Sustainability Synergies and Trade-offs of a Thai Metal Manufacturing Company

Vichathorn Piyathanavong
Sirindhorn International Institute of Technology (SIIT)
Thammasat University
99 Moo 18, Paholyothin, Khlong Luang, Pathum Thani 12120,
Thailand

School of Knowledge Science
Japan Advanced Institute of Science and Technology
1-1 Asahidai, Nomi, Ishikawa, 923-1292,
1-2 Japan
Vichathorn.Piy@dome.tu.ac.th

Van-Nam Huynh
School of Knowledge Science
Japan Advanced Institute of Science and Technology
1-1 Asahidai, Nomi, Ishikawa, 923-1292,
1-2 Japan
Huynh@jaist.ac.jp

Jessada Karnjana
National Electronics and Computer Technology Center (NECTEC)
National Science and Technology Development Agency (NSTDA)
111 Thailand Science Park (TSP), Phahonyothin,
Khlong Luang, Pathum Thani 12120,
Thailand
Jessada.Karnjana@nectec.or.th

Sun Olapiriyakul*
Sirindhorn International Institute of Technology (SIIT)
Thammasat University
99 Moo 18, Paholyothin, Khlong Luang, Pathum Thani 12120,
Thailand
Suno@siit.tu.ac.th

Abstract

Improving sustainability performance across the Triple Bottom Line (TBL), which encompasses social, environmental, and economic aspects, is crucial for companies operating in the manufacturing sector. Particularly in countries with emerging economies, there is a significant demand for responsible and sustainable business practices. Using a Thai manufacturing company case study, this study investigates the synergies and trade-offs among TBL dimensions. Additionally, the study explores the impact of Industry 4.0 technologies and Circular Economy (CE) practices on these synergies and trade-offs. A qualitative method, specifically a semi-structured interview, was adopted in this study. The findings indicate that the performance of economic and environmental dimensions is more

tangible when compared to social performance. The manufacturing company recognizes the long-term benefits of improving TBL performance. Our study explains how adopting Industry 4.0 technologies and CE practices improves sustainability. The outcomes of this research can serve as valuable inputs for industrialists and practitioners, assisting manufacturing companies in improving and balancing their TBL performances.

Keywords
Industry 4.0, Circular Economy, Triple Bottom Line, Sustainability, Metal Manufacturing

1. Introduction
Triple Bottom Line (TBL) performance improvement is increasingly important to mitigate adverse impacts caused by manufacturing operations (Yip et al. 2023). The linkage between Industry 4.0 and sustainability has been previously examined (Braccini and Margherita 2019). The manufacturing sector can obtain various benefits from implementing Industry 4.0 technologies. These technologies can support a supply chain in multiple dimensions such as enhancing flexibility and responsiveness (Raman et al. 2023). When implemented together, Industry 4.0 and the Circular Economy (CE) are recognized for their contribution to improving resilience and sustainability (Behl et al. 2023).

The transition toward the CE also requires participation from stakeholders. Shevchenko et al. (2023) demonstrate the importance of consumer participation in the CE transition. Industry 4.0 technologies have the potential to link the CE stakeholders (Kristoffersen et al. 2020). Engaging stakeholders to obtain and align the sustainability requirements is necessary for CE development. Without active stakeholder engagement, the wide adoption of CE could be hindered (Gupta et al. 2019), limiting TBL performance improvement.

In circular supply chain literature, economic and environmental dimensions receive more attention than the social dimension (Sudusinghe and Seuring 2022). Therefore, strengthening a social dimension in sustainability studies can raise awareness of social performance development. In the emerging economy context, the positive impacts of Industry 4.0 technologies on economic performance are evidenced. On the other hand, their impact on environmental and social performances is far less recognized (Nara et al. 2021). To achieve sustainable development, it is essential for manufacturing firms to effectively engage all the dimensions of TBL. They should focus on exploiting opportunities through Industry 4.0 technologies and CE practices, particularly in the environmental and social dimensions. This process requires a good understanding of the role of Industry 4.0 technologies and CE practices on synergies and trade-offs among the TBL dimensions.

This study aims to broaden knowledge in this area by investigating the synergies and trade-offs of sustainability dimensions within a Thai manufacturing company. Currently, the research that connects Industry 4.0 and the CE with the synergies and trade-offs among the TBL dimensions, particularly within the context of Thailand, is still in the early stage. The balanced development of TBL dimensions is essential for sustainable development in the long run. It is expected that the outcomes of this study will provide Thai manufacturing companies with valuable perspectives on sustainability synergies and trade-offs. These companies may utilize the outcomes of this study to develop effective plans for sustainability improvement.

This paper consists of five sections. The first section introduces this research. Section 2 provides a review of relevant literature. Section 3 describes the research methodology. The results are presented in Section 4. The last section, Section 5, discusses and concludes the research findings and provides suggestions for future research.

2. Literature Review
Industry 4.0 technologies positively impact the performance of manufacturing companies in various aspects (Dalenogare et al. 2018). As summarized by Pozzi et al. (2023), adopting Industry 4.0 technologies leads to many benefits, including the effective development of business model innovation and extension. To ensure Industry 4.0 technologies implementation success, firms must build a suitable environment and readiness for adopting Industry 4.0 technologies by considering factors such as organizational strategy and employee adaptability (Sony and Naik 2020). Support from top management is one of many factors crucial to the Industry 4.0 adoption success (Raj et al. 2020).

The potential of Internet of Things (IoT) technology in promoting CE is evident in the literature (Awan et al. 2021). Industry 4.0 technologies are vital in facilitating data-driven and interconnected information flow (Kristoffersen et al. 2020), which supports the efficient circular flow of materials. Promoting closed-loop systems offers various sustainability benefits (Barros et al. 2021). The study of Braccini and Margherita (2019) demonstrates the potential of Industry 4.0 in supporting three dimensions of the TBL. Jamwal et al. (2021) summarize the possibility of how Industry 4.0 promotes sustainability of the manufacturing sector, e.g., by reducing operational costs, enhancing working conditions, and reducing energy consumption. Interconnected information flow within the supply chain is the foundation to improve TBL performance under the CE model (Gupta et al. 2019). To push TBL performances, firms should carefully consider sustainable business models and business model innovation (Evans et al. 2017). Firms must also assess the impacts of Industry 4.0 technologies when implementing them (Bai et al. 2020). The improved understanding of the impacts on each TBL dimension allows manufacturing firms to accurately address the technological requirements to achieve their sustainability targets. When implementing Industry 4.0, harmonizing sustainability requirements in the supply chain results in effective TBL benefits (Toktaş-Palut 2022).

While the impacts of Industry 4.0 and CE on sustainability is an evolving area of research, few studies have focused on the synergies and trade-offs among the TBL performances enhanced by Industry 4.0 and the CE. The improved understanding of the interaction between economic, environmental, and social impacts allows firms to make more informed and responsible decisions in pursuing their sustainable development path. Firms can focus on creating shared benefits and addressing multiple sustainable challenges simultaneously. Additionally, firms can prioritize trade-offs, collaborate with stakeholders transparently and constructively, and operate in a more sustainability-driven business landscape in the long term. The case of the Thai manufacturing sector also offers an interesting perspective on sustainable development as it illustrates the ongoing efforts to balance economic growth with environmental and social considerations. It is still common for firms to prioritize short-term financial gains over sustainable development efforts requiring significant upfront investment.

3. Methodology
A case study of a manufacturing company in Thailand is adopted to conduct this qualitative research. Previous researchers have adopted the semi-structured interview to gain in-depth information about the sustainability dimensions of businesses (Ahmad et al. 2021), and the possible linkage between Industry 4.0 and the CE (Nascimento et al. 2019). Therefore, the semi-structured interview is considered appropriate for this study.

3.1 Case Study
Our study uses a case of a metal manufacturing company in Thailand. The company is a large-sized manufacturing company with more than 200 employees. Steel pipes and metal sheets are the main products of the company. For steel pipes, the company offers a wide range of diameters and thicknesses of steel pipes for applications such as building structures and piping systems. For metal sheets, various sizes and thicknesses of metal sheets are also offered. The company mainly serves B2B customers, such as customers from the construction industry and machinery industry. This company offers standard-sized products and make-to-order products, e.g., cut-to-length steel pipes.

3.2 Data Collection
To obtain the data for this study, this study adopts a semi-structured interview to explore the role of Industry 4.0 technologies and CE practices on the synergies and trade-offs among TBL dimensions. A semi-structured interview allows this study to gain comprehensive knowledge related to the sustainability aspects of the manufacturing company. The company's executives with expertise in company operations participated in this interview. The findings obtained from this interview should provide insightful knowledge for manufacturing companies in promoting sustainability performance under Industry 4.0 and the CE. Our study does not disclose the company name and participants' information to protect their privacy.

4. Results
This section presents the interview findings related to the effects of Industry 4.0 and the CE on TBL and the synergies and trade-offs among TBL dimensions.

4.1 Effects of Industry 4.0 and the Circular Economy on TBL of Sustainability
Various benefits obtained from Industry 4.0 technologies implementation are recognized by the company. These technologies help the company improve production productivity. The company highlights that a good understanding of the business is required to successfully embed Industry 4.0 technologies with the operations. Among other Industry 4.0 benefits, the company can accurately track manufacturing costs. Industry 4.0 technologies support the company not only to improve manufacturing efficiency but also to monitor maintenance activities. This allows the company to manage maintenance costs more effectively. The technological improvement of production lines through Industry 4.0, e.g., IoT and Data Analytics, leads to higher CE readiness, assisting the firm to reduce waste and prevent pollution. These technologies have also been adopted to support other functions such as human resources and sales. The company can plan for the sale activities and identify target customer segments having high-profit margins, assisting the company to gain economic benefits. In terms of social performance, the adoption of Industry 4.0 technologies results in a better work environment.

The company currently adopts CE practices to reduce waste which also leads to cost savings. Among the TBL dimensions, the benefits of Industry 4.0 and CE practices on economic performance and environmental performance are measurable. While social performance improvement is essential, the outcome is still hard to measure. Table 1 summarizes a key question and key findings related to the effects of Industry 4.0 and the CE on TBL.

Table 1. Summary of the findings related to how Industry 4.0 and the CE affect TBL

Key Question	How does Industry 4.0 and the Circular Economy adoption affect Triple Bottom Line performance?
Key findings	• Adoption of Industry 4.0 technologies enables real-time monitoring of the manufacturing operations. This helps the company improve production efficiency and productivity, and minimize losses, promoting both economic and environmental performances. • Industry 4.0 technologies also help reduce employees' workload and enhance working conditions, leading to improved social performance. • Although the CE practices help improve environmental performance, the company is seeking new business models to capture CE benefits. Economic incentives are among the main drivers to push CE development.

4.2 Synergies and Trade-offs among TBL Dimensions
The company notices a clear synergy between economic and environmental dimensions. It is possible to create value from environmental benefits. For instance, promoting environmental performance creates business differentiation for some groups of customers, requiring green products. Industry 4.0 technology, i.e., IoT, offers real-time monitoring, which is linked to enhanced production line optimization. This optimization is, in turn, promoting the CE practice, i.e., waste reduction. For the synergy between economic and social aspects, digital technologies allow the company to effectively measure employees' performance and identify areas for improvement. A reward system for employees is implemented. Therefore, not only can the company improve manufacturing efficiency, but also employees receive a reasonable reward according to their performance. In terms of environmental and social dimensions synergy, this synergy is still limited compared to other synergies. Even though Industry 4.0 technologies allow analytical capability and data transparency, which help enhance the company's sustainability, the company emphasizes that most sustainability benefits in the social dimension are still intangible and hard to measure.

For synergies among the three TBL dimensions, the company emphasizes that adopting Industry 4.0 and the CE leads to long-term business survivability. Digital transformation and CE practices help facilitate the business to achieve sustainability targets. The company also recognizes the importance of TBL benefits for long-term business growth. Industry 4.0 technologies enable efficient production, resulting in long-term positive benefits. The company highlights the importance of good working conditions as it is difficult to seek a skilled workforce. Industry 4.0 technologies have

a positive role in supporting the company's operations and enhancing good working conditions. With the ability to monitor the production line and analyze the data under Industry 4.0 technologies, the company can better track and analyze environmental performance. The company also notices that Industry 4.0 technologies implementation can improve the ability to develop strategic direction.

The trade-offs between environmental and economic dimensions exist at a certain level. The cost of improving environmental performance might exceed economic benefits when the company focuses only on short-term benefits. Although promoting environmental and social performance positively impacts the company's brand image, improving TBL performances is still a long-term process to realize the benefits fully. It could take considerable time to obtain a return on investment from implementing Industry 4.0 technologies and CE practices. The company must balance the vision related to short-term and long-term benefits. Identifying trade-off relationships between social and other two dimensions is challenging because of the intangible nature of the firm's perception of its social impacts. Furthermore, the company perceives its efforts in preserving good working conditions for employees and good living conditions for residents as obligatory. Therefore, there is no trade-off relationship between the environmental and social aspects from the company's perspective. A key question and key findings related to synergies and trade-offs among TBL dimensions are demonstrated in Table 2.

Table 2. Summary of the findings related to the synergies and trade-offs among TBL dimensions

Key Question	What are the synergy and trade-off relationships among Triple Bottom Line dimensions under Industry 4.0 and the Circular Economy implementation?
Key findings	• The synergy between TBL's economic and environmental dimensions is evident. The company sees the opportunity from improving environmental performance by differentiating products for environmentally conscious customers. • The use of Industry 4.0 technologies aids the company to plan and manage its production operations better. With real-time monitoring capability, the company can optimize its production lines and support the CE in waste reduction. This results in the improvement of both economic and environmental benefits. • The company sees the importance of employee performance management. Industry 4.0 technologies not only help the company monitor production activities, but also help the company track employees' performance. This allows the company to improve its operations and offer a fair reward system for employees based on their performance. Therefore, both economic and social performance are improved. • In terms of the trade-off between economic and environmental dimensions, it might take time to realize the economic benefits obtained from improving environmental performance. Thus, the company needs to perceive long-term benefits when improving environmental performance. • Even though the company recognizes the necessity of improving TBL performances, social performance is still hardly recognized and measured.

5. Discussion and Conclusion

Our findings align with the previous study focusing on the benefits of Industry 4.0 technologies on TBL performance, demonstrating that Industry 4.0 technologies support manufacturing companies to improve sustainability performance, i.e., economic, environmental, and social performances (Braccini and Margherita 2019). In the research area of sustainable manufacturing, Yip et al. (2023) emphasize the connection between economic and environmental dimensions, but the social dimension is still not entirely connected with the other dimensions. This aligns with our findings as the company notes that economic and environmental performances are more tangible and easier to measure

than social performance. While the company realizes the importance of all TBL dimensions, due to the highly competitive nature of the business, the economic aspect tends to be the leading dimension of the TBL that the company prioritizes. The impacts of Industry 4.0 technologies on TBL performance improvement are summarized in Table 3.

Table 3. Summary of Industry 4.0 technologies impact on TBL

Economic	Environmental	Social
• Improve efficiency and productivity of manufacturing operations. • Effectively track manufacturing costs.	• Promote effective monitoring of environmental performance. • Reduce manufactuting loss and waste.	• Reduce employees' workload and enhance working condition. • Enhance employees' reward systems.

The company believes that Industry 4.0 technologies and CE practices are vital for long-term business survival. To promote CE implementation success, the company notices that stakeholders' participation is essential to transition toward the CE, aligning with the previous study (Gupta et al. 2019). Although the company recognizes obvious synergy between economic and environmental dimensions, there is still an existing trade-off between these dimensions. The company needs to recognize long-term benefits of improving environmental performance. The company also reveals that stakeholders within the company's ecosystem need to first recognize and then perceive the value of the TBL benefits for sustainable development. It is also crucial to ensure employees' understanding of Industry 4.0 technologies to smoothly adapt to the Industry 4.0 environment (Majumdar et al. 2021). In the long run, the company sees the benefits of promoting TBL performances to ensure sustainable development. The interesting findings of this study which may be applicable to the manufacturing sector of other developing countries are summarized as the followings.

- Industry 4.0 implementation provides benefits for all TBL dimensions.
- Among the TBL benefits, the performances of economic and environmental dimensions are more tangible than that of social dimension. Hence, it is still difficult for a company to recognize the social implications of its operations.
- Sustainability improvement is the long-term process. A well-structured plan for recovering investments in Industry 4.0 technologies and the CE is essential for a company committed to long-term sustainability improvement.

In conclusion, our study promotes the understanding of the effects of Industry 4.0 technologies and CE practices on TBL performances in the Thai manufacturing context through a case study of a metal manufacturing company. The synergies and trade-offs among TBL dimensions are highlighted. The findings of this study can help manufacturing companies properly allocate their sustainable development efforts among the TBL dimensions. Industrialists and practitioners could utilize the findings to help enhance the sustainability performance of manufacturing companies. Future studies can engage in a broader industrial sector, e.g., other manufacturing industries. A survey-based study could also help advance the understanding and generalize the findings on the synergies and trade-offs among the TBL dimensions of the manufacturing industries.

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Biographies

Vichathorn Piyathanavong is a Ph.D. student at both the School of Manufacturing Systems and Mechanical Engineering (MSME), Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand and the School of Knowledge Science, Japan Advanced Institute of Science and Technology (JAIST), Japan. He received a Bachelor of Engineering in Industrial Engineering from SIIT, Thammasat University, Thailand, and a Master of Science in Engineering Business Management from Warwick Manufacturing Group (WMG), the University of Warwick, the United Kingdom. His main areas of interest include sustainability, operations management, and the Circular Economy.

Van-Nan Huynh received the Ph.D. degree in mathematics from the Vietnam Academy of Science and Technology, in 1999. He was a Visiting Professor with the National Electronics and Computer Technology Center, Thailand, in 2019; an Adjunct Professor with Chiang Mai University, Thailand, from 2015 to 2017; and a part-time Lecturer with Tsukuba University, Japan, from 2011 to 2015. He is currently a Professor with the School of Knowledge Science, Japan Advanced Institute of Science and Technology (JAIST). His current research interests include decision analysis and management science, AI and machine learning, modeling and reasoning with uncertain knowledge, argumentation, multiagent systems, and Kansei information processing and applications. He currently serves as an Area Editor for the International Journal of Approximate Reasoning, the Editor-in-Chief for the International Journal of Knowledge and Systems Science, and an Area Editor for the journal Array.

Jessada Karnjana received his B.Eng. degree in Electronics Engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand in 1999, M.Eng. degree in Microelectronics from Asian Institute of Technology, Thailand in 2006, his Ph.D. degree in Information Science from JAIST, Japan in 2016, and his Ph.D. degree in Engineering and Technology from Sirindhorn International Institute of Technology, Thammasat University in 2017. His research interests include data analysis and machine learning, reasoning with uncertainty, signal processing, and wireless sensor networks. He has worked at NECTEC, Thailand since 1999.

Sun Olapiriyakul is an Associate Professor in the Industrial Engineering and Logistics Systems program at the Sirindhorn International Institute of Technology (SIIT) of Thammasat University, Thailand. Dr. Olapiriyakul received a doctoral scholarship from the Royal Thai Government in 2005 to study industrial engineering and conduct research related to nanotechnology. He holds a Ph.D. in Industrial Engineering from the New Jersey Institute of Technology, US. His current research focuses on applied Operations Research and sustainable development, with a particular emphasis on sustainable logistics and supply chain management. His primary ongoing research topics revolve around achieving supply chain operational objectives while simultaneously addressing environmental consequences and resolving sustainability issues, such as gender inequality and environmental injustice.