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Regulatory Compliance and Innovation: A Literature Analysis on the Impact of Sustainability Legislation on Engineering and Supply Chain Innovations by the Example of the German Circular Economy Act

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Abstract: This paper examines the effects of sustainability laws on innovation, with a particular focus on the German Circular Economy Act. The study investigates whether strict environmental regulations promote technological advances and sustainable business practices. The results show a differentiated picture. While the German Circular Economy Act and similar regulations encourage companies to adopt resource-efficient practices, the level of innovation varies significantly between industries. Industries such as packaging and high technology are showing remarkable progress, including the development of sustainable materials and optimized product designs for recycling and repair. In contrast, challenges such as high initial costs, technological complexity and regulatory uncertainties make it difficult to innovate, especially for small and medium-sized enterprises. In addition, supply chain innovations are often consistent with lean management principles, which shows how regulatory frameworks can contribute to leaner processes and a reduction in waste.

Keywords: circular economy; innovation; regulatory compliance; resource efficiency; supply chain management; sustainability

1 INTRODUCTION

The past few years have seen an increase in the number of environmental, social and governance (ESG) laws and regulations being adopted around the world. There has been a reported 155% increase in the number of regulations enacted in the current decade compared to all previous decades [1]. However, their effectiveness and usefulness is still being debated and not only questioned but scrutinised by politicians, the public and economists [2].

Over the past decade, several pieces of legislation have been passed for example by the European Union (EU) with a clear determination to implement a more sustainable way of living. This is particularly important as the EU is one of the world's biggest polluters per capita. Nonetheless, politicians and entrepreneurs still believe the amount of regulations is impeding innovation and that the free market would handle sustainability and the circular economy much better without government intervention [3].

This paper will analyse the implementation of sustainability laws and their impact on innovations in supply chain management and engineering, using the German Circular Economy Act as an example. Finally, the paper will prove or disprove the hypothesis if "sustainability legislation has a positive impact on sustainability and related innovations". In addition, the paper will discuss challenges and solutions companies face when implementing circular economy laws and strategies.

2 METHODOLOGY

The methodology of the paper is based on a systematic literature review, which is an essential part of any scientific work. The literature was obtained by searching the university's own research tool BOSS, as well as the website Google Scholar. While Google Scholar was generally used with keywords relevant to the topic and chapters, the BOSS research tool allowed for a more precise search. In this system, the authors specified keywords, a publication period and that the papers listed should be peer-reviewed. This was the first step in the filtering process of relevant literature.

To ensure the quality of the papers, the German VHB Jourqual 3 and the Resurchify website were used to check the journals in which the selected papers appeared. The VHB Jourqual has its own ranking system in the form of letter grades, from the best with "A+" to the worst with "D". For this paper, all journals ranked from "A+" to "C" were considered as high qualitative literature. Additionally, the Resurchify website was used based on the corresponding H-index to integrate all international journals due to the fact that not all journals are listed in the VHB Jourqual [4].

3 CONCEPTUAL FRAMEWORK OF REGULATORY COMPLIANCE AND CIRCULAR INNOVATION

3.1 Regulatory Compliance

At its most basic, compliance is the act of obeying laws and regulations set by governments. These can be governing bodies at different levels, for example local, national or international. Failure to comply with regulations may result in some form of penalty. These penalties can take different forms and are often influenced by the governing body, the content of the legislation and the people affected by the rule.

A well-known distinction of laws is the soft law to hard law scale. Soft Laws are often brought to existence by a group of people or institutions agreeing to something and possibly signing something to show their public commitment, but if the participants choose to disregard these guidelines, there is no prosecution or penalty, apart from possible public outrage. Examples are the United Nations Sustainable Development Goals or the Paris Climate Agreement [5, 6].

On the other hand, hard laws are issued by bodies that have an executive. Failure to obey and comply with these

laws will result in different levels of consequences. These laws are also less open to interpretation, meaning that their purpose is much clearer and examples are given. The consequences may vary, some may be of a monetary nature, and others may exclude companies from governing body's projects, such as for example invitations to tender. In the most extreme cases, it can result in a prison sentence for the person responsible [6].

Another consequence of hard law, similar to soft law, is a loss of reputation. Many large companies in the EU and around the world already recognise corporate social responsibility and publish information about their own businesses and initiatives. Going against their written word would affect the interests of shareholders and stakeholders, which most companies prefer to avoid if possible [7].

3.2 Circular Economy and Circular Innovation

The concept of circular economy has been defined on numerous occasions throughout the last decade, most notably by the Ellen MacArthur Foundation. They characterise the circular economy as a system in which all materials and products are retained within a continuous cycle, through the implementation of maintenance, recycling and composting practices. The objective of a circular economy is to combat climate change and transform the economic system, by decoupling it from the consumptive use of finite resources [3, 8-12].

A literary summary of 117 different definitions, describes circular economy comprehensively as: "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 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 and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers [13]."

On official level, the EU defines circular economy as: "A system which maintains the value of products, materials, and resources in the economy for as long as possible, and minimises the generation of waste. This means a system where products are reused, repaired, remanufactured, or recycled [14]."

Following the definition of circular economy, circular innovations can be described as innovations focused on closing the consumption loop, extending the product lifecycle and reducing energy consumption. Circular innovations aim at sustainable development through the lens of the economic, social and environmental dimensions of sustainability [8, 11, 15-18].

The Porter hypothesis is a frequently employed theoretical framework in current research, as it continues to offer insights relevant to contemporary contexts. The hypothesis maintains that the implementation of precise and unyielding environmental regulations can lead to an influx of efficiency and innovations, fostering a more competitive market and resulting in a positive economic effect. Despite occasional criticism, e.g. from Cohen and Tubb 2018 [19], the Porter hypothesis has been utilized as the basis for numerous scientific papers, including this one, and has also been applied in policy-making [15-17, 20].

4 THE GERMAN CIRCULAR ECONOMY ACT

4.1 General Overview of the German Circular Economy Act

Germany has enacted numerous legislation initiatives with a focus on sustainability, many of which have been derived from the EU. One of the most important regarding the implementation of circular economy is the German Circular Economy Act, which is grounded in a multitude of EU directives, most notably Directive 2008/98. The directive was published in November 2008 and was scheduled for adaptation into national law by the end of 2010. Subsequently, in 2018, the directive was expanded and updated in the light of the introduction of the EU Circular Action Plan, which set out a series of objectives designed to ensure accountability at the EU level [21].

The objective of the directive was to establish a waste hierarchy, which provides a descending classification and regulatory framework for the management and treatment of waste. The primary objective – level one – is the prevention of waste. This encompasses the utilisation of more intelligent engineering methodologies that are designed with the objective of reducing waste. The second level is the reuse of material in the after-use-phase of products, which also encompasses the application of intelligent engineering and enhanced supply chain management. The third level is the recycling of waste, whereby the material is separated into its original components and processed to become a new resource. The waste is recovered for alternative purposes [3, 17, 22].

Therefore, the German Circular Economy Act is mostly talking about recycling and recovery to avoid to talk only about overconsumption and implement a more radical use and implementation of the so called ten Rs, which are an expansion of the popular three Rs, known as reuse, reduce and recycle [17].

R0 to R2 are focused on a general mind change through refusal, rethinking and reducing. Even simple changes can lead to a lower resource consumption. This could include the refusal of a plastic bag at the store, bringing one‘s own silverware instead of using disposable cutlery, or simply ordering less takeout food as an end consumer. Similarly, companies can change their ways of thinking and easily minimize the number of resources used and the amount of waste created.

R3 to R7 include the following aspects in chronological order: reuse, repair, refurbish, remanufacture and repurpose. The thought behind these steps is to extend the lifecycle of the final product or its parts. Companies have to reconsider the final product design already at the beginning of the development process to ensure sustainable solutions at the end of its lifecycle.

R9 and R10 are focused on recycling and recovery. In this context, components are disassembled into their base materials and repurposed accordingly. The use of waste for energy recovery through incineration is only seen as the last possible option, as it does not reintroduce the material back into the cycle [3, 17].

4.2 Case Studies Illustrating the Implementation of the German Circular Economy Act

The following five case studies from different industries in Germany demonstrate alternative ways to implement the German Circular Economy Act.

Case one – New packaging: a large packaging producer and manufacturer of packaging machines decided to use a more radical approach by developing innovative packaging materials. The new packaging concept was developed following the implementation of the new law and the global popularisation of circular economy [10].

Case two – Lifetime extension through regeneration: a company using industrial catalysts decided to lessen their risk of partaking in a highly volatile market by reusing the materials multiple times. Industrial catalysts use metals from the platinum group, meaning the material is a by-product of another raw material, making the market extremely dependant from the main material. Palladium and other platinum metals are also mined in countries that are known for high export taxes, making the market for these materials even more uncomfortable [23].

Case three – Less packaging: a well-known grocery chain in Germany decided as part of circular economy strategy to reduce the amount of packaging. This was done by removing all plastic packaging on single products, leaving only a small sticker for the recognition of the product. They also encouraged customers to bring their own reusable bags by not offering free plastic bags anymore [24].

Case four – Recycling of material: multiple jet engine manufacturers use rhenium in their superalloys for jet engines and other components. Since rhenium is a by-product of molybdenum, the market revolves around the market for molybdenum, making the sourcing very difficult. Once circular economy became more known and viable, the manufacturers started to optimize their processes to reduce material losses and to recover the rhenium from older products and reuse it [23].

Case five – Extension of life through a new business model: a well-established appliance manufacture, which previously did only focus on business to business sales, introduced a new leasing option for business to consumer sales. To ensure the financial viability of this leasing option, the appliances needed to remain durable enough to serve multiple clients. As a result, the company extended the lifespan of their manufactured products [10].

5 THE IMPACT OF SUSTAINABILITY LEGISLATION ON ENGINEERING INNOVATIONS

Engineering nowadays, includes a variety of specialized areas, such as the design and enhancement of infrastructure, machinery, vehicles, electronic devices, materials, and energy systems [25].

As previously stated, case one is focused on the introduction of new packaging materials. The company chose to invest in a start-up with the objective of developing a material to be used as an alternative to the company's existing packaging options. The start-up was already engaged in the development of a paper packaging solution that was distinguishable from the options offered by the parent company, which predominantly utilized plastic packaging. The start-up was granted permission to retain its entrepreneurial structure, allowing it to engage external personnel when necessary to acquire expertise and perspective [10].

In case four the production process was optimised and rhenium was recovered through disassembly. Hereby, one of the main engineering challenges was the designing of components with their post-use lifecycle in mind. This was done to avoid unnecessary costs connected to the disassembly and recycling of materials. In addition to modify the parts for enhanced disassembly, it was also necessary to ensure that the product could be repaired in a cost-effective way, thereby extending its operational lifecycle, similar to case five. In this case, the implementation of circular economy strategies has resulted in notable benefits for the manufacturer while simultaneously creating a positive environmental impact [10, 23].

Case two is the final example of engineering changes and corresponding innovations. To reduce their dependency on the platinum metals market, these industrial catalyst users initiated a regeneration process, making it possible to recycle the rare earth elements. In essence, a previously unused process was established to remove carbon coatings, significantly extending the product's lifecycle and creating a closed loop for the catalysts, thereby effectively enforcing a circular economy.

All these measures are not solely driven by regulatory compliance. By implementing these innovative processes, companies can achieve a more resource-efficient operation, leading to a range of benefits, including reduced material costs [23].

Studies showed that circular economy can most effectively be implemented through radical changes within a company. Start-ups often take the lead as frontrunners, driven by radical ideas that have the potential to disrupt the markets they enter. What start-ups are often missing is capital. Similarly, large companies have the capital, but they often cannot implement radical innovations, as they are not accepted within the organization. This situation leads to collaborative measures. Large corporations often acquire start-ups, letting them continue their quest to innovate. Once the start-up's solution is well-established, the corporation can integrate it across the whole organization, gaining a significant competitive advantage [10, 11].

The implementation of circular economy forces companies to invest in applicable procedures, as these often go hand in hand with cost efficiency. This approach enables businesses to operate in a more risk averse and independent manner, such as through the reuse of rare earth elements.

Hereby, manufacturers reduce their reliance on external markets and mines by using their own reserves during periods of scarcity and peak prices [23].

Furthermore, political initiatives by the EU to fight climate change significantly influenced material pricing. New resources and recycled materials now have almost the same price, whereas recycled materials were far cheaper before. This shift has reduced the financial risk for companies opting for resource-efficient options [3].

6 THE IMPACT OF SUSTAINABILITY LEGISLATION ON SUPPLY CHAIN INNOVATIONS

A supply chain describes an interwoven network of moving materials, parts, and products from the creation level to the end consumer [26]. Many circular economy strategies focus on a leaner supply chain by optimizing the corresponding products and processes. A leaner management approach is caused by the removal of inefficient and wasteful parts in the supply chain [8].

In case three, a popular grocery store in Germany decided to remove all plastic packaging on single products and replace it with identification stickers where necessary. This allows the product to bypass an additional stop before reaching the grocery store, reducing transport distances and enabling the use of more regional products, as they no longer needed to be sent to an external packaging facility. This created a more direct supply from the farmer, without the use of any intermediaries. Favourably, with respect to the Circular Economy Act, the grocery chain generated less waste for which they were accountable as face to the end costumer. The use of new packaging solutions optimised the supply chain and created a leaner flow with no negative impact on the customer side [24].

A further example of an organisational adaptation to circular economy is the introduction of a new business model in case five. A new unit was established to drive innovation beyond the traditional activities and encourage a more creative problem-solving. One initiative was the development of a leasing option for the company´s appliances. Previously, sales were limited to a business-to-business model, but the new leasing model introduced a business-to-consumer solution, enabling the firm to engage directly with the end customers. To ensure economic viability, appliances were designed for easy repairs, as the leasing offer included repairs and replacements. The most significant benefit was for the end consumers, as middlemen were eliminated, allowing direct communication with the manufacturer. Furthermore, the leasing system led to a superior product quality for the end customers [3, 10, 13].

As previously discussed, two of the cases presented in this paper focused on the implementation of circular economy strategies connected to rare earth elements. In addition to the engineering innovations required for recycling these metals, the innovations also led to improvements in the supply chain conditions for the companies. As a consequence, the companies were less dependent on the timely sourcing of materials, thereby affording them higher levels of negotiation power. Consequently, the companies were able to select their suppliers and plan more effectively, rather than being entirely at the mercy of the metal market. This results in more advantageous supply chain management options and opportunities, which are financially beneficial to the companies [23].

The implementation of innovative practices within the supply chain can be a highly advantageous strategy for businesses, providing them with a competitive advantage in their respective marketplaces. As the global scope of supply chains expands, the number of competitors rises accordingly. The implementation of effective supply chain management strategies ensures the consistent and reliable supply of materials, parts, and finished products in order to meet the customer demand. In times of global distress, such as global pandemics, wars or natural catastrophes, a reliable supply chain is the most important for a company's survival [23].

Nevertheless, modifications to supply chain networks have the potential to result in dissatisfaction among suppliers. If a company identifies a step in its process that does not add value to the product or service, the supplier responsible for that step is removed from the supply chain. Such actions result not only in the alienation of business partners, but also in a reduction in business for the supplier. Should other companies adopt a similar approach, the supplier may be forced into bankruptcy [10, 24].

These disruptive measures are often to extreme for many companies, leading to only incremental changes. This slows the full adoption of circular economy, as companies frequently fail to reach the final stages of implementation before reverting to previous practices. Achieving these changes requires a fundamental shift in the approaches [10].

The implementation of circular economy practices in the EU has led to the mainstreaming of reverse logistics and reverse supply chain practices, creating a novel market for logistics services to meet the need for the retrieval of products. The concept gained popularity within the rise of circular economy, particularly with the adoption of the "polluter pays" principle [3, 10, 13].

7 KEY DRIVERS OF INNOVATION ADOPTION AND REGULATORY COMPLIANCE

The following chapter will examine the factors that influence the decision-making processes of companies with regard to the adoption of innovative practices in the context of circular economy.

The majority of companies only comply with regulations to avoid penalties or other forms of punishment. Many companies avoid taking the additional step of innovating, as it requires significant investments in labour and capital for research and development – costs that often exceed their financial capabilities. The result is that companies tend to implement only the minimum necessary to comply with the relevant regulations, as the economic benefits of circular economy innovations are often not deemed significant enough to justify greater investment [8].

One of the most significant factors influencing the implementation of circular economy legislation is public perception. A company’s primary objective is to meet market

demands. However, circular economy operates on a belief system that may not align with traditional business priorities. Moreover, the belief system has been regarded as less pertinent by the general public since the Covid-19 pandemic. During the pandemic, single-use items regained popularity as fear of the virus reached its peak, contradicting the principles of circular economy [22].

Another factor contributing to the reluctance of companies to progress is the internal disruption that often occurs when implementing circular economy strategies. The need for a change in company values and visions can be challenging to address. The complexity of change management can lead to difficulties in maintaining sustainable solutions in the long term [10]. Despite the fact that numerous academic papers and the EU itself cite technological barriers as a significant factor influencing the implementation of circular economy strategies, a comprehensive survey of industry professionals identified cultural challenges as the main obstacle to the adoption [13].

Literature also confirms that a lack of clarity and inherent ambiguity in regulations creates room for interpretation, which is one of the greatest challenges for companies dealing with international sustainability legislation. Small and medium-sized enterprises are particularly affected by such policies, as they often rely on policymakers and the government to provide directions [8].

Another challenge faced by many companies is the lack of resources dedicated to innovation management, which is often seen as too costly and time-consuming. Regarding regulatory compliance, many companies expect that the regulatory authorities provide substantial assistance and incentives for innovations during the compliance process. Possible incentives may include preferential treatment in projects, direct financial aid, or funding of collaborative research initiatives [8, 15].

Significant organizational barriers present another challenge. Companies that merely adhere to regulations without exceeding them to embrace the principles of circular economy are not fully aligned with its core values. This often results in a half-hearted implementation, which creates barriers to internal change, necessary to align the company with a more circular strategy. As a result, the implementation is often set up for failure from the outset [3, 10, 13].

The results show that internal resistance and missing financial ressources are the main hurdles for organizations on their transition to circular economy. Studies show that a radical adoption of circular economy principles often provides higher benefits than incremental changes, but at the same time it also has a higher risk of failure. A cultural change within organizations is essential, but also quite difficult to achieve.

Some larger companies face change management challenges by creating an independent innovation team within the company. These teams operate autonomously and report directly to top management. This approach leads to minimal disruptions to the core organization while at the same time enabling the exploration of circular economy strategies. However, such initiatives often require significant financial resources, making them impossible to smaller companies.

Therefore, the challenges of implementing circular economy regulations differ fundamentally with the company size. Small and medium enterprises (SME) often face greater financial and operational limitations, making it difficult to allocate resources to compliance and innovation. The high cost of research and development combined with limited access to finance leads to a greater focus on short-term survival rather than long-term sustainability strategies [27].

8 CONCLUSION

In conclusion, the selected case studies support the hypothesis that sustainability legislation can positively impact innovation, at least regarding the German Circular Economy Act. However, the extent of this impact remains unclear. Industries demonstrating strong innovation in response to circular economy regulations benefit from technological adaptability, access to capital, and established research and development structures. High-tech manufacturing progresses rapidly, leveraging existing know-how to develop new materials and optimise production processes. In contrast, traditional manufacturer and SMEs struggle with high acquisition costs, technological complexity, and regulatory uncertainties that limit their ability to implement sustainable innovations.

Due to the short number of impactful case studies, it would be beneficial for companies to make their efforts more widely known in collaboration with researchers. Therefore, future research should seek to quantify the impact of sustainability legislations on innovation. In addition, future research could explore alternative theoretical models to further analyse the relationship between sustainability legislation and innovation. For example, the Green CMD model provides a framework to assess how environmental regulations drive eco-investments and eco-innovations [28]. Similarly, Bocken et al.'s archetypes of sustainable business models can help explain the cultural and organizational changes required to adopt sustainable approaches [29]. Furthermore, future studies could explore how these findings apply to other countries with different regulatory and economic contexts.

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