Can a Circular Economy Lead to Resource Conservation? A Case Study of Long-Term Resource Efficiency Measures in the Small Manufacturing Company

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1 Introduction

Globalisation, technological advancement, and resource consumption have enabled economic growth and social progress. However, at the same time, the frequency of extreme weather events such as heatwaves, fires, floods, and droughts has increased in recent decades, suggesting that the planetary capacity to sustain human development has been overwhelmed. As a result, people are increasingly looking at ways to transition to more sustainable living (Hedberg et al., 2019).

Circular economy (CE) is a model aiming at decoupling economic growth from resource constraints by keeping materials and resources in the economy for as long as possible, thus minimising waste and virgin resource use. Decoupling economic growth from resource use is expected by redesigning the products and processes and decreasing the material's use in operations and the amount of waste generated. The concept has been around since the late 1960s and has been discussed under several definitions, such as "regenerative design", "industrial ecology", and "cradle to cradle" (Hens et al., 2018). Sustainable development is CE's desired end goal that may be achieved by applying circular economy strategies in social, economic, and environmental dimensions (Lindgreen et al., 2020).

CE goes beyond the conventional "reduce, reuse, and recycle" approach, including repurposing and rethinking materials and repairing, refurbishing, and maintaining products to be cycled back into supply chains. New business models, which allow for shifting from selling products to selling services, have been described (Guldmann and Huulgaard, 2020; Kristoffersen et al., 2020; Lacy et al.,

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G. B. Melles and C. Wölfel (eds.), *Design for a Sustainable Circular Economy*, Design Science and Innovation, https://doi.org/10.1007/978-981-99-7532-7_6

2014; Lewandowski, 2016). CE promises to reduce the use of resources in the economy while simultaneously increasing employment opportunities and achieving economic growth (European Commission, 2020). The decrease in resource use and the associated amount of pollution is critical to allow time for pollution mitigation technologies such as carbon capture and carbon storage to mature (Kearns et al., 2021).

However, researchers have identified several limitations to the ability of CE to deliver on its promises of resource conservation (Korhonen et al., 2018). Complex compensatory mechanisms, collectively called rebound effects, come into play to offset efficiency gains and result in higher resource use. The rebound effect is a suite of behaviour and economic changes whose combined effect reduces or eliminates energy and material savings achieved through efficiency measures (Aramendia et al., 2021; Gillingham, 2016).

The rebound effect is sometimes referred to as Jevon's paradox. It occurs when technological progress or governmental policy increases the efficiency of resource use which results in the increased rate of consumption of that resource as the falling cost of use increases demand (Bauer et al., 2009). The effect counteracts the ability of efficiency measures to lower resource consumption and is often ignored by the proponents of efficiency measures and policymakers (Freire-González, 2021).

The role and mechanisms of the rebound effect in the circular economy have been described (Castro et al., 2022; Zink and Geyer, 2017). Moreover, Zink and Geyer (2017) noted that the economic conditions at which circular companies can avoid the rebound effect (matching the prices and taking the customers off the primary producers) were not part of the CE approach being proposed to the companies. This mismatch creates a conflict between some of the currently proposed circularity indicators, such as resource-saving, with other indicators, such as growth and new market creation (Ellen MacArthur Foundation et al., 2015).

The lack of a unified approach to implementing the circular economy on a micro level and the mixed messages regarding the success resulted in the reluctance of many companies to adopt circular economy business models. At the same time, companies are essential agents in the economy and their participation is required if any change is to be achieved practically.

When the adoption of a circular economy with Australian SMEs was discussed in 2020, many owners felt it was prudent to investigate decreasing the environmental impact of their business, but it was not high on their priority list. They valued business survival and profitability for providing their families and employees with a livelihood. Having limited resources to implement changes to their processes, the environmental concerns alone did not provide sufficient reason to embark on the change journey. As a result, it was not clear what steps would be required.

Similar confusion on how to transition to CE was uncovered in the survey of leading companies in Greece, even among large companies (Trigkas et al., 2020). Another study of 286 small and medium companies in France, Belgium, and the UK found that 23% of business owners wanted to see the quantified practical economic benefit of the circular economy, which was followed by incentives (17%) and funding (15%) for the implementation (Fusion, 2014).

This chapter uses the case study on a zero-water, zero-carbon manufacturer's energy efficiency journey to show the efficiency measures' drivers, barriers, and outcomes and to demonstrate to the designers the environment in which companies are making business decisions. Some case study analysis has been published recently (Konash and Nasr, 2022). The interplay between the economic and technical sides of manufacturing the product is discussed in the context of the circular economy rebound as it happened at the company level. The recommendations highlight that profit-making is often incompatible with the overall reduction of environmental impacts.

2 The Case Study

The following illustrative case study is based on evidence gathered during a Fullbright Fellowship by the author based in Rensellaer Polytechnic Institute (RPI) in 2021. Illustrative case studies (Simons, 2009) enable an embedded analysis and reporting of organisational change.

The company was founded in 1977 in New York State. It started as a general-purpose machine shop specialising in manufacturing complex parts through CNC machining and injection moulding. The customer segments included industries such as industrial automation, medical, aerospace, agricultural, electronic, robotics, oil and gas, hardware, plumbing, optics, and other manufacturers. In 2021, the company employed 150 people and had a turnover of $20mln. The company used 40 CNC machines, 30 injection moulding machines, and plastic and metal 3D printers. Materials worked included different qualities of steel, aluminium, brass, copper, and engineering plastics. Other value-added services provided included CAD design, prototyping, CAM programming, assembly, laser welding, laser engraving, inventory management, and outsourced finishing services (grinding, plating, heat treating, and nodizing).

The company started its journey in sustainable manufacturing back in 1990. The electricity supply at the time had stability issues with power outages and surges costing the company tens of thousands of dollars in damaged equipment, labour, and wasted material. The solution suggested by the utility company was to install the transformer for US$100k (cost to the company) that the utility company would own. However, even then, the utility company would not guarantee that the transformer would solve the supply instability. So the company decided to investigate other options and thus started its journey of becoming one of the few zero-carbon manufacturing companies in the world. In 2001, cogenerating heat and power microturbines were installed. They were upgraded in 2015. In 2002, the company became one of the first wind turbine owners in the US. The company upgraded its lighting system in 2007 and again in 2015.

Getting certified for ISO14001 opened up new ways to decrease the environmental footprint. The hydraulic mechanisms on injection moulding machines were substituted for electric. This modification resulted in quieter operations and lower energy requirements. The moulding machines were further modified with glass fibre insulation of the company's design. Installing an absorption chiller allowed cost-effective air-conditioning on the manufacturing floor, thus creating more comfortable working conditions and saving on the dryer for the materials. A pond was constructed next to the facility to provide a process water heat sink and the water for fire system sprinklers. Improved energy management resulted in lower water requirements for cooling and lower overall water consumption by the company. The efforts to improve material efficiency resulted in establishing a new revenue source from selling the company's pre-customer plastic waste as input for other companies. The company invested in collection, preparation, storage, and logistics to enable the sales of its waste stream. The company collaborated with several local charities and not-for-profit organisations to further education in renewable energy and support people affected by the lack of clean water. The company developed and manufactured a water purification product for low-resource settings.

Table 1 shows the connection between CE strategies and relevant company initiatives.

The company started its transformation before the circular economy became prevalent in the public discourse. Nevertheless, the company implemented several strategies compatible with CE by targeting environmental impact. To further analyse the company's fit with CE, the interpretation of the CE concept from Lindgreen et al. (2020) was used (Table 2).

Table 1 The fit between CE strategies and the company's initiatives

Circular economy strategy	Company's initiatives	Comments
Renewable energy	Wind turbine	The energy output is not suitable for the business operation, difficulties with integration into the utility company system
Decrease waste	Sort all waste; return packaging; identify a user for pre-consumer waste	Only one company was interested in using the waste. Additional resources for sorting and storing the materials
Regenerate natural systems	Pond ecosystem established	Space required as well as the redesign of the water-cooling system
Decrease resource use	Energy-efficient measures (lighting, heating, energy generation on-site)	Governmental funding, difficulties with utility company integration
Social impact	The profit-sharing scheme; water purification device for developing economies	Democratic decision-making, multiple stakeholders management

Table 2 Matching CE concept to previous concept and company's achievements

CE concept	Concept explanation	Company's achievement	Pre-CE concept
Value retention	Aim to decouple raw material extraction and growth	Recycling the waste, decreasing water consumption	Sustainable manufacturing
Hierarchical framework	Provides priorities of resource management: reduce, reuse, recycle	Achieved zero-carbon, zero-water manufacturing. It aims at zero waste. Sort waste for internal and external use	Zero-waste manufacturing
Sustainable development	Multidimensional impact: environmentally friendly, economically viable, and socially just	Implemented a profit share scheme, and worked with NGOs on access to clean water	Triple bottom line

Implementing all the initiatives that fit into the CE concept did not fundamentally change the company's business model (Osterwalder and Pigneur, 2010). Key activities and resources remained the same. The sorting of waste and better working conditions became a part of standard manufacturing processes. The cost and revenue structure remained largely the same. The revenue from selling the company's waste plastic did not add substantially to the overall revenue due to the cost of logistics and the limited number of companies interested in purchasing the waste. For example, the company had to rent additional warehouse space to accumulate enough waste material to make shipping viable. The company expanded its network of stakeholders to include energy and material efficiency-promoting organisations and created a new value proposition for its customers: carbon–neutral manufacturing and reporting. However, the new connections did not result in new customers. The company discovered that the sustainability network was more of a community of like-minded people than a customer-recruiting channel.

Many of their usual customers were either unfamiliar with the carbon–neutral manufacturing concept or did not consider it a service for which they were willing to pay. In addition, the larger global companies were not interested in adding the case study company to their suppliers' network due to the complicated supplier evaluation process. Being a contract manufacturer to several OEMs, the company had little influence on the product design. In addition, the recovery of the parts from the final product was also tricky as the company did not have direct access to the product user. When managing the upstream value chain as a small manufacturer, the company had limited influence on its suppliers. For example, although it requested the suppliers to provide ethically sourced materials, the company could not implement any formal system to enforce this request.

This case study demonstrated how the company must work within the limitations and constraints of a small company in the middle of a supply chain.

On the positive side, the company created a reputation for being an innovative and responsible business. The introduction of energy-efficient technologies increased the business's profitability and improved the company's standing in

Table 3 Examples of business case calculations for energy efficiency measures

Project	Scope	Motivation	Projected benefit	Cost	ROI
250kW wind turbine	Install and operationalise the wind turbine	The company needs >3 million kWh/year to operate; 3 million kWh costs $420k/year ($0.14/kWh); the company also pays $$ for taxes and $$ for insurance	Projected energy production = 300,000 kWH +/− 10% per year Electric savings $42,000/year that adds directly to the bottom line	$400,000	9–10 years
Lighting system upgrades	Replace every fixture and ballast plus high bay sodium with new T-8 type fluorescent bulbs and sensors	To improve the light quality on the shop floor by using wider spectrum light and save on electricity, the company needed new reflectors	Total annual electric savings $38,000 per year Staff satisfaction/ improved productivity	$65,000 (decreased to $41,000 via NYSERDA grant and direct federal tax credit)	1.5 year

the community. The company has become an employer of choice for the new generation of workers. The company established itself as a local and global leader in sustainable manufacturing. It educated customers, employees, and the broader community on sustainability and energy efficiency. The company developed reporting metrics for economic benefits derived from resource efficiency. The company's owner credited economic and financial benefits as the main driver for implementing sustainability features.

The examples of calculations that the company uses to build a business case and secure funding for the efficiency measures are presented in Table 3.

3 Waste Reuse and Recycling

The decision on the material used for manufacturing (including any recycled material) lies with the company designing the product. Therefore, the manufacturing company has to follow the material requirements of the designers. Most importantly, the product's design may have to be changed to incorporate any reused material and preserve the performance. Before including any recycled material, an investigation into the trade-offs and impact transfers is required. In addition, the quantity and quality of recycled material vary, increasing the complexity of the input materials in the design process.

However, the first task in the reuse process is to make the material available. The case study company contributed by separating, sorting, shredding, and finding applications for plastic waste. One example of such waste produced by injection moulding is mixed plastic waste. This waste is made during the resin changeover when the machine has produced parts of different kinds of resin. This material contains a mixture of both resins and is called a purge**.** This material cannot be automatically put back into the company's process as the properties of the purge are not identical to the virgin resin. While unable to reuse it themselves, the company located another plastic parts manufacturer that could utilise this type of mixed waste to improve the quality of their products. Thus, in a circular fashion, the case study company created an example of an industrial ecosystem (Hagnell and Åkermo, 2019), where the waste from one company becomes the feeding stock to another company.

The case-study company's leading service was high-variety low-volume injection moulding manufacturing using high-performing engineering resins. The injection moulding process produced a lower waste volume than CNC manufacturing. Some scrap could be recycled back into the manufacturing process. For manufacturing reuse purposes, post-industrial (or pre-consumer) scrap could be carefully separated, shredded, mixed with virgin material, and fed back into the injection moulding machine. For the case-study company, the customer determined the limit on how much of such pre-consumer plastic waste could be used. The durability, colour pigment, and other factors influenced the amount that can be reused.

4 Circular Economy: Sufficiency and Degrowth

It is important to note that the growth of economic activities, circular included, necessarily leads to increased environmental impact. Population growth, improved living standards, and urbanisation in developing countries drive economic growth that contributes to the global environmental impact. Thus, resource conservation and waste reduction in manufacturing, as opposed to new market creation (Ellen MacArthur Foundation et al., 2015; Victorian Department of Environment Land Water and Planning, 2020), became the primary goal of the circular economy and a means for a more sustainable lifestyle. While material availability issues might slow the introduction of new technologies and the manufacture of new products, climate change due to increased pollution threatens the foundation of societal stability (UN Security Council, 2021). Conserving the resources and the associated pollution is critical to allow time for carbon capture and carbon storage technologies to scale up (Kearns et al., 2021). Until recently, CE resource conservation efforts were focused on resource efficiency initiatives. For example, for energy use, energy efficiency and introducing renewable energy sources were the main strategies for lowering the carbon footprint of manufacturing processes (Thomas et al., 2019). However, as all technologies impact the environment and thus have a limit on their extension (Krier and Gillette, 1985), there is a growing call for sufficiency as an additional necessary strategy for constrainingenvironmental impact of any future energy and material mix (Spengler, 2016).

Concentrating on only the first two strategies (efficiency and renewables) as environmental crisis solutions may lead to the failure to solve the crisis and create undesirable social and ecological consequences (backfire and rebound effect) (Freire-González, 2021). For example, despite substantial technological development in energy efficiency, global energy demand continues to grow at a steady 2% per year (Enerdata, 2021). While more controversial and less developed than energy efficiency and renewable energy, energy sufficiency is a necessary complementary strategy (Muller, 2009; Thomas et al., 2019). All three concepts: energy efficiency, renewable energy, and energy sufficiency, are required to achieve the desired ecological and social outcome of conserving energy (Burke, 2020).

The widespread marketing and promotion of a high-consumption lifestyle as desirable or normal leads to a low social acceptance of sufficiency measures. However, if the contemporary consumption culture remains, CE will fail to change the course of the current unsustainable economic development (Grosse, 2010). For example, the desired outcome of circular economy initiatives originates in the conflict between energy consumption required for human well-being and the adverse environmental and social effects of generating that energy. It is widely understood that energy use and energy services are a means for achieving human well-being and not an end in themselves (Chiao et al., 2011; Smil, 2010). Humans require a minimal level of energy use to meet their basic needs. However, a maximum energy consumption level must also exist. The increase in life quality due to higher energy consumption does not justify the environmental and social harms created during the generation of this extra energy. A recent review has found that a high level of human well-being could be supported by a relatively low amount of energy (Burke, 2020).

Given that the climate change emergency is mainly driven by the changes in the atmosphere resulting from greenhouse emissions, reducing energy consumption, which is responsible for most greenhouse gas emissions worldwide, seems like a good starting point and a priority. However, the strong historical link between energy consumption and economic growth questions whether continued economic growth is compatible with energy conservation targets (Aramendia et al., 2021).

It is possible that global warming is inseparable from economic growth, and reducing it may lead to reduced economic growth as measured by GDP (Lang and Gregory, 2019). Suppose a more significant decoupling of energy consumption from economic growth is not achieved. In that case, it will be necessary to rapidly scale up low-carbon energy supply, carbon capture, and storage technologies to meet energy demand and prevent catastrophic global warming. These low and negative-emission technologies have limitations, including large-scale investment, extensive land use, and significant lead times. Thus, expanding them will be politically challenging and will take time (Aramendia et al., 2021).

On the other hand, an overemphasis on technical matters of energy generation, transition to renewable energy sources, and carbon capture may prevent society from questioning the necessity of high energy consumption. Therefore, it is crucial to consider the societal structures that drive high levels of energy use to ensure the application of technology will achieve the desired energy conservation goals (Toulouse et al., 2019). There is growing momentum among scholars and activists to advocate "degrowth," a critique of capitalist economic development that supports the shrinking of production and consumption, reorienting societies to use fewer natural resources and to live more sustainably (e.g. Schröder et al., 2019).

Recently, there has been an increased emphasis on sufficiency strategies—refuse, rethink, and reduce in CE literature (Bocken et al., 2022). A similar shift was observed previously in the energy sector regarding energy conservation efforts through a sufficiency strategy (Burke, 2020; Krier and Gillette, 1985; Muller, 2009; Spengler, 2016; Thomas et al., 2019). The sufficiency model is closely related to degrowth concepts (Buch-Hansen and Carstensen, 2021). Both models recognised that all human activities, including economics, were subject to physical laws; thus limitless growth in a limited environment was impossible (Cosmea et al., 2017). However, unlike degrowth, the sufficiency strategy allows for growth as long as this growth is environmentally sustainable (Bocken and Short, 2016). Several reports described examples of companies looking to adopt degrowth or sufficiency models (Bocken et al., 2022; Nesterova, 2021) in similar terms. Both reports indicate that "no growth" is impossible for new businesses. As the founder of a degrowth startup puts it: ".. you cannot build a company that doesn't grow because that isn't a good experience for the people in the business. We must address how we grow, dematerialise growth, and create businesses with less drawdown on natural capital. The pace of growth most VCs (venture capitalists, SK) have come to expect is not sustainable for the planet or the people in the business" (Webb, 2022).

The discussion with the case study company owner revealed that the "no growth" strategy had widespread opposition among stakeholders in the current economic situation. It went against the expectations of banks, employees, and customers. Banks require growth to secure a loan, which is essential for business continuity and innovation. The employees who partook in larger profits through the profit-share scheme also needed growth. It demonstrated the difficulties facing CE approaches that aim to improve all three areas of human activities: social, environmental, and economical. It again highlighted that in an environment with limited resources, growth in one place came at a cost and deterioration in another area (Moreau et al., 2017).

As the owner was motivated to do the right thing for the environment and minimise the business's ecological footprint, temporary energy conservation was achieved with constant investment in innovative technologies. However, the company's expansion resulted in other environmental impacts such as higher land use (pond, wind turbines), construction of the new building, and higher consumption potential for the employees through profit sharing. Therefore, even environmentally-driven business decision-makers cannot achieve the desired decrease in the company's footprint. Significant structural socio-economic changes are needed to enable individual companies to consider sufficiency strategies along with efficiency measures. Without sufficiency-directed policies and regulations (Thomas et al., 2019), companies are trapped in the “business as usual” model. As a result, they are limited to efficiency and renewable energy strategies, which fail to provide long-term resource conservation outcomes, as demonstrated here.

The interview with other business owners in the same geographic region revealed strong scepticism about the ability of efficiency measures and renewable energy to provide a complete solution for climate change (unpublished data). This observation suggests that highlighting best resource efficiency practices without policies and regulations limiting the use of resources is unlikely to inspire the necessary change in the manufacturing sector. On the contrary, concentrating on resource conservation while curbing consumption as the primary goal of circular economy activities will increase CE potential to enable long-term sustainable development (Basiago, 1998; Moreau et al., 2017).

5 Designers as Change Drivers: Conviviality

The main appeal of circular economy is the ability to design reduced use of material and energy, thus enabling the goal of equity in harmony with the environment. The resulting society models proposed include “slow living”, minimalist living, and localised self-sufficient communities.

For the designers to support such living, the concept of “conviviality” was introduced and developed (Lizarraldea and Tyl, 2018). A Low-tech and sufficiency approach presents a potential solution to industrial and global technological solutions. The designers’ choices of implemented technology and materials play an essential role in socio-political, economic, and cultural outcomes. In one example, the promotion of small-scale, distributed technology production and end-of-life systems (i.e. localisation) enhance autonomy and equity while providing access and knowledge to produce and maintain technologies (Lizarraldea and Tyl, 2018). Another conviviality criterion—frugal material use—challenges the designers to create less complex products with locally-sourced materials, which again improves the autonomy and stability of the supply chain.

The primary strategy to address the circular economy rebound effect should be to ensure that the secondary market targets the same consumers at the same price point. This outcome could be achieved by providing equivalence in quality between the primary and secondary products and educating consumers to remove the prejudices associated with secondary products.

The second strategy to avoid the rebound effect from circular activities is limiting those activities to markets with low product price sensitivity controlled by a few companies. In this case, it would be possible to ensure that the increase in the supply from the introduction of secondary products does not lower the price or increase the demand for the product. For example, large agricultural machinery could be one such market. Conversely, in markets where the prices cannot be controlled and the demand/price sensitivity is high, the increase in supply would lower the price, increasing the demand.

Both strategies should result in effective 1:1 substitution of the primary products by the secondary products. However, such a substitution would mean the shrinking of the primary market for the manufacturer, which goes against the interests of multiple stakeholders in the current economic environment. Thus, it is unlikely that any company would target either of the above strategies to stay competitive in the current economic conditions.

6 Conclusion

While analysing the case study's business model, it was found that little to no change in the business model was necessary to implement efficiency-based sustainability measures. This outcome suggests that changing the business model is unnecessary for a company to transition to a circular economy. A detailed discussion of the energy, water, and material efficiency measures was presented, with the drivers and challenges for each. Implementing resource efficiency initiatives was mainly driven by the strong moral beliefs of the owner and the desire to differentiate and establish the company as an innovative and responsible leader. Integrating energy generation technologies with the utility grid was the biggest challenge. Sustained innovation and entrepreneurship were the essential enablers.

Two strategies for the designers to avoid the rebound effect were presented. However, it seems unlikely they can be implemented in the current economic conditions. Therefore, there is a need to find new forms of interpretation and intervention to confront environmental crises and challenge corporate visions of the circular economy. The most urgent priority is to challenge entrenched corporate and societal views about growth. Current circular economy policies fail to challenge the capitalist imperative for growth, glossing over "reduction" among the *R*s of the circular economy. However, on a deeper level, which goes beyond the limits of the circular economy, there is a need to tackle questions about values, inequality, and future generations.

Acknowledgments Anastassija Konash gratefully acknowledges financial support for this research by the Fulbright U.S. Scholar Program, which the U.S. Department of State and the Australian-American Fulbright Commission sponsors. This chapter is solely the author's responsibility and does not necessarily represent the official views of the Fulbright Program, the Government of the United States, or the Australian-American Fulbright Commission. The author thanks Professor Nabil Nasr for his support during the fellowship and the case study data collection.

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