specific geographic region. Chen et al. used data from the China Stock Market & Accounting Research Database (CSMAR) to analyze nearly 15,000 firm-year

[61] Carvalho Araújo et al. (2019), p. 1 ff.; Battesini Teixeira et al. (2023), p. 1 ff.; Barón et al. (2020), p. 1 ff.
[62] Roci et al. (2022), p. 97 ff.; Bressanelli et al. (2020), p. 1 ff.

datasets of Chinese companies and found a positive impact of circular economy practices on the firm performance. However, they only analyzed the general impact of circular economy practices and their impact and did not focus their research on any specific practices or outcomes. Mora-Contreras et al. used the government data from the Colombian government and analyzed the impact of circular manufacturing practices on the sustainability performance of the companies.[63] They used the data of 1544 manufacturing companies and employed a longitudinal quantitative study on them, resulting in the conclusion, that circular manufacturing could potentially lead to sustainable performance, such as higher economic value from selling waste, increased water reuse or creating green jobs.[64]

In summary, at present there is no scientific research regarding the connection of circular economy practices and policies and their particular outcomes, which is based on quantitative data of an independent and extensive database. Moreover, research based on literature review or case studies concerning this link between the practices/policies and outcomes focuses for a greater part on just a single or a small number of connections and does this mostly in a qualitative way, without quantifying the results with actual numbers. So, although circular economy practices are substantial for the future development of the manufacturing industry, regarding the economic and environmental challenge the sector will be facing, there is dearth of empirical evidence to support the numerous claims among the literature, that circular economy practices are the key to solve these problems. This study narrows these research gaps in the circular economy literature.

[63] Chen; Dagestani (2023), p. 1 ff.
[64] Mora-Contreras et al. (2023a), p. 77 ff.

4 Theory and hypothesis development

Based on the results conducted through the systematic literature review, the following chapter explains the theory used in this paper and how it is applied in the context of circularity. Subsequently, based on the theory and the literature review, assumptions are formulated in the form of hypotheses, which are then tested with statistical means.

4.1 Resource based view

Studies regarding the circular economy have extensively investigated numerous aspects of it, with a wide range of different theories used throughout them.[65] In this study, the well-established and commonly used theoretical framework of the resource-based view is utilized to investigate the direct influence of circular economy practices and policies on their immediate circular economy outcomes. This theory provides a solid foundation for this research and helps to enhance the understanding of this connection. The development of the resource-based view leads back to 1984, to the work of Wernerfelt. He pointed out, that seeing a firm from another perspective, namely the resource-based one, could lead to a different understanding, especially of different business strategies. Thereby, the resource-based view represents an alternative to the much older and well know product-based view. Wernerfelt classifies resources as anything that could be thought of as a strength or weakness of a firm, like knowledge of technology, employment of skilled personnel or efficient processes and machinery.[66] Competitive advantage can be sustained through the use of resources that are valuable, rare, imperfectly imitable, and non-substitutable.[67]

As the theory evolved, further aspects have been taken into account regarding this theory. DeSarbo et al. pointed out that the resource-based view also needs to take the heterogeneity into account. They state that it is not enough to say, that resources and performance are in a relationship, but that this relationship can vary, based on the used resources and also on the performances achieved due to the heterogeneity of the different firms.[68] Sarkis et al. suggest, that future studies should include a theoretical view and make use of the resource-based view to achieve outcomes through the circular economy. Additionally, five out of the eight papers including a

[65] Kurapatskie; Darnall (2013), p. 49 ff.
[66] Wernerfelt (1984), p. 171 ff.
[67] Barney (1991), p. 99 ff.
[68] DeSarbo et al. (2007), p. 103 ff.

theoretical perspective which were identified in the literature review, are using the resource-based view to build upon their study.[69]

4.2 Circular economy practices/policies lead to circular economy outcomes

There are several papers which state the positive impact of circular economy practices on the performance of a company. Chen and Dagestani identified a positive impact of circular economy practices on firms' performance.[70] Yin et al. found a positive correlation between circular economy practices and enterprise performance, environmental factors and financial indicators.[71] However, there has been no research on the specific outcomes of the most practiced circular economy practices or policies conducted with an extensive database. The existing literature narrows the results down to only one or two practices or outcomes or talks about benefits in general, like Alvarado-Bawab et al. who focus the outcome of recycling only on waste reduction, or Khan who mentions material and energy reduction as the only impacts of circular design practices.[72] To give a better understanding to the decision-makers of the manufacturing companies about the induced circular economy outcomes through the implementation of certain practices or policies, there is a need to draw exact connections between those two factors. Practitioners have to know which circular economy practice will have which outcomes and if it even has a worthy enough outcome to invest money in implementing it.

To substantiate the connections between those practices/policies and their potential outcomes, some of the most mentioned practices and outcomes identified by the systematic literature will be analyzed. This will be done by categorizing the circular economy practices and policies, as well as their potential outcomes in the first step.

4.2.1 Categorization and selection of circular economy practices/policies

Regarding the practices, a categorization can be done according to the 9R framework of Potting et al.. He divides the circular economy initiatives in three groups with increasing circularity and thus less environmental pressure. The first group covers

[69] Sarkis et al. (2011), p. 1 ff.
[70] Chen; Dagestani (2023), p. 1 ff.
[71] Yin et al. (2023), p. 1 ff.
[72] Alvarado-Bawab; Villa Marenco (2023), p. 191 ff.; Khan; Haleem (2021), p. 357 ff.

the end of pipe initiatives which he summarizes as "*useful application of materials*" (Potting et al. (2017), p. 15.). Recycling is dedicated to this group and will represent the end of pipe initiative in this study. The second group focuses on the extension of lifespan of products and its parts and includes the repair or remanufacture initiatives for example. As those practices were not as frequently mentioned as other ones, there will be no analysis regarding this group of initiatives. The third and potentially most circular group contains the prevention strategies, which focus on smarter product use and manufacture. Out of this group the focus will be laid on the Redesign strategy, as it was one of the most mentioned practices throughout the identified papers in the literature review.[73]

4.2.2 Selection of circular economy outcomes

Regarding the outcomes of the previously mentioned policies, in total five different outcomes have been selected, as specific circular economy outcomes. The first one is the amount of generated waste (which was also the second most frequently mentioned circular economy outcome). Waste has certain characteristics, as the fact that it is unwanted solid material, that it has no further use and that it creates costs. The second outcome variable is the recycling ratio.[74] The third and fourth outcome variable concern usage amounts, namely the discharged water and the usage of energy. The final outcome variable regards the emission of CO_2 gases and CO_2 equivalents. Altogether, this makes a total of five circular economy outcomes (Table 13).

Table 13: List of circular economy outcomes

Circular economy outcomes
Produced waste
Recycling ratio
Discharged water
Energy use
CO_2 emissions

[73] Potting et al. (2017), p. 1 ff.
[74] Turunen (2018), p. 60 f.

4.2.3 Relation between recycling and circular economy outcomes

The first practice that will be looked at in more detail is also the one that is most often mentioned in the literature, the recycling practice. Recycling is an end of pipe initiative and can basically be divided into three different approaches. Functional recycling is the process of recovering materials for the purpose they were originally used or for other purposes. Downcycling converts the recovered materials into new materials of lesser quality and functionality and in general requires less energy and work to undertake. The third possibility of recycling is also the one the least used and is called upcycling. Upcycling converts materials into new materials with a higher value and quality and increased functionality.[75]

The EU defines the Recycling principle as : "*any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations*" (EU (2008)). Recycling of waste offers various benefits, for example the opportunity to benefit from still usable resources and thereby reduce the total quantity of waste that needs to be dealt with. Recycling prevents the problems of treating and disposing waste which leads to landfill, thus decreasing the related environmental and economic impacts.[76] Recycling is also part of the most used of the R frameworks, the 3R framework (reduce, reuse, recycle) and among all studies the practice most commonly mentioned along with the circular economy.[77] Because of its importance across the literature it is of great significance to analyze the specific circular economy outcomes of the recycling practice.

In the literature, there are several implications of the influence of recycling on the recycling ratio. Albertsen et al. stated that recycling rates rise if the recycling process is optimized by specializing on certain products and Stewart and Niero mention the recycling ratio as a target KPI to achieve circular economy through recycling.[78] Even more scientific work refers to a direct influence of recycling and the reduction of waste. This specific connection was mentioned in nearly a quarter of all the papers included in the systematic literature review and is thereby the most frequently

[75] World Economic Forum (2014), p. 25.
[76] Cagno et al. (2005), p. 593 ff.; Zhu (2008), p. 3 ff.
[77] Kirchherr et al. (2017), p. 221 ff.
[78] Albertsen et al. (2021), p. 6.; Stewart; Niero (2018), p. 1011.

mentioned connection identified. Yu et al. stated in his findings, that recycling effectively leads to reduced waste and Ramsheva et al. came to the same conclusion while analyzing recycling outcomes in the concrete business.[79] Sousa-Zomer et al. pointed out *"reducing valuable materials losses"* (Sousa-Zomer et al. (2017)) as an environmental benefit of recycling and Rodriguez-González et al. found out that recycling facilitates not only the reduction of production costs but also of industrial waste in the automotive industry.[80]

Regarding the other three circular economy outcomes, which are the reduction of the discharged water, the energy usage and the emission of CO_2, literature also mentions those as potential outcomes of recycling practices. Although no specific evidence has been found, throughout the literature review, connecting recycling practices or policies and reduction of water consumption, this outcome was mentioned in general as a positive benefit of circular economy practices in one fifth of all analyzed papers. The reduction of energy usage was even mentioned twice as much, for example in the results of the case studies of Bressanelli et al.. They investigated the outcomes of circular economy practices through four case studies, in which one of them a reduction of energy consumption of 77% was achieved through implementing recycling initiatives. Bressanelli et al. also observed the reduction of CO_2 emissions as a potential outcome of circular economy practices. In one case, the company observed in the case study, was able to reduce their emission of CO_2 gases by 95% by using a recycling strategy.[81]

Based on these implications of the literature, the first hypothesis is formulated.

H_1: Recycling practices/policies relate to circular economy outcomes

4.2.4 Relation between redesign and circular economy outcomes

The second circular economy practice which will be analyzed regarding its direct circular economy outcomes is the redesign or circular design strategy, which is part of the prevention strategies. The redesign strategy is part of the extension of the 3R concept (reduce, reuse and recycle) to the 6R concept, along with recover and remanufacture.[82] The Ellen MacArthur Foundation mentions the product design as one

[79] Ramsheva et al. (2020), p. 11.; Yu et al. (2022a), p. 9.
[80] Rodríguez-González et al. (2022), p. 5.; Sousa-Zomer et al. (2017), p. 34.
[81] Bressanelli et al. (2021), p. 4.
[82] Khaw-ngern et al. (2021), p. 1440 ff.

of the fundamental principles of the circular economy. By designing products with the intention to fit within biological and technical material cycles, waste will not exist anymore. The products should be further designed for disassembly and refurbishment to be used again with minimal energy and highest quality retention.[83] The principle of the product integrity guides circular design, as it is the degree to which a product remains equal to its original quality over time and at the same time is minimizing the environmental costs of the product.[84]

Bakker et al. distinguish six different main strategies of circular design, ranked by their importance. The first strategy, "Design for attachment and trust," focuses on building an emotional bond with users to extend product lifespan. The second strategy, "Design for durability," aims to prevent product failure by enhancing reliability and aligning with economic and stylistic lifespans. The third strategy, "Design for standardization and compatibility," promotes easy repair with interchangeable parts and reduced consumption through versatile product use. The fourth strategy, "Design for maintenance and repair," seeks to increase product longevity by simplifying components and joints, thereby reducing labor requirements. The fifth strategy, "Design for adaptability and upgradability," focuses on facilitating future product modifications. Lastly, the sixth strategy, "Design for ease of disassembly and reassembly," aims to create products and parts that are easily disassembled, reassembled and recycled.[85]

The redesign strategy integrates the circular economy idea at the earliest possible stage of a product, the design process. This is important, because once product specifications are made, only minor changes are possible.[86] This huge potential impact of redesigning products to achieve different circular economy outcomes is also backed by the literature, as redesign was overall the third most mentioned circular economy strategy, referred to in more than 50% of the identified papers.

The relationship between redesign practices or policies and their benefits regarding its circular economy outcomes have been identified in several different papers. Yu et al. for example stated, that the recycling ratio and the extent to which a product can be recycled in the final stage of its life cycle, is already determined in the earliest stage of

[83] World Economic Forum (2014), p. 21 ff.
[84] Valusyte (2021), p. 1 ff.
[85] Bakker et al. (2014), p. 1 ff.
[86] Bocken et al. (2016), p. 308 ff.

the product when it is designed.[87] In addition, this paper mentioned, that waste can be prohibited by *"implementing sustainable practices of green environmental protection […] in product design"* (Yu et al. (2022a), p. 9.). Mora-Contreras et al. mentioned the minimization of waste as one of the benefits of the correct product design and Bressanelli et al. even go one step further and stated that without respecting the capability of a product to be recycled, it cannot be further processed at the end of its life cycle and might be sent to a landfill and thereby produces more waste.[88]

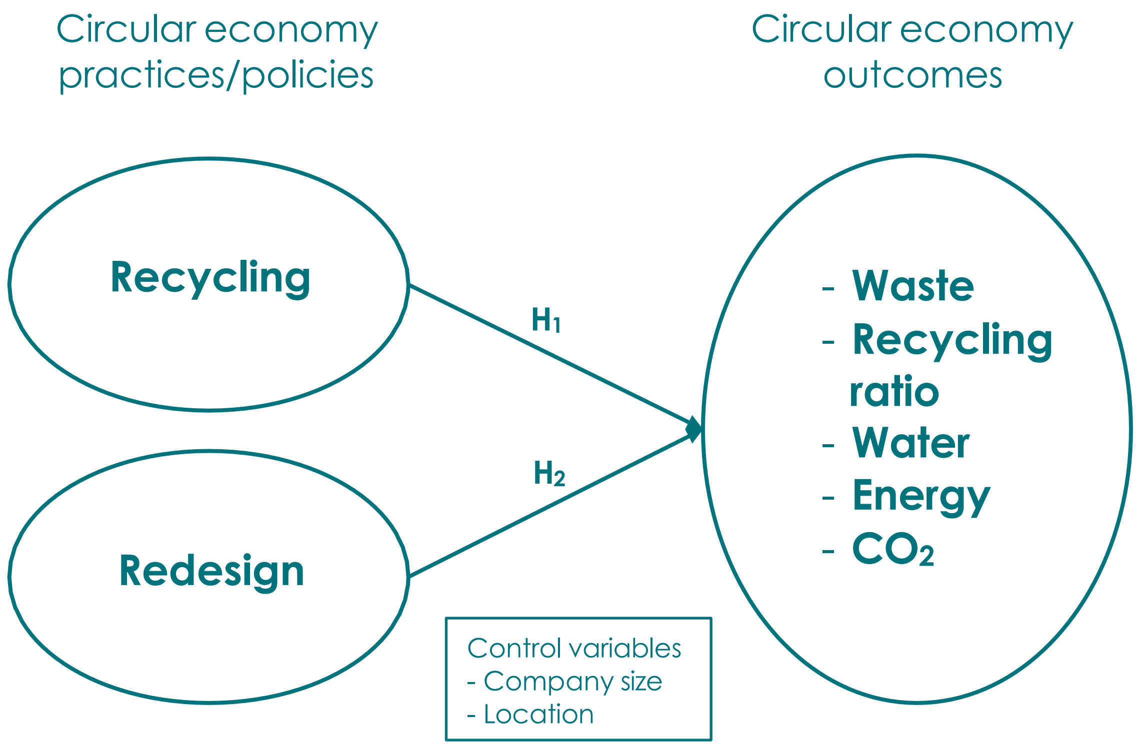

Figure 7: Research model

Through product design, companies can also effectively reduce their waste emissions and thereby alleviate their environmental pressure.[89] Additionally, the overall consumption of resources (including water) and energy can be reduced by taking these factors in consideration already during the design phase of the product, stated by Mora-Contreras et al. in their research about circular economy practices and their influence on sustainability. Khan and Haleem listed several circular economy practices

[87] Yu et al. (2022a), p. 9.
[88] Mora-Contreras et al. (2023b), p. 103.; Bressanelli et al. (2021), p. 3.
[89] Yu et al. (2022b), p. 9.

and in doing so they mentioned the reduced energy consumption as one of the main benefits of the redesign strategy.

Thus, the second hypothesis is formulated and completes the research model (Figure 7).

H_2: Redesign practices/policies relate to circular economy outcomes

5 Methodology

The main objective of this study is to investigate the relationship between certain circular economy practices/policies and specific circular economy outcomes. By the execution of a literature review these practices as well as outcomes were selected and defined as "circular", due to their frequency of references across the literature. This study was conducted considering information from 447 manufacturing companies worldwide through a cross-sectional study with data of the years 2020 and 2021, compared to other studies which conducted longitudinal studies of the impact of circular economy strategies, like Mora-Contreras et al. or Chen and Dagestani.[90] The data includes indicators of the adaption of different circular economy policies and quantitative data regarding different performances like waste or emissions.

5.1 Data sampling

This study used company data mined from the EIKON database. The well-regarded EIKON database is supplied by LSEG (formerly Refinitiv and Thomas Reuters) and contains extensive economic, company and financial data from companies all over the world. This also includes ESG (Environmental, Social and Governance) data, which were used in this study. The ESG dataset includes 178 measurements, consisting of environmental, social and governance indicators. As this study focuses on the impact of circular economy practices and policies, the indicators used for the relation with circular economy outcomes are all part of the environmental pillar of the EIKON dataset.

5.1.1 Independent variables

In total, three different independent variables are used in this study, which represent different groups of the 9R framework, as already described previously. The independent variable "ENPIDP047" covers the recycling strategy in this study. This indicator is named Take-back and Recycling Initiatives and indicates if a company reports about take-back procedures and recycling programs applied in their organization, or not (nominal scaled with yes or no options) in the year 2020. The second and last used independent variable, which should cover the redesign strategy of the 9R framework, is represented by the indicator Eco-Design Products with the code "ENPIDP069" of the year 2020 in the database. This indicator represents, if a

[90] Mora-Contreras et al. (2023a), p. 77 ff.; Chen; Dagestani (2023), p. 1 ff.

company officially reports on their products, that they are redesign for reuse, recycling or the general reduction of environmental impacts.

5.1.2 Dependent variables

Since this study is comparing data from different manufacturing companies in different sectors, there are variations not only in their size but also their production processes and the goods they are producing. Currently, the field of environmental indicators already shows countless diversified approaches in terms of their usage in different studies. Olsthoorn et al. showed in their literature and practice review that there is little comparability between the displacement of environmental factors and that they are displayed most of the time without known standardization. In order to make the data more relative and comparable across these different factors, they suggest that the quantitative data (for example the energy used in a year) of the dependent variables are standardized through normalization to increase credibility and transparency of the data.[91]

There are several options to do so, but for environmental factors, literature particularly suggests choosing economic, financial and/or monetary quantities to scale the information. Thus, these modified environmental indicators are commonly formulated in ratios, containing the economic or financial quantity in the denominator and the environmental quantity as numerator. For the denominator it is important that it adequately represents the activity or size of the production unit (e.g. the company). Examples for these economic, financial and monetary quantities are the production volume, the number of employees or the investment volume, each one fitting a specific type of activity. However, in this study the dependent variables will be standardized by using the total revenue of the company. The revenue was chosen as standardization method, as it is used frequently across different studies to easily compare environmental performance and the companies all belong to the same sector (manufacturing sector).[92] This method follows the procedure of other works, for example Ismail et al., as these ratios are basic eco-efficiency indices, evaluating the environmental impact of their output generation.[93]

[91] Olsthoorn et al. (2001), p. 453 ff.
[92] Olsthoorn et al. (2001), p. 453 ff.
[93] Ismail et al. (2013), p. 3401 ff.

However, an issue arises when it comes to standardizing economic practices across various sectors or countries due to the varying levels of incorporating environmental costs into prices. In economies where environmental taxes are scarce, companies enjoy economic advantages over those in regions with robust environmental taxes. Metrics that adjust for revenue tend to favor businesses in regions with less integration of environmental costs.[94]

The first dependent variable used is the waste generated by the company per dollar of revenue in a year. By taking the indicator "ENERDP049" of the EIKON database, which expresses the total tons of solid waste produced by the company in a year and dividing it by the revenue of that year, the waste is standardized and can be compared across the different companies. The second dependent variable is the recycling ratio of the company. For this indicator, the values of the database with the code "ENERDP098" are used, which represent the waste recycling ratio of the company if it is reported. If not reported by the company itself, it is calculated manually through dividing the total generated waste with the waste recycled.

The discharged water is represented by total volume of discharged water per year in m^3 per dollar of the total revenue. For the volume of the water the indicator "ENERDP057" of the database is used, which represents all the wastewater with no further usage, discharged by the company. The fourth dependent variable represents the used energy as the ratio of total energy consumption (includes direct and indirect energy) in Gigajoule per dollar of revenue. The energy consumption is again represented by an EIKON indicator with the code "ENRRDP033" which shows the energy usage reported by the company in one year. The final fifth variable is the emitted CO_2 emissions in tons per dollar of revenue in one year. The measure is calculated by the taking the "ENERDP023" indicator of the EIKON database, which reports the total CO_2 and CO_2equivalent emissions according to the GHG Protocol in tons per year, as the numerator and the revenue of the company of the same year as the denominator.

The independent variables state if the company had any circular economy practices in action in the year 2020, while the dependent variables are the values from one year

[94] Olsthoorn et al. (2001), p. 453 ff.

later. The reason for this is to ensure that the circular economy practices are already fully implemented at the start of the year.

5.2 Control variables

Generally, larger corporations tend to garner greater sales revenue and possess more extensive resources and capabilities for implementing circular economy practices or policies. Consequently, these larger entities often exhibit elevated levels of CE and subsequently reap greater benefits. Moreover, the propensity of companies to embrace CE practices varies across different locations worldwide. Consequently, this study incorporates control variables for both company size (regarding their revenue) and geographical location in subsequent hypotheses testing, following the example of previous works. To separate the companies regarding their geographical location, but still keep the subsamples large enough for analysis, the continent of the headquarter of the companies has been chosen as the best control. As there is only a minority of the companies located in Africa, and Oceania, only Asia, Americas and Europe qualify as reliable control factors regarding the geographical location. In order to integrate the location into the regression model, three dummy variables have been created, each for one of the three continents used for this control variable. These are "HQ_Asia", "HQ_Americas" and "HQ_Europe" each defined as binary variables with values of 0 (company´s headquarter is not located on this continent) and 1 (company´s headquarter is located on this continent).[95]

5.3 Analysis method

As the literature suggests, the reasons for choosing a particular method of data analysis must be argued, in order to explain its relevance to the readers.[96] Linear regression is one of the most commonly used statistical method to measure relationships between independent and dependent variables and a basic type of regression useful for conduction analysis. Linear regression finds the best possible estimates for the constant factor and the multiplier and is also a very quick method.[97] In order to take in the different dependent variables as well as the control variables, a multiple linear regression will be performed to analyze, which factor has a significant impact on the independent variables. To make sure, that there exists no multi-

[95] Yu et al. (2022a), p. 1 ff.
[96] Lopes de Sousa Jabbour, Ana Beatriz et al. (2022), p. 1 ff.
[97] Hope (2020), p. 67 ff.; D'Adamo et al. (2020), p. 1 ff.

collinearity of the dependent variables, a correlation matrix will be generated and additionally the VIF (variance inflation factor) is analyzed. A multiple linear regression is a proven statistical method, as of its simplicity and the widespread use in other literature and will be used to test the hypotheses due to these factors. To guarantee a definite relationship between the independent and dependent variables, a cut off for the significance of 95% ($p < 0,05$) has been chosen.[98]

The proposed model exploring the implications of circular economy practices on the defined circular economy outcomes is presented as follows:

Formula 1: Model formula

$$CEO_i = \beta_0 + \beta_1 * Rec + \beta_2 * Red + C_1 * Rev + C_{2a} * Loca + C_{2b} * Locb + C_{2c} * Locc + \varepsilon_i$$

where CEO_i represents one of the five circular economy outcomes (i), β_0 represents the constant value, the β and C values represent the coefficient of respective independent variables and control variables, *Rec* represents the adoption of recycling activities while *Red* represents the adoption of redesign activities. *Rev* is the yearly revenue in dollar, *Loca*/*Locb*/*Locc* represent the binary dummy variables for the headquarters in Americas/Asia/Europe and ε_i represents the error for equation i.

[98] Vitolla et al. (2023), p. 1 ff.; D'Adamo et al. (2020), p. 1 ff.

6 Results

This section presents the results of the regression analysis. In the first step the sampling data will be analyzed on a descriptive basis. Subsequently, the hypothesis will be tested for validation with multiple linear regression and the outcomes are presented. The multiple linear regression was performed with the IBM SPSS Statistic 29.0.0 tool.

6.1 Descriptive analysis

In total the initial dataset included 21,651 companies in the manufacturing sector worldwide. By excluding all companies which did not report on the selected independent and dependent variables and some statistical outliers, the final dataset concluded with 447 companies, containing all the relevant data. Most of the companies' headquarters are located in Asia (63%) and America (22%). About 12% of the companies are located in Europe, while Africa and Oceania only make up a minority of the locations of the headquarters (Figure 8).

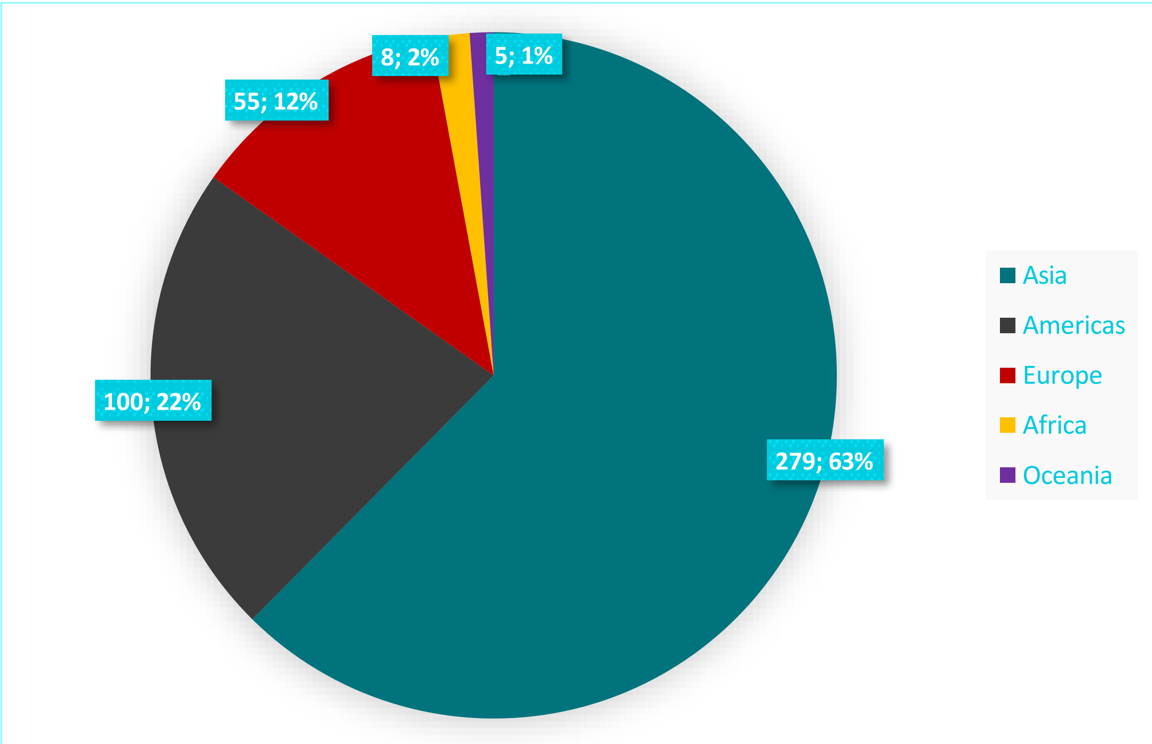

Figure 8: Location of the headquarters

Figure 8 gives an overview of the different subsectors of the manufacturing industry, in which the companies are mainly operating in. Overall, the companies are operating in 20 different subsectors, from food industry to chemical manufacturing or wood products. However, most of them represent only a very small quantity of companies. Therefore, only the most common subsectors are represented as an own sector in this study and the other subsectors are consolidated in the sector "Other", which represents about 13% of all companies. The two biggest groups are clearly the chemical manufacturing sector and the computer and electronic product manufacturing sector, each representing more than 20% of the dataset (22.10 and 20.36). Machinery manufacturing includes 34 companies, transportation equipment manufacturing 29 and food manufacturing 28. The other subsectors (beverage and tobacco, electrical equipment, paper, petroleum and coal products and primary metal) are rather small groups, each containing between four and six percent of the dataset.

Table 14: Subsector distribution of the dataset

Subsector	Number of companies	Number of companies [%]
Beverage and Tobacco Product Manufacturing	23	5.15
Chemical Manufacturing	99	22.10
Computer and Electronic Product Manufacturing	91	20.36
Electrical Equipment, Appliance, and Component Manufacturing	22	4.92
Food Manufacturing	28	6.26
Machinery Manufacturing	34	7.61
Paper Manufacturing	18	4.03
Petroleum and Coal Products Manufacturing	18	4.03
Primary Metal Manufacturing	26	5.82
Transportation Equipment Manufacturing	29	6.49
Other	59	13.20

To categorize the companies regarding their size, different approaches exists. Total assets, production volume, number of employees or revenue are only some examples for the various different options to categorize companies. However, this study will follow along with the classification of the European commission, to group companies according to their total yearly revenue of 2021 (entitled as "annual turnover by the European Commission). The categorization exists of four different categories: a turnover threshold of 2 million € applies for micro sized enterprises, between 2 and 10 million € for small companies, above 10 million € and below 50 million € for medium-size companies and everything above 50 million € is categorized as a large enterprise.[99] Hence simplicity and volatile exchange rates between the European Euro and the American Dollar, the categorization of the companies will be made according to the Euro values and no currency conversion will be made.

Table 15: Company categorization (by European Commission (2003))

Category	Annual turnover	Number of companies	Number of companies [%]
Micro enterprise	<= € 2 m	0	0.00
Small enterprise	<= € 10 m	0	0.00
Medium-sized enterprise	<= € 50 m	0	0.00
Large enterprise	<= € 2 b	96	21.47
Very large enterprises	<= € 10 b	188	42.06
Mega enterprises	> € 10 b	163	36.47

As of the fact, that according to this classification, all companies are ranked as large companies, two additional categories have been included, to allow better comparability. Very large enterprises with a revenue of more than 2 billion $ and below 10 billion $, and mega enterprises with a revenue exceeding 10 billion dollars. 96 companies (21.48%) out of the dataset categorize as large enterprises, 188 (42.06%) as very large ones and 163 (36.46%) are belonging to the group of mega enterprises (Table 15).

6.2 Regression analysis

The following section will summarize the results of the multiple linear regression analysis and according to its results if the different hypotheses are supported or not. The first step, even before conducting the multiple linear regression, was conducting a correlation test and look for multi-collinearity and significant relationships. This approach follows the procedure of other studies, which confirms the multiple linear regression as an effective statistical tool to indicate relationships between circular economy practices and their outcomes.[100] Table 16 presents the results of the correlation test, which includes the two independent variables (recycling and redesign), the two control variables (revenue for company size and headquarter location defined through three dummy variables) and the five dependent outcome

[99] European Commission (2003).
[100] Del Giudice et al. (2021), p. 337 ff.; Chen; Dagestani (2023), p. 1 ff.

variables (waste/revenue, recycling ratio, water/revenue, energy/revenue and CO_2/revenue).

Table 16: Correlation results

	1	2	3	4	5	6	7	8	9	10	11
1.Redesign 2020	1										
2.Recycling 2020	,270**	1									
3.HQ_Asia	,067	-,120*	1								
4.HQ_Americas	-,086	,111*	-,692**	1							
5.HQ_Europe	,033	,042	-,483**	-,201**	1						
6.Revenue 2021	,162**	,288**	-,062	,136**	-,040	1					
7.Waste/Revenue 2021	-,095*	-,057	-,109*	-,034	,211**	-,004	1				
8.Recycling Ratio 2021	,149**	,153**	,259**	-,129**	-,181**	,076	-,216**	1			
9.Water/Revenue 2021	-,057	-,074	,016	-,028	,012	-,050	,048	-,083	1		
10.Energy/Revenue 2021	-,073	-,117*	-,153**	,125**	,062	-,077	,247**	-,146**	,115*	1	
11.CO_2/Revenue 2021	-,118*	-,114*	,028	-,030	-,006	-,057	,092	-,016	,037	,665**	1

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level

The results of the correlation analysis indicate that no multi-collinearity exists, as no correlation value exceeds the value 0.7. What stands out across these correlation results, is the fact that for redesign as well as recycling a negative correlation exist regarding all independent variables, apart from the recycling ratio. This indicates that there exists some kind of connections between the usage of recycle or redesign activities and the reduction of waste, water, energy and CO_2 emissions and also the increase of the recycling ratio. Additionally, most of these correlations are significant, what allows for further investigation regarding their relationship. The only exception seems to be the discharged water, which has no significant correlation with the implementation of recycling or redesign strategies.

As the correlation analysis showed no alarming multi-collinearity, the next step is to perform the multiple linear regression. This is done by selecting the variables for the recycling and redesign and the control variables for the size and the location as independent variables and one of the five outcomes as dependent variables for each iteration of the multiple regression.

Table 17: Multiple linear regression results (waste)

	Dependent Variable: Waste/Revenue 2021						
Coefficients	*β*	*Std. Error*	*β(stand.)*	*t*	*p*	Collinearity	
						Tolerance	*VIF*
(Constant)	0.00030	0.00052		0.581	0.561		
Recycling 2020	-0.00022	0.00022	-0.051	-1.025	0.306	0.851	1.175
Redesign 2020	-0.00036	0.00019	-0.094	-1.925	0.055	0.901	1.110
Revenue 2021	2.7414E-15	3.90023E-15	0.034	0.703	0.483	0.891	1.123
HQ_Asia	0.00002	0.00052	0.005	0.039	0.969	0.118	8.509
HQ_Americas	0.00003	0.00055	0.007	0.056	0.955	0.146	6.843
HQ_Europe	0.00127	0.00057	0.221	2.228	0.026	0.217	4.610

n = 447; R^2 = 0.058; adjusted R^2 = 0.045; Significance = <0.001

Table 17 summarizes the results of the multiple linear regression regarding the dependent variable generated waste per revenue. The VIF (variance inflation factor) for each independent variable is below a value of 10, what confirms the previous correlation results of no existing multi-collinearity. The threshold value of 10 for the VIF was selected following the example of Chen and Dagestani.[101] The overall model is highly significant (p < 0.001). While the model indicates no significant relationship between recycling activities and the waste/revenue, a slightly significant p value (0.055) is present for the relationship between redesign practices and waste. Regarding the control variables, no significant correlation has been identified, apart from the control variable "HQ_Europe". There is a significant positive correlation if the headquarter of the company is located in Europe, what means more generated waste if the company is located in Europe.

Table 18: Multiple linear regression results (recycling ratio)

	Dependent Variable: Recycling Ratio 2021						
Coefficients	*β*	*Std. Error*	*β*(stand.)	*t*	*p*	Collinearity	
						Tolerance	*VIF*
(Constant)	56.171323	7.380541		7.611	<0.001		
Recycling 2020	9.604030	3.088017	0.151	3.110	0.002	0.851	1.175
Redesign 2020	5.036518	2.657652	0.090	1.895	0.059	0.901	1.110
Revenue 2021	3.23278E-11	5.58907E-11	0.028	0.578	0.563	0.891	1.123
HQ_Asia	16.290833	7.521646	0.284	2.166	0.031	0.118	8.509
HQ_Americas	3.023550	7.839890	0.045	0.386	0.700	0.146	6.843
HQ_Europe	-3.630721	8.163461	-0.043	-0.445	0.657	0.217	4.610

n = 447; R^2 = 0.114; adjusted R^2 = 0.102; Significance = <0.001

101 Chen; Dagestani (2023), p. 1 ff.

Table 18 contains the regression results with the recycling ratio as dependent variable. A very significant positive correlation is present regarding recycling activities and a slightly significant (0.059) correlation (also positive) regarding redesign practices. Regarding the control variables, only a headquarter in Asia leads to a significant positive correlation regarding the recycling ratio. The overall model is again, very highly significant and no VIF exceeds 10.

Table 19: Multiple linear regression results (water)

	Dependent Variable: Water/Revenue 2021						
Coefficients	*β*	*Std. Error*	*β* (stand.)	*t*	*p*	Collinearity	
						Tolerance	*VIF*
(Constant)	0.007352	0.008029		0.916	0.360		
Recycling 2020	-0.003496	0.003359	-0.054	-1.041	0.299	0.851	1.175
Redesign 2020	-0.002361	0.002891	-0.041	-0.817	0.415	0.901	1.110
Revenue 2021	-3.10459E-14	6.07982E-14	-0.026	-0.511	0.610	0.891	1.123
HQ_Asia	0.000886	0.008182	0.015	0.108	0.914	0.118	8.509
HQ_Americas	-0.000506	0.008528	-0.007	-0.059	0.953	0.146	6.843
HQ_Europe	0.001771	0.008880	0.020	0.199	0.842	0.217	4.610

n = 447; R^2 = 0.008; adjusted R^2 = -0.005; Significance = 0.721655681340367

The third regression iteration (Table 19) is the only one of the five models, which is not significant overall (p = 0.72). This model analysis the multiple linear regression regarding water/revenue as dependent variable. None of the independent variables nor the control variables has a significant correlation with the discharged water of the companies. The VIFs are also in this case all below 10, so no multi-collinearity is present here.

Table 20: Multiple linear regression results (energy)

	Dependent Variable: Energy/Revenue 2021						
Coefficients	*β*	*Std. Error*	*β* (stand.)	*t*	*p*	Collinearity	
						Tolerance	*VIF*
(Constant)	0.006438	0.003076		2.093	0.037		
Recycling 2020	-0.002996	0.001287	-0.117	-2.329	0.020	0.851	1.175
Redesign 2020	-0.000443	0.001107	-0.020	-0.400	0.689	0.901	1.110
Revenue 2021	-2.70361E-14	2.32907E-14	-0.057	-1.161	0.246	0.891	1.123
HQ_Asia	-0.001545	0.003134	-0.067	-0.493	0.622	0.118	8.509
HQ_Americas	0.002927	0.003267	0.109	0.896	0.371	0.146	6.843
HQ_Europe	0.001875	0.003402	0.055	0.551	0.582	0.217	4.610

n = 447; R^2 = 0.047; adjusted R^2 = 0.034; Significance = 0.0016803978714072

The fourth multiple linear regression analysis (Table 20) qualifies as a significant overall model and uses the energy/revenue as its dependent variable. Multi-collinearity can again be successfully denied, as all VIFs are below 10. Regarding the correlation, the only significant one found is regarding the recycling practice.

Table 21: Multiple linear regression results (CO_2)

	Dependent Variable: CO_2/Revenue 2021						
Coefficients	*β*	*Std. Error*	*β* (stand.)	*t*	*p*	Collinearity	
						Tolerance	*VIF*
(Constant)	0.000560	0.000356		1.571	0.117		
Recycling 2020	-0.000233	0.000149	-0.080	-1.562	0.119	0.851	1.175
Redesign 2020	-0.000250	0.000128	-0.097	-1.950	0.052	0.901	1.110
Revenue 2021	-7.78692E-16	2.69793E-15	-0.014	-0.289	0.773	0.891	1.123
HQ_Asia	0.000023	0.000363	0.009	0.064	0.949	0.118	8.509
HQ_Americas	-0.000067	0.000378	-0.022	-0.176	0.860	0.146	6.843
HQ_Europe	-0.000002	0.000394	0.000	-0.004	0.997	0.217	4.610

n = 447; R^2 = 0.022; adjusted R^2 = 0.009; Significance = 0.12732298317443

Table 21 summarizes the results of the last multiple linear regression, containing the CO_2 emissions per revenue as dependent variable. VIFs are all below ten, so no multi-collinearity is present. The overall model is not significant (0.127) and the only slightly significant correlation of the CO_2 emissions is with the redesign strategy (p = 0.052). Neither the location of the headquarter nor the revenue of the companies has any influence according to the significance of the regression analysis.

The results of the five iterations of the multiple linear regression imply that companies, which implement recycling activities into their operating processes, can benefit from some specific circular economy outcomes. Significant relationships between recycling practices of companies and the increase of their recycling ratio as well as the reduction of the used energy/revenue are present. These findings show evidence in favor of H_1. However, although recycling correlates with a reduction of waste, water usage and CO_2 emission, no significant relationship was identified. Due to this factor, the hypothesis H_1 is partially supported.

For the redesign strategy, in contrast, different outcome dimensions indicated a significant relationship. Although only the significance is only slightly (between 0.05 and 0.06), redesign shows significant correlation with the reduction of waste as well as CO_2 and also the increase of the recycling ratio. Results showed no significant effect of redesign on the water or energy usage. Combining the results of the multiple linear regression regarding the redesign strategy, H_2 is also partially supported, as redesign leads to some kind of circular economy outcomes. The results and main impacts are summarized again in Table 22.

Regarding the control variables, very few significant correlations could be identified. The size of the company (according to the revenue) showed not even a slightly significant connection to the impact on circular economy outcomes. Regarding the headquarters of the company, the only insights worth mentioning are on the one hand, that a headquarter in Asia has significant benefits on the recycling ratio, compared to all other locations, and on the other hand, that if the company´s headquarter is located in Europe, the regression indicates an increase of waste/revenue, which implies that companies in Europe generate more waste than their competitors around the world.

Table 22: Results of hypothesis testing

Hypothesis	Path	Inference	Main impacts
H_1	Recycling ➔ circular economy outcomes	Partially supported	Significant increase of recycling ratio Significant reduction of energy
H_2	Redesign ➔ circular economy outcomes	Partially supported	Significant increase of recycling ratio Significant reduction of the generated waste and emitted CO_2

7 Discussion

This study investigated the relationship between certain circular economy practices and circular economy outcomes in the manufacturing industry through analyzing secondary data of the EIKON database, consisting of 447 manufacturing companies worldwide. The research model is based on the RBV, which helps to explain the complexity of complementary capabilities. The findings of this study confirm that circular economy practices, namely recycling and redesign in this case, have a positive impact to some degree on circular economy outcomes. Both analyzed practices show significant increase of the recycling ratio for companies where they are implemented. An interesting finding regarding this relationship is that the significance of recycling and higher recycling ratio is higher than regarding its significance with redesign activities. This finding is in contrast with the 9R frame of Pitting et al. which suggests that prevention strategies (like redesign) have a higher level of circularity and thereby better results than end of pipe strategies like recycling.

Several studies, like the one from Oliveira Rosa and Oliveira Paula, Ramsehva et al. and Rodríguez-González, mention that recycling practices lead to the effective reduction of waste.[102] Looking at the generation of waste, recycling practices have no impact of the reduction of the amount of waste according to the results of this study. This amplifies, that recycling strategies do not prevent the generation of waste in the first place and only use the waste to substitute other primary materials. However, a significant reduction of waste could be identified for companies using any type of redesign strategies. Due to the fact, that companies already consider the minimization of waste generation in the design phase of the product, this goal can effectively be achieved in practice, as this study shows. This result also backs the findings by Bressanelli et al. and Yu et al., which state, that if a product was not designed for recycling or reuse, it could lead to the fact that large quantities have to be qualified as waste and are sent to landfills.[103]

Apart from the recycling ratio, the only significant beneficial relationship identified with the recycling strategy in manufacturing companies is the reduction of energy consumption. This effect is caused most likely due to the reason, that using recycled materials has a lower energy profile than using primary resources for production, which

[102] Rodríguez-González et al. (2022), p. 1 ff.; Oliveira Rosa; Oliveira Paula (2023), p. 421 ff.; Ramsheva et al. (2020), p. 1 ff.
[103] Bressanelli et al. (2020), p. 1 ff.; Yu et al. (2022a), p. 1 ff.

supports the findings of Bressanelli et al., who state that recycling can reduce the energy consumption as the need for virgin materials shrink.[104]

Another relationship of high significance is the reduction of the emitted CO_2 gases and CO_2 equivalents by applying a redesign strategy within the company. This correlation is in line with the findings of Barón et al. who identified in their study that emission reduction is induced by the eco-design of the products.[105] Yu et al. discovered the same connection and stated *"product design can effectively reduce waste emissions"* (Yu et al. (2022a)), which additionally supports the findings of this study.

The fact that no significant relationship regarding circular economy practices and water consumption was identified, leads to the conclusion that regarding this set of companies, the reduction of water usage has not been a priority or specified goal in the course of implementing a recycling or redesign strategy. The literature supports these findings, as no study could have been identified, which mentions a distinct connection between a circular economy practice and the reduction of water usage. However, although no distinct connection is present in the literature, several studies state, that a general benefit of circular economy is the reduction of water usage. It shows that benefits of the circular economy are frequently and in various characteristics mentioned across the literature, but in some cases these benefits are not supported by the analysis of actual data what could lead to confusion amongst the literature.[106]

That there is almost no influence on the outcomes of circular economy practices regarding the location or size of the company, implies that circular economy practices are effectively working and do not necessarily depend on heavy resources, the economic or political environment of the company or other external influences. The only exception is the significant correlation of a higher recycling ratio and the location of the headquarter in Asia. As Asia, and especially China, has always been a pioneer in the fields of the circular economy, this long-time effect significantly makes a difference regarding the recycling ratio. Chen et al. analyzed the performance impact of circular economy practices in China and supports this relationship, as they identified a positive impact on waste recycling by circular economy practices.[107]

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[104] Bressanelli et al. (2020), p. 1 ff.
[105] Barón Dorado et al. (2022), p. 1 ff.
[106] Baumer-Cardoso et al. (2023a); Mora-Contreras et al. (2023a); Khan; Haleem (2021).
[107] Chen; Dagestani (2023), p. 1 ff.

7.1 Implications

Based on the results of the multiple linear regression analysis, this study holds practical insight of high significance for the manufacturing industry. The implications are relevant for decision-makers and managers in companies as well as public administration. Given the necessity for companies to initiate circular economy practices on their own in order to overcome the fatal effects of climate change and the overconsumption of primary resources,[108] the identification of relevant circular economy practices that can effectively reduce various environmental influences can help promote strategies that are aimed for maximization. The results of this study show, that circular economy is not just a theoretical construct and that there are certain relations of practices and outcomes which can help manufacturing companies to benefit regarding different indicators. Business managers should therefore invest in the implementation of recycling or redesign strategies to improve their environmental performance. However, while doing so, it has to be considered that different enterprises react different to the implementation of certain circular economy practices and therefore the implementation of a circular economy activity has to fit within the business environment. In doing so, managers should respect the different impacts of the redesign and recycling strategy, as redesign is part of the prevention strategies and therefore has impact on waste and CO_2 reduction, while recycling as an end of pipe strategy has shown no significant relation of the reduction of these types of waste, as the waste and emissions were already generated. Another important feature this study provides for managers and companies is the improvement of competitiveness, as these results help the companies to decide on the correct circular economy practice to achieve their goals.

Additionally, the findings of this study also provide valuable insights for policymakers. Demonstrating the positive impact of circular economy practices on circular economy performance can help policy development aimed at enhancing the adoption and assessment of circular economy initiatives. Policymakers can utilize these insights to encourage more businesses to address their environmental footprint by adopting effective circular economy practices.

108 Pietikäinen (2020), p. 43 ff.

Also, in the academical environment these significant impacts of recycle and redesign on circular economy outcomes based on secondary data of a database of manufacturing companies can lead more researchers to look in this field of research.

7.2 Limitations

While this study examined links between certain circular economy practices and circular economy outcomes, there remain some constraints or drawbacks that need to be addressed. First, as the study was conducted as a cross-sectional analysis, it neglected possible dynamic or long-term results. Second, most of the companies included in the initial dataset (more than 21000) could not be analyzed, as they did not report on recycling, redesign or any of the outcome variables. Due to this, the statistical analysis was limited on a rather small sample of data of 447 companies. Third, the variables regarding recycling and redesign of the EIKON dataset are defined as binary variables. For that reason, it is not known to which extent each company adopted the circular economy strategy, as there is no gradation present. Fourth, this analysis concentrated on specific circular economy practices (recycling and redesign) and a set of outcome variables. Relationships between other practices and outcome variables could be subject of future research. Fifth, although significant benefits of the recycling and redesign strategy were identified, there is no comparison regarding effort and costs to the mainly environmental outcome variables. Sixth, it could be possible, that companies without adopted circular economy practices are affected by those who already have done so, but due to data reasons this impact is very difficult to explore.

8 Conclusion

This study examined the relationship between circular economy practices or policies and circular economy outcomes. Manufacturing companies are faced with various problems nowadays, as the environmental situation is very tense due to the climate change, but also global competitiveness and economic reasons put manufacturers under pressure. The circular economy has matured to a very promising and well researched concept to overcome the outdated linear "make-take-dispose" economy while offering manufacturers opportunities regarding various beneficial outcome dimensions. But as there is such a high quantity of scientific research on different levels, confusion and mixture with other environmental or ecological strategies are getting more and more common. For that reason, the first step of this study was to filter through the existing literature with a systematic literature review and find the most common mentioned circular economy practices/policies and circular economy outcomes. Based on these results and the implications of the theoretical foundation, which mentions a large number of circular economy practices/policies as well as outcome, two hypotheses were formulated. These hypotheses tested recycling and redesign for specific circular economy outcomes (waste, recycling ratio, water, energy and CO_2) based on the RBV theory, with company size and location functioning as control variables.

The main objective of this study was then, to discover significant relationships between these circular economy practices and circular economy outcomes. This was done through a cross-sectional analysis of a data sample consisting of data from the years 2020 and 2021 of manufacturing companies worldwide from the EIKON database. By performing a multiple linear regression including control variables, certain significant relations were identified. A significant positive impact of recycling on the reduction of energy usage and the increase of the recycling ration was identified. Regarding the redesign strategies, the manufacturers resulted in even more significant relationships, as redesign shows significant correlation with the decrease of waste and CO_2 emissions and also a very significant connection to an increased recycling ratio. These results were for a greater part relatively independent of firm size and location.

The results of the regression analysis indicate that companies which implement recycling and/or redesign strategies can significantly benefit from these practices regarding the mentioned significant relationships. However, certain limitations such as the static structure of the analysis, the focus on a small set of practices and outcome variables and the reliance of the results on only one database with 447 manufacturers have to be taken in consideration when further processing these results. Further research can continue to analyze this relationship of circular economy practices and circular economy outcomes by using a larger dataset or primary data. Furthermore, other researchers could focus on different circular economy practices as reduce or reuse, which were also commonly mentioned across the literature. Additionally, the outcome and control could be extended with more factors, in order to find other important relationships and correlations among them.

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10 Appendix

Reference	Circular economy practice/policy	Circular economy outcome
(Albertsen et al. (2021))	Recycle	Higher Revenue/Profit
	Recycle	Higher recycling ratio
(Alvarado-Bawab; Villa Marenco (2023))	Recycle	Reducing waste
	Reuse	Reducing waste
	Reduce	Reduce/Improve energy
	Reduce	Reduce/Improve water
	Redesign	Less primary material
(Barón et al. (2020))	More environmental-efficient production	Reduce emissions
	Redesign	Extension of life cycle
	Take-back system	Extension of life cycle
(Barreiro-Gen; Lozano (2020))	-	-
(Battesini Teixeira et al. (2023))	Reuse	Extension of life cycle
	Reuse	Reuse of waste
	Recycling	Reuse of waste
(Carvalho Araújo et al. (2019))	Recycling	Reuse of waste
	Reuse	Reuse of waste
(Khan; Haleem (2021))	Redesign	Less primary material
	Redesign	Reduce/Improve energy
	More environmental-efficient production	Reducing waste
(Ramsheva et al. (2020))	Recovery	Reuse of waste
	Recycling	Reducing waste
	Recovery	Reducing waste
	Reuse	Reducing waste
	Recovery	Less primary material
	Recycling	Less primary material
(Stewart; Niero (2018))	Redesign	Less primary material
	Redesign	Extension of life cycle
	Recycling	Product quality
	Recycling	Higher recycling ratio

Reference	Circular economy practice/policy	Circular economy outcome
(Bressanelli et al. (2021))	Repair	Extension of life cycle
	Recycling	Less primary material
	Refurbish	Reducing waste
	Reuse	Reducing waste
	Recovery	Lowering purchasing/production costs
	Recovery	Higher Revenue/Profit
	Reuse	Higher Revenue/Profit
	Refurbish	Higher Revenue/Profit
	Redesign	Less primary material
	Redesign	Reducing waste
(Garcia-Saravia Ortiz-de-Montellano et al. (2023))	Reduce	Reduce/Improve energy
	Reuse	Less primary material
(Hrdlička; Severová (2022))	Refurbish	Job creation
(Keßler et al. (2021))	Reuse	Extension of life cycle
	Repair	Extension of life cycle
	Refurbish	Extension of life cycle
	Recycling	Higher Revenue/Profit
	Reuse	Higher Revenue/Profit
(Liu et al. (2018))	Reuse	Less primary material
	Refurbish	Less primary material
	Reuse	Reduce/Improve energy
	Refurbish	Reduce/Improve energy
(Liu et al. (2023))	Redesign	Less primary material
	More environmental-efficient production	Reduce/Improve energy
	More environmental-efficient production	Reducing waste
	More environmental-efficient production	Reduce emissions

Reference	Circular economy practice/policy	Circular economy outcome
(Mansilla-Obando et al. (2022))	Reduce	Customer responsibility for the product
	Reuse	Customer responsibility for the product
	Recycling	Customer responsibility for the product
(Marrucci et al. (2022))	Reuse	Reduce emissions
	Recovery	Reduce emissions
	Reuse	Less primary material
	Recovery	Less primary material
(Padilla-Rivera et al. (2020))	-	-
(Russell; Nasr (2023))	Refurbish	Less primary material
	Repair	Less primary material
	Reuse	Less primary material
	Refurbish	Reduce/Improve energy
	Repair	Reduce/Improve energy
	Reuse	Reduce/Improve energy
	Refurbish	Reduce emissions
	Repair	Reduce emissions
	Reuse	Reduce emissions
	Refurbish	Reducing waste
	Repair	Reducing waste
	Reuse	Reducing waste
	Refurbish	Lowering purchasing/production costs
	Repair	Lowering purchasing/production costs
	Reuse	Lowering purchasing/production costs
	Refurbish	Job creation
(Valusyte (2021))	Redesign	Extension of life cycle
(Walker et al. (2021))	CE workforce training	Higher training hours/more trained staff
(Yu et al. (2022b))	-	-
(Barón Dorado et al. (2022))	-	-

Reference	Circular economy practice/policy	Circular economy outcome
(Baumer-Cardoso et al. (2023a))	Redesign	Extension of life cycle
(Baumer-Cardoso et al. (2023b))	Recycling	Less primary material
(Bracquené et al. (2022))	Recycling	Less primary material
	Recycling	Reducing waste
(Saraji; Streimikiene (2022))	Recycling	Lowering purchasing/production costs
(Bressanelli et al. (2020))	Recycling	Reducing waste
	Recovery	Reduce/Improve water
	Recovery	Reducing emissions
	Recovery	Customer responsibility for the product
	Recycling	Reduce/improve energy
	Recycling	Reducing emissions
	Recycling	Less primary material
(Chen; Dagestani (2023))	Reuse	Reducing waste
	Reuse	Lowering purchasing/production costs
(Fernando et al. (2021))	Recycling	Reducing waste
	Refurbish	Reducing waste
(Khan et al. (2023))	-	-
(Khan et al. (2022))	-	-
(Mora-Contreras et al. (2023a))	Recovery	Reuse of waste
(Mora-Contreras et al. (2023b))	Redesign	Less primary material
	Redesign	Extension of life cycle
	Redesign	Reduce/Improve energy
	Redesign	Reducing waste
	Recycling	Reducing waste
	Refurbish	Reducing waste
	More environmental-efficient production	Reduce/Improve energy
	More environmental-efficient production	Reduce/Improve water
	More environmental-efficient production	Reducing waste

Reference	Circular economy practice/policy	Circular economy outcome
(Oliveira Rosa; Oliveira Paula (2023))	Recycling	Reducing waste
	Reuse	Reducing waste
	Reduce	Reduce/Improve water
	Redesign	Less primary material
(Peter John; Mishra (2023))	Recycling	Higher Revenue/Profit
(Roci et al. (2022))	Redesign	Extension of life cycle
(Rodríguez-González et al. (2022))	Recycling	Higher Revenue/Profit
	Reuse	Higher Revenue/Profit
	Recycling	Reducing waste
	Reuse	Reducing waste
	Recycling	Lowering purchasing/production costs
	Reuse	Lowering purchasing/production costs
(Sousa-Zomer et al. (2017))	Redesign	Extension of life cycle
	Recycling	Reducing waste
	Refurbish	Less primary material
	Redesign	Less primary material
(Susanty et al. (2020))		
	Redesign	Reuse of waste
	More environmental-efficient production	Reducing waste
(Yin et al. (2023))	-	-
(Yu et al. (2022a))	Recycling	Reducing waste
	Redesign	Reducing waste
	Redesign	Higher recycling ratio