International Journal of Information Management Data Insights 4 (2024) 100243

Contents lists available at ScienceDirect

International Journal of Information Management Data Insights

journal homepage: www.elsevier.com/locate/jjimei

Enhancing sustainability integration in Sustainable Enterprise Resource Planning (S-ERP) system: Application of Transaction Cost Theory and case study analysis

Kushal Anjaria

Institute of Rural Management Anand (IRMA), Anand, India

A R T I C L E I N F O

Keywords:
Sustainability criteria
Input-output systems
Environmental impact assessment indicators
Business process
Sustainable Enterprise Resource Planning (S-ERP)

A B S T R A C T

Environmental stewardship and sustainability have become critical priorities in the contemporary business environment. Corporations are integrating sustainable practices at the business process level via Sustainable Enterprise Resource Planning (S-ERP). However, a recognised shortfall of S-ERP systems lies in their potential inability to integrate sustainability metrics across all business functions holistically. To navigate this limitation, our study introduces the application of Transaction Cost Theory (TCT). By treating business processes as input-output systems, we apply this theory to quantify sustainability likelihood and overall losses. This novel approach bridges the gap, allowing for the comprehensive integration of sustainability metrics across all processes. The essence of our methodology is to leverage static input data collected by S-ERP regarding environmental impact and to extrapolate this data to provide a broader understanding of potential losses and gains. We've tested and validated this approach through two comprehensive case studies; one is about sustainable product design and development, and the other is about the sustainability evaluation of modular versus conventional construction methods. The results inform the formulation of robust sustainability policies at the business process level for systems akin to S-ERP, paving the way for more sustainable business practices.

1. Introduction

In today's world, where everything is more connected, the importance of sustainability in business has grown along with the increasing connections between economies and societies. Accelerated by burgeoning trade, the exchange of technological knowledge, and the fast diffusion of information, the international commercial panorama has undergone a radical metamorphosis. As a result, the imperative of addressing sustainable practices emerges as organisations confront the environmental, social, and economic tribulations spawned by this newly interwoven world. Sustainability's crux resides in the equilibrium between the pursuit of economic expansion and the difficulties of environmental conservation and social fairness (Taylor, 2020). By embracing sustainable practices, enterprises can attenuate the detrimental ecological repercussions of their endeavours while concurrently ensuring their enduring viability (Afshar Jahanshahi et al., 2020, Mittal et al., 2023).

For multiple reasons, considering sustainability at the business process level is vital for enterprises (Raut et al., 2019, Babber & Mittal, 2023). Firstly, it ensures the long-term viability of the business by optimising resource use and reducing over-dependence. It also increases cost efficiencies by minimising waste and improving energy use (Lim et al., 2022). Moreover, meeting increasingly stringent government environmental regulations is critical, thus avoiding potential legal complications (Zhang et al., 2022). By incorporating sustainable practices, a company can differentiate itself in the market, attract eco-conscious customers and investors, and drive process innovation (Zhang & Xie, 2022). It also enhances employee engagement by aligning staff with the company's values. Importantly, sustainability aids in risk management by identifying and mitigating environmental and social risks (Zhu et al., 2022). It can enhance brand reputation and customer loyalty while satisfying stakeholders' expectations for businesses to be more responsible. Thus at the business process level, embracing sustainability is essential to reducing the environmental impact, demonstrating the company's commitment to corporate social responsibility.

Business processes are implemented through Enterprise Resource Planning (ERP) solutions (Lutfi et al., 2022). With their integrated approach to managing various business functions, ERP solutions provide an ideal platform for implementing sustainable business processes. By leveraging process automation and resource tracking, businesses can

E-mail address: kushal.anjaria@gmail.com.

https://doi.org/10.1016/j.jjimei.2024.100243

Available online 23 April 2024

optimise operations, reduce waste, and make strategic decisions that align with sustainability goals. Furthermore, advanced ERP systems can generate sustainability reports, enhancing transparency for stakeholders who value corporate responsibility (Olsen, 2023). Hence, ERP solutions can be pivotal in driving sustainability at the business process level.

However, current ERP systems face multifaceted sustainability difficulties despite the above-mentioned advantages. These systems often struggle with comprehensively integrating diverse environmental, social, and governance (ESG) metrics (Dumitru et al., 2023, Hahn et al., 2015). This leads to difficulties in capturing, processing, and reporting sustainability data, creating a gap in understanding the environmental impact of business processes in real time (Wu et al., 2016). Additionally, the limited agility of ERP systems in adapting to constantly evolving sustainability-related regulations and standards poses a significant compliance challenge (Zabukovšek et al., 2023). This is compounded by the lack of adequate features for engaging stakeholders on sustainability issues, thereby limiting transparency and communication about corporate sustainability efforts. Moreover, implementing and maintaining ERP systems with advanced sustainability features can be resource-intensive and costly, particularly challenging for smaller organisations (Bradač Hojnik & Huđek, 2023). Finally, the lack of standardisation in sustainability measurement and reporting adds another layer of complexity, making it challenging for ERP systems to address sustainability across different industries and regions uniformly (Bakarich et al., 2020).

Scholars have pioneered the development of Sustainable Enterprise Resource Planning (S-ERP) systems to confront the multifaceted sustainability difficulties modern enterprises face (Chofreh et al., 2020). S-ERP systems herald a new era in business management, seamlessly intertwining sustainability principles with the intricate mechanisms that govern an organisation's operations (Chofreh et al., 2017a). As the clarion call for ecologically responsible practices grows ever more resounding, S-ERP systems serve as a beacon of hope, guiding businesses toward a more environmentally conscious and socially equitable modus operandi (Chofreh et al., 2017b). At the heart of these systems lies a harmonious marriage between technological prowess and sustainability, providing businesses with the tools to navigate the labyrinthine pathways of a globalised marketplace while minimising their ecological footprint.

With its myriad capabilities, the S-ERP system allows organisations to optimise resource utilisation, streamline processes, and foster transparency while adhering to the stringent tenets of environmental stewardship and social responsibility (Chofreh et al., 2014). In a time when the demand for sustainable practices echoes throughout industries, the S-ERP system stands out as a model of progress, reflecting the unyielding human drive for constant innovation and betterment (Chofreh et al., 2018a). By harnessing the power of data analytic, and automation, these systems enable businesses to chart a course through the turbulent waters of an ever-changing global landscape, guided by the North Star of sustainability.

Central to the effectiveness of S-ERP systems is their ability to execute functions with the support of well-defined business processes, ensuring seamless integration and enhanced operational efficiency (Chofreh et al., 2017b). One cannot overstate the importance of business processes in S-ERP systems, as they form the foundation for successful implementation and utilisation (Chofreh et al., 2014). Business processes, essentially a series of related tasks and activities aimed at achieving specific organisational goals, play a crucial role in the overall functioning of S-ERP systems. By integrating and streamlining various processes, S-ERP systems can help organisations achieve operational efficiency, reduce waste, and make informed decisions that align with their sustainability objectives. When business processes are well-defined and effectively managed, S-ERP systems can work to their full potential, fostering a comprehensive understanding of resource utilisation, cost control, and environmental impact. This understanding enables organisations to identify areas for improvement, optimise resource allocation, and promote environmentally friendly practices, thus contributing to their sustainability goals.

Moreover, by automating repetitive tasks and reducing manual intervention, S-ERP systems can also help minimise errors and enhance the organisation's overall productivity (Chofreh et al., 2020). In addition, well-structured business processes provide a clear road map for employees, allowing them to understand their roles and responsibilities within the context of the organisation's sustainability objectives. As a result, this fosters a sense of ownership and commitment to sustainable practices among the workforce. The integration and support of business processes within S-ERP systems are vital for achieving long-term sustainability, operational efficiency, and overall organisational success (Abobakr et al., 2023, Backer et al., 2023). Abobakr et al. (2023) have demonstrated that S-ERP can alleviate the limitations of traditional ERP systems by applying institutional theory. Similarly, through an exploratory study, Backer et al. (2023) have suggested that S-ERP can overcome the limitations of ERP systems.

From the standpoint of business processes, S-ERP systems exhibit certain limitations. Firstly, while S-ERP systems endeavour to incorporate sustainability principles, they might not fully integrate sustainability metrics across all business processes (Kouriati et al., 2022). This incomplete integration could lead to sub-optimal decision-making and impede progress towards sustainability objectives. Secondly, each organisation possesses unique business processes that may necessitate customising S-ERP systems to guarantee seamless integration. Adapting S-ERP systems to accommodate specific business processes can be time-consuming and costly (Rutz et al., 2023). Thirdly, modelling business processes with sustainability elements presents a complex and challenging task. S-ERP systems may need help accurately depicting the intricate relationships among processes, resources, and environmental impacts, thereby constraining their effectiveness in promoting sustainable business practices (Broccardo et al., 2023). Lastly, organisations must consistently monitor and refine the processes within their S-ERP systems to ensure the ongoing optimisation of business processes for sustainability. This requirement can be resource-intensive and potentially strain an organisation's resources.

In the present work, we aim to address the limitations mentioned above of S-ERP by utilising Transaction Cost Theory (TCT) (Li & Fang, 2022) as a foundation for understanding the sustainability aspects associated with each business process. The choice of TCT was guided by its effectiveness in analysing and optimising the resources, time, and effort involved in executing business practices (Schmidt & Wagner, 2019). This theoretical framework is particularly relevant for assessing sustainable business practices, as it allows for a detailed evaluation of the trade-offs and efficiencies associated with various sustainability initiatives (Mach et al., 2020). In pursuing sustainable practices, TCT sheds light on optimising supply chains, balancing market mechanisms with governance interventions, and designing effective circular economy models (Chiu & Lin, 2022). For instance, it can guide firms in managing lower-tier sustainability within their networks, minimising environmental footprints at the source (Zhang et al., 2023). Furthermore, when information asymmetries make assessing environmental performance challenging, transaction cost analysis suggests that well-designed regulations can lower transaction costs and incentivise sustainable practices, bridging the gap between market failures and efficient outcomes (Leimona et al., 2023). Finally, transaction cost insights aid in choosing optimal organisational structures for product lifecycles, promoting resource reuse and reducing waste within circular economy models (Burke & Wang, 2023). By illuminating the cost dynamics shaping sustainable choices, TCT offers valuable tools for navigating the complex landscape of sustainable development (Marín-Rodríguez et al., 2023).

Subsequently, the methodology focuses on the seamless integration of process-level sustainability within S-ERP systems (Chari et al., 2023). This aspect of our approach was shaped by recognising the need for a more automated and integrated system for managing sustainability data (Mölder et al., 2021). We facilitate data collection, reporting, and analysis automation by directly embedding sustainability criteria and performance indicators into ERP systems. This strategic integration was essential for reducing manual efforts and errors and enhancing the visibility and accessibility of sustainability-related information across the enterprise. To encapsulate, although previous studies have utilised diverse theoretical frameworks to explore the nexus of ERP systems and sustainability (see, for instance, (Schmidt & Wagner, 2019), (Ghobakhloo et al., 2022)), our employment of TCT stands apart. We uniquely leverage this theory to intricately analyse and optimise the allocation of resources, time, and effort to execute sustainable business practices (Schmidt & Wagner, 2019).

Our approach leverages TCT to enhance the sustainability aspects of business processes through implementing a sustainability matrix, seamless integration of sustainability criteria in S-ERP systems, and ongoing sustainability monitoring at the business process level. Initially, we implement a sustainability matrix across the entire business process. Our decision to implement a sustainability matrix across the entire business process was influenced by the need for a comprehensive and systematic approach to sustainability (Ketokivi & Mahoney, 2020). The matrix serves as a framework for identifying, evaluating, and prioritising sustainability-related objectives, risks, and opportunities (Ghobakhloo et al., 2022). It was developed in response to the observed gap in how organisations visualise and manage the interdependencies between different processes, resources, and stakeholders in sustainability (Herrera & de las Heras-Rosas, 2020). The matrix enables organisations to make more informed decisions regarding resource allocation and long-term sustainability initiatives. By adopting this comprehensive strategy, organisations can optimise their operations, reduce inefficiencies, and drive sustainable growth in the long run. TCT offers a framework for understanding business processes by focusing on organising and executing transaction costs. Organisations can enhance their overall performance and competitiveness by examining various transaction costs. These costs arise from factors like information asymmetry, bounded rationality, and opportunistic behaviour among parties involved in a transaction. Organisations can better understand the trade-offs in different process configurations and coordination mechanisms by analysing these costs. Applying TCT helps organisations identify efficient structures and mechanisms for coordinating activities, such as procurement, production, and distribution. Research in this field, as exemplified by studies like (Gupta et al., 2020, De Felice & Petrillo, 2021), has employed a sustainability matrix to evaluate the efficiency of various business processes. These studies typically concentrate on cost optimisation, decision-making, digital integration and digital collaboration (Zoppelletto & Bullini Orlandi, 2022). In our current work, we expand upon this foundation by integrating sustainability considerations directly into the process configuration alongside these aspects. Our approach involves assessing the transaction costs associated with diverse process configurations, enabling organisations to identify the most suitable sustainability governance structures. This ranges from in-house management to external outsourcing or forming partnerships. Additionally, our analysis facilitates vertical integration or disintegration decisions based on the comparative efficiencies and transaction costs involved.

In the present work, we deploy TCT with the input-output configuration of the business process. TCT, with the input-output process, aids organisations in understanding the implications of technological advancements on their business processes (Agafonow & Perez, 2023). Digital technologies have significantly reduced information search, processing, and communication costs, leading to shifts in the optimal organisation of business processes. By understanding these changes, organisations can adapt their processes to capitalise on new technological opportunities, manage sustainability criteria, and maintain a competitive edge. Additionally, TCT, with the input-output configuration of business process, guides organisations in managing relationships with suppliers, customers, and other stakeholders while maintaining sustainability (Chen et al., 2022). Examining the transaction costs associated with different contractual arrangements and collaboration models helps organisations develop more effective strategies for managing their supply chain, customer relationships, and other critical business process interactions. TCT, with input-output driven processes, informs the development of performance measurement and management systems. By recognising the various transaction costs and their drivers, organisations can design performance metrics and management systems that minimise them, leading to more sustainable, efficient and effective business processes. TCT assists organisations in understanding the complexities of business processes by analysing the costs associated with organising and executing transactions (Wong et al., 2021). This understanding enables informed decisions about process configurations, governance structures, technological adaptations, stakeholder relationship management, and performance measurement systems, ultimately improving efficiency and competitiveness.

In our current research, we meticulously review the data about business processes and their sustainability dimensions. Subsequently, we tackle correlating an independent yet interconnected sustainability matrix. This is accomplished by conceptualising business processes as input-output systems and monitoring their transactions (Cong & Chen, 2015). Existing S-ERP systems grapple with establishing an independent yet comprehensive sustainability matrix linked to business processes. To address these emerging challenges and further our understanding of S-ERP systems, this study poses the following Research Questions (RQs):

1. **RQ1:** How can TCT be applied to enhance the integration of sustainability metrics in S-ERP systems across all business functions?
2. **RQ2:** What are the implications of using TCT in evaluating and improving the sustainability of business processes within S-ERP systems?
3. **RQ3:** How can a sustainability matrix, grounded in TCT, address the current limitations of S-ERP systems in terms of holistic sustainability integration?
4. **RQ4:** What are the practical implications of implementing TCT in S-ERP systems for various industries, particularly in the contexts of sustainable product design and modular versus conventional construction methods?

The literature discusses the implementation of S-ERP systems and their importance in integrating sustainability into business processes (Chofreh et al., 2020, Abobakr et al., 2023). Our first RQ extends this by exploring how TCT can be specifically applied to enhance this integration, focusing on the effectiveness of sustainability practices within S-ERP systems. Existing studies highlight the need for effective implementation strategies for S-ERP systems (Chofreh et al., 2020, 2018b). Our second RQ explores the broader implications of applying TCT within this context, particularly how this theory can aid in evaluating and improving the sustainability of business processes managed through S-ERP systems. While researchers focus on general guidelines for S-ERP implementation (Chofreh et al., 2018c, 2020), our third RQ delves into developing a sustainability matrix grounded in TCT to overcome the limitations of S-ERP systems discussed in the present section. This RQ seeks to address how such a matrix can enable a more holistic integration of sustainability metrics in S-ERP systems. Furthermore, existing research underscores the practical aspects of implementing S-ERP systems in businesses (Patalas-Maliszewska & Kłos, 2019, Olsen, 2022). Our fourth RQ explores the practical implications of applying TCT in S-ERP systems across different industries. This involves understanding how such an approach can benefit sectors like sustainable product design and construction methods.

The four RQs above are framed using the CIMO (Context, Intervention, Mechanisms, Outcomes) framework (Denyer & Tranfield, 2009). This framework is commonly used in management, business, and administration disciplines to structure questions focusing on the context of a problem, the intervention applied, the mechanisms through which the intervention works, and the outcomes achieved (Denyer & Tranfield, 2009). The above RQs fit this framework as they investigate the application of TCT within S-ERP systems (the intervention) across various business functions and industries (the context), aiming to understand how TCT can enhance sustainability integration or improve business processes (the mechanisms) and the implications of TCT application for sustainability and efficiency within S-ERP systems (the outcomes).

Following the introductory segment, the composition of this paper is as follows: The subsequent segment, Section 2, constructs a framework for sustainable business process management rooted in the existing literature. In Section 3, we crystallise the proposed methodology. Moving on, Section 4 delves into a detailed examination of two salient case studies. After that, Section 5 presents a discourse on the suggested approach's merits and potential constraints, and Section 6 elucidates contributions. Ultimately, Section 7 encapsulates the conclusions drawn from the current investigation.

2. Developing a sustainable business process management framework: a literature-based approach

The current study focuses on three pivotal aspects: S-ERP, TCT, and developing a sustainable matrix via input-output systems. Accordingly, this section is structured into distinct subsections, each dedicated to one of these critical topics. The discourse commences with an in-depth examination of S-ERP.

2.1. Sustainable Enterprise Resource Planning (S-ERP)

The concept of sustainability in business operations has gained significant momentum since the late 20th century, paralleling the rapid evolution of distribution systems and globalisation (Gatto, 2020, Chung, 2014). This shift has notably intensified the focus on environmental responsibilities and integrating sustainable practices into business processes (Hasan et al., 2019). The drive towards embedding sustainability into business operations was further propelled by the inefficiencies and limitations inherent in traditional information systems, which struggled to manage sustainability-related data effectively (Chofreh et al., 2017b). This challenge laid the groundwork for the conceptualisation and subsequent development of S-ERP systems. S-ERP systems mark a significant evolution in integrating sustainability within the core framework of business processes (Chofreh et al., 2017a). Designed to seamlessly consolidate environmental, social, and economic data across various business functionalities, these systems aim to align business operations with overarching sustainability objectives (Chofreh et al., 2014). Emerging from the traditional ERP systems, which are predominantly centred on optimising internal resources, S-ERP systems embody a more comprehensive approach. They balance profitability with environmental and social responsibilities, representing a paradigm shift in business process management.

The foundation of S-ERP systems is deeply rooted in the theoretical frameworks of sustainability, information systems, and project management (Chofreh et al., 2020). These frameworks inform the design and functionality of S-ERP systems, combining principles from ERP implementation strategies with methods for evaluating and optimising sustainability performance. The theoretical basis of these systems underscores a 'triple bottom line' approach, which seeks a harmonious balance between economic performance and environmental and social impacts (Scuri et al., 2022). However, the implementation of S-ERP systems is not without its challenges. Issues such as the complexity of the systems, aligning the interests of various stakeholders, and effectively integrating qualitative sustainability data remain significant hurdles. Additionally, transitioning from traditional ERP systems to S-ERP platforms necessitates substantial organisational change management. This highlights the critical need for a thorough understanding of S-ERP implementation's technical and cultural facets, underscoring the complexity of integrating these systems into existing business structures.

The existing research on S-ERP systems is diverse, covering aspects such as system design, implementation strategies, and their impact on organisational performance (Gholamzadeh Chofreh et al., 2016). Various studies have emphasised the imperative of integrating sustainability into all facets of business operations, from product design to supply chain management. However, they also reveal the inadequacies of traditional information systems in supporting a holistic approach to sustainability (Xia et al., 2022). This shortfall has led to the development of S-ERP systems as a more capable solution. Research in this area also delves into the challenges encountered while implementing S-ERP systems, particularly highlighting the need for strategic alignment between sustainability initiatives and information system strategies (Xia et al., 2022). A notable gap in S-ERP research is its relatively early stage of development and implementation (Chofreh et al., 2020). While the concept and potential advantages of S-ERP systems are increasingly acknowledged, there remains a paucity of extensive practical applications and empirical studies. This gap offers a fertile ground for future research to investigate real-world implementation processes, challenges, and long-term effects of S-ERP systems within various organisational contexts.

In recent times, S-ERP research has begun exploring innovative solutions like cloud-based platforms (Anjaria & Patel, 2021), Service-Oriented Architecture (SOA) (Anjaria & Mishra, 2017a), and big data analytics (Yoshikuni et al., 2023), which could significantly enhance the scalability and efficiency of S-ERP systems (Mantravadi et al., 2023). These advancements indicate a shift towards more agile, adaptable, and technologically sophisticated S-ERP solutions, suggesting an exciting trajectory for future development in this field (Mantravadi et al., 2023). Concluding this subsection, integrating TCT into S-ERP systems, as proposed by our research, is paramount (Abobakr et al., 2023). This integration provides a foundational understanding of the current state of S-ERP systems. It illuminates the necessity for novel approaches that effectively enhance the integration of sustainability metrics throughout business functions. Our research thus contributes to this evolving field, aiming to refine and elevate the efficacy of S-ERP systems in achieving sustainable business practices. The following subsection discusses the TCT.

2.2. Transaction Cost Theory (TCT)

Ronald Coase, often hailed as the father of Transaction Cost Theory (TCT), laid the foundational stone for this influential framework in 1937 (Akbar & Tracogna, 2018). His seminal work aimed to elucidate why firms arise in specialised exchange economies, proposing that the cost of utilising the price mechanism in market transactions could be more efficiently managed within the confines of a firm. This pivotal concept set the stage for TCT's development, which has profoundly shaped the fields of information technology outsourcing (ITO) (Anjaria & Mishra, 2017b, Bui et al., 2019) and marketing (Sgroi & Sciancalepore, 2022) over the past 80 years. Building upon Coase's initial insights, TCT became a crucial lens through which the organisation of transactions is examined, particularly within marketing, multinational firms' boundary decisions and economic contexts (Wang et al., 2023, Chen & Kamal, 2016). Its theoretical structure is anchored in critical dimensions such as asset specificity, uncertainty, and frequency, coupled with bounded rationality and opportunism among economic actors (Cevikparmak et al., 2022). This theoretical framework facilitates a comparative analysis of transaction costs across diverse organisational structures, whether market-based or within a firm's internal mechanisms.

Oliver Williamson significantly advanced TCT by elaborating on these dimensions (Akbar & Tracogna, 2018). In the 1980s, Williamson's work enriched the theory by pinpointing specific attributes of economic transactions and actors, such as asset specificity and opportunism. His contributions provided a robust framework for empirical assessment and broadened TCT's application across various scholarly fields, enhancing our understanding of how different modes of organising transactions incur varying costs (Potoski et al., 2023). However, in the rapidly evolving digital landscape marked by the Fourth Industrial Revolution, TCT faces the challenge of remaining relevant. Advanced technologies like 3D printing and blockchain are revolutionising how transactions are coordinated and monitored, signalling a potential shift in the applicability and pertinence of TCT (Mitra, 2022). This period of technological transformation has prompted critical re-assessments of TCT's traditional focus on market versus firm dichotomies.

In this context, the work of scholars like Yochai Benkler is instrumental in modernising TCT (Benkler, 2017). Benkler argues that democratising digital tools has given rise to new forms of economic organisation, such as social production, which challenge the conventional dichotomy of market and firm outlined in TCT (Benkler, 2017). His perspective underscores the need for TCT to adapt and encompass these emerging organisational forms. Despite these challenges and critiques, particularly in the digital age where phenomena like open-source software and crowdsourcing are gaining prominence, TCT remains highly pertinent, especially in S-ERP systems (Cordelia, 2006). TCT's focus on minimising transaction costs and enhancing the efficiency of transaction organisation offers valuable insights into the structuring and management of ERP systems (Cordelia, 2006). It underscores the potential for these systems to integrate sustainability effectively and optimise transaction processes in business practices, proving that TCT, while evolving, continues to be a vital tool in understanding and navigating the complexities of modern economic activities.

Continuing from the established relevance of TCT in the context of ERP systems, exploring how TCT can be further adapted and applied in this rapidly evolving digital landscape is imperative (Yang et al., 2023). The increasing integration of technologies such as artificial intelligence, big data analytics, and the Internet of Things (IoT) into business operations presents a new frontier for TCT (Dwivedi et al., 2023, 2021). These technologies, while enhancing the capabilities of S-ERP systems, also introduce additional layers of complexity in transaction management (Lutfi, 2023). TCT can offer a framework to assess and mitigate the transaction costs associated with these technological integrations, ensuring that adopting new technologies aligns with the overall goal of cost efficiency and sustainability (Potoski et al., 2023). Moreover, the rise of a more interconnected global economy demands a reassessment of how transaction costs are perceived and managed in cross-border and multi-entity operations. In this context, S-ERP systems are tools for internal resource management and platforms for global collaboration and data exchange. TCT's principles can guide the development of resilient governance structures within these systems, adaptable to diverse regulatory environments and conducive to sustainable global trade practices.

Furthermore, as businesses increasingly recognise the importance of corporate social responsibility and environmental stewardship, TCT's role in S-ERP systems becomes even more crucial (Mookwon Jung & Yayla, 2023). The theory can aid in evaluating the trade-offs between economic efficiency and sustainable practices, helping organisations find a balance that does not compromise on their environmental and social commitments for cost savings. In summary, as we delve deeper into the intricacies of S-ERP systems in a digital and globally connected environment, the principles of TCT can provide a compass to navigate these complexities (Cuypers et al., 2021). By continuously adapting and applying TCT to the evolving landscape of enterprise resource planning, businesses can harness these systems' full potential to achieve economic efficiency and make strides in their journey towards sustainability and corporate responsibility. The following subsection discusses input-output-driven business processes and the sustainability matrix.

2.3. Input-output driven business processes and sustainability matrix

We begin this subsection by exploring various dimensions of business processes. From the industrial engineering perspective, "a business process is a set of logically related tasks to achieve a defined business outcome (Davenport & Short, 1990)". From the business corporation perspective, "a business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer (Hammer, 2014)". From an architectural perspective, "a business process is a coordinated and structured set of activities, resources, and information flows that are organised to accomplish a specific organisational goal, such as providing a product or service to a customer (Weske, 2019)." From the business model perspective, "A business process is a complex and structured set of activities and tasks, designed to achieve specific organisational goals and produce valuable outputs for internal or external stakeholders (Melao & Pidd, 2000)."

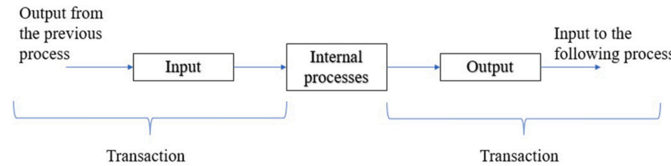

Fig. 1. Business process as an input-output system in an arbitrary functional boundary.

From the above list of definitions, we use a definition presented by Hammer (2014) as it considers business processes as input-output systems (Unal et al., 2023). Further, this definition offers a more holistic view of business processes, making it suitable for capturing the essence of the sustainability concept without significant limitations. A holistic view of a business process allows organisations to consider the entire lifecycle, from sourcing raw materials to delivering the final product or service. This comprehensive approach is necessary to evaluate and address the process's environmental, social, and economic impacts at every stage (Leclère et al., 2020). Moreover, an input-output perspective enables organisations to analyse and optimise their use of resources, including materials, energy, and labour (Ge, 2023). By identifying inefficiencies and potential areas for improvement, businesses can minimise waste, reduce costs, and enhance their overall sustainability.

Input-output-based business processes support S-ERP by analyzing resource flows, optimizing efficiency, and minimizing waste (Zhou et al., 2023). They enable life cycle assessment, tracking products from extraction to disposal, to identify and reduce environmental impacts. S-ERP integrates sustainability criteria into product design and procurement, promoting eco-design and green procurement practices. Considering input-output dynamics, S-ERP helps organizations make informed decisions and enhance their overall sustainability performance.

Understanding the inputs and outputs of a business process helps organisations assess their environmental impacts, such as emissions, water usage, and waste generation (Weber et al., 2022). This information is essential for developing strategies to minimise adverse environmental effects and promote sustainable practices. Additionally, considering the input-output system of a business process helps organisations identify the value created for various stakeholders, including customers, employees, suppliers, and the broader community. This approach aligns with the triple-bottom-line concept of sustainability, which emphasises creating value in economic, social, and environmental dimensions. Finally, analysing the input-output system of a business process allows organisations to monitor their progress towards sustainability goals, identify areas where further improvement is needed, and adapt their strategies accordingly (Castiglione et al., 2022). This continuous improvement mindset is crucial for achieving long-term sustainability. Fig. 1considers a business process an input-output system.

Fig. 1 shows input and output in the form of transactions. Transactions play a crucial role in understanding a business process as an input-output system, as they serve as the fundamental building blocks of any organisation's operations (Subhan et al., 2021). By analysing the flow of transactions, one can understand how various resources are utilised and transformed throughout a business process, ultimately leading to the creation of products or services. In essence, Zhang et al. (2016) suggested that transactions represent exchanging resources, services, control or information between different processes or parties, such as suppliers, customers, and employees. As these exchanges occur, they create a dynamic interplay of inputs and outputs, revealing the inner workings of a business process. By studying the patterns and relationships between these transactions, decision-makers can identify opportunities for improvement, optimise resource allocation, and pinpoint potential bottlenecks hindering performance. Moreover, understanding transactions as part of an input-output system allows businesses to establish a clear and measurable framework for evaluating their performance (Antràs & Chor, 2022). By tracing the flow of transactions, companies can track key performance indicators and assess how efficiently they convert inputs, such as raw materials, labour, and capital, into desired outputs, like revenue, customer satisfaction, and brand reputation. Fig. 1 shows that the output of the previous business process can be input into the following business process. Fig. 1 aligns with the tripartite structure proposed by Bahli and Rivard (2005), encapsulating agency and TCT.

Understanding sustainability often involves managing a complex symphony of inputs and outputs. Fig. 1 views this interplay through the lens of an input-output system. Imagine a matrix where economic, social, and environmental factors weave an intricate dance. Economic activity (inputs) like resource extraction fuels growth but generates environmental outputs like pollution and depletion (Cámara & Llop, 2021). Meanwhile, social capital like education and healthcare (inputs) enhances human well-being (outputs) but can be eroded by environmental degradation (Cazcarro et al., 2011). The key lies in optimising this dance, minimising undesirable outputs while maximising positive ones. Ecological Input-Output Analysis (EIOA) offers a powerful tool for quantifying the environmental footprints of economic sectors (Piluso et al., 2008). Integrating it with social metrics, like the Human Development Index, we can build comprehensive sustainability matrices, revealing trade-offs and synergies between dimensions. Drawing inspiration from research like (Ali et al., 2018), this systemic approach allows us to move beyond siloed thinking and orchestrate a sustainable future where economic dynamism coexists with environmental health and social equity.

In our current research, we endeavour to establish a formalisation of business processes as input-output systems. Within this formalisation, we assert that the output of any given business process i cannot be consumed by the process itself, thereby endorsing a highly cohesive process. The ideal system should exhibit high cohesion and low coupling (Saidani et al., 2019), as these fundamental principles underpin the design of robust, maintainable, and scalable systems. Adhering to high cohesion and low coupling as essential design principles results in a more comprehensible, maintainable, and adaptable system architecture. By embracing these principles, developers can construct modular and scalable systems, which exhibit increased resilience to change and are more manageable in the long term. For any business process i, the input matrix is denoted as In_i, the processing matrix is denoted as P_i, and the output matrix is denoted as O_i. From a sustainability perspective, the input In_i to a system, business process, or machine refers to the resources used or the information fed into it for it to function or produce a desired output. These inputs can be categorized broadly into tangible and intangible inputs.

Tangible inputs include raw materials, energy, and water that are directly used in the production or functioning of the system. For example, a car factory uses steel, plastic, and other materials to produce cars and electricity to operate the machinery. Intangible inputs, such as labour, knowledge, or data, are less physical or less direct but equally important. For instance, human expertise is necessary to design and operate the machinery, while data might be used to optimize production processes or to develop new products. Sustainability comes into play when we consider the source and impact of these inputs (Li et al., 2019). Sustainable inputs are sourced responsibly, with minimal environmental impact, and can be replenished naturally or recycled within a reasonable timeframe (Ncube et al., 2020). For example, using renewable energy like solar or wind power instead of fossil fuels is a more sustainable choice because it doesn't deplete finite resources or contribute significantly to greenhouse gas emissions. Similarly, using responsibly sourced materials or creating systems that require less material input overall can also enhance sustainability. Further, from a social perspective, sustainability also considers the fairness and ethics of labour practices. Using skilled labour in a manner that respects human rights, offers fair wages, and ensures good working conditions is considered a sustainable input from this viewpoint. Thus, from a sustainability perspective, the input to a system, business process or machine is not just about what physically goes into the process but also about how those inputs are sourced and their broader impacts on the environment and society. In a nutshell, In_i includes raw materials, energy, and water (and other environmental elements like air, soil etc.) (Mezquita et al., 2017), labour, knowledge (Fatimah et al., 2020), information or data (Mach et al., 2020). The processing stage, denoted as P_i, refers to the actions or changes a system or machine performs on the input to produce the output. Depending on the nature of the system or machine, this could include physical transformations, chemical reactions, computational operations, etc. From a sustainability perspective, this stage is critical because it's often where the most significant environmental impacts occur. We derive crucial elements related to processing from literature. These elements are as follows:

1. Energy Efficiency (Okorie, 2021, Paris et al., 2022): This refers to how much useful work a system or machine can perform per unit of energy it consumes. High energy efficiency is desirable from a sustainability perspective because less energy is wasted as heat or other non-useful forms. For example, an energy-efficient light bulb uses a higher proportion of its electricity to produce light (useful work), and less is wasted as heat.
2. Renewable Energy (Al-Othman et al., 2022, Amjith & Bavanish, 2022, Quito et al., 2023): If a process requires energy, it's more sustainable if that energy comes from renewable sources, such as solar or wind power, rather than non-renewable sources like coal or natural gas. For example, a factory that runs on electricity from solar panels is more sustainable than one that runs on coal-fired power plants.
3. Waste Production (Kamal Abdelbasset et al., 2022, Tian et al., 2022): Many processes produce waste, either as a by-product of the process itself or from the wear and tear on the system or machine. Minimizing this waste is a key aspect of sustainable processing. For example, in a manufacturing process, waste can be minimized by using efficient design, recycling scrap material, and maintaining equipment to prevent breakdowns that could lead to waste.
4. Emissions (Elahi & Khalid, 2022): These are gases or particles released into the air during processing. They can contribute to air pollution or climate change. For example, burning fossil fuels releases carbon dioxide, a greenhouse gas. Reducing or capturing emissions before they're released, is another essential aspect of sustainable processing.
5. Resource Consumption (Meglin et al., 2022):Does the process consume resources other than energy, such as water or raw materials? Using these resources efficiently, or finding ways to reduce their use or replace them with more sustainable alternatives, can also improve sustainability.

Next, we analyse the business process output, denoted as O_i, in the above discussion. The output of a business process or system is what results from the processing of inputs. In terms of sustainability, we have derived several key aspects of these outputs from the literature:

1. Waste Generated (Rani et al., 2022): A key focus of sustainable output is minimizing waste. Waste can be solid, liquid, or gaseous, and the goal is to reduce, reuse, or recycle it to limit its environmental impact. Many businesses now aim for zero waste output, which

means they strive to reuse or recycle all materials that would otherwise be discarded.
2. Resource Efficiency (Domenech & Bahn-Walkowiak, 2019): Sustainable outputs should maximize the value derived from inputs. The more product or services you can create from a given number of resources, the more sustainable the process.
3. Product Life Cycle (Corallo et al., 2022): Sustainable outputs consider the entire life cycle of a product, not just its creation. This includes its use, potential for reuse, recyclability, and eventual disposal. Ideally, a product should have a long useful life, be recyclable, or be biodegradable at the end of its life.
4. Emissions (Cheng et al., 2022, Vieira et al., 2023): Sustainable outputs should minimize harmful emissions, whether they're greenhouse gases contributing to climate change or pollutants affecting air, water, or soil quality. Some businesses offset their emissions by investing in renewable energy or reforestation projects.
5. Social Impact (Buchmayr et al., 2022): The outputs should also be evaluated based on their social impact. Does the product or service improve quality of life? Is it accessible and affordable? Does it promote equity and social justice?
6. Economic Impact (Guo et al., 2022): From a sustainability perspective, the output should be profitable and contribute to a healthy economy. This includes providing fair wages, supporting local economies, and not engaging in practices that lead to economic disparity.
7. Adaptability (Ardanza et al., 2019, d'Aquino & Bah, 2013): Sustainable output requires adaptability to changing conditions, such as market demands, resource availability, regulatory changes, and climate change effects.

Assessing the results yielded by business procedures or systems according to these benchmarks allows us to gain a more lucid comprehension of their sustainability and to pinpoint potential areas for enhancement. Building upon the literary facets discussed earlier, we construct the model depicted in Fig. 2. This illustration expands on the ideas introduced in Fig. 1. The transactions in Fig. 2 show the strategic interactions among the input processing and output components so businesses can make strategic sustainability choices, balancing initial costs against potential economic and ecological future gains. The idea is that firms choose to organize transactions where the cost is lowest, often having significant implications for sustainability. For instance, if a company decides to source sustainable raw materials, it may have to interact with several suppliers, increasing transaction costs. These costs include searching for suppliers, negotiating terms, and ensuring quality and compliance. However, long-term benefits like improved brand image, customer loyalty, and regulatory compliance can offset these additional costs.

The elements listed under In_i, P_i and O_i in Fig. 2 are examples rather than a comprehensive listing. Employing the framework presented in Fig. 2, we carry out a detailed sustainability analysis at the process level, utilising the principles of TCT. The following section discusses the proposed methodology.

3. Methodology

The proposed methodology is rooted in the TCT, which allows us to analyse the entire lifecycle of business processes (Cong & Chen, 2015). This lifecycle comprises seven phases: Plan, Analysis, Design, Model, Implement, Monitor, and Refinement. These provide a standardised approach to streamlining and refining business operations with situation awareness (Anjaria & Mishra, 2017c). To understand the lifecycle of the business process, two essential elements of the TCT are brought into play: conditional likelihood and total cost (Bigelow et al., 2019). Conditional likelihood pertains to the probability of a company opting to insource or outsource a service given certain conditions. Meanwhile, total cost considers the cost of making a transaction, including

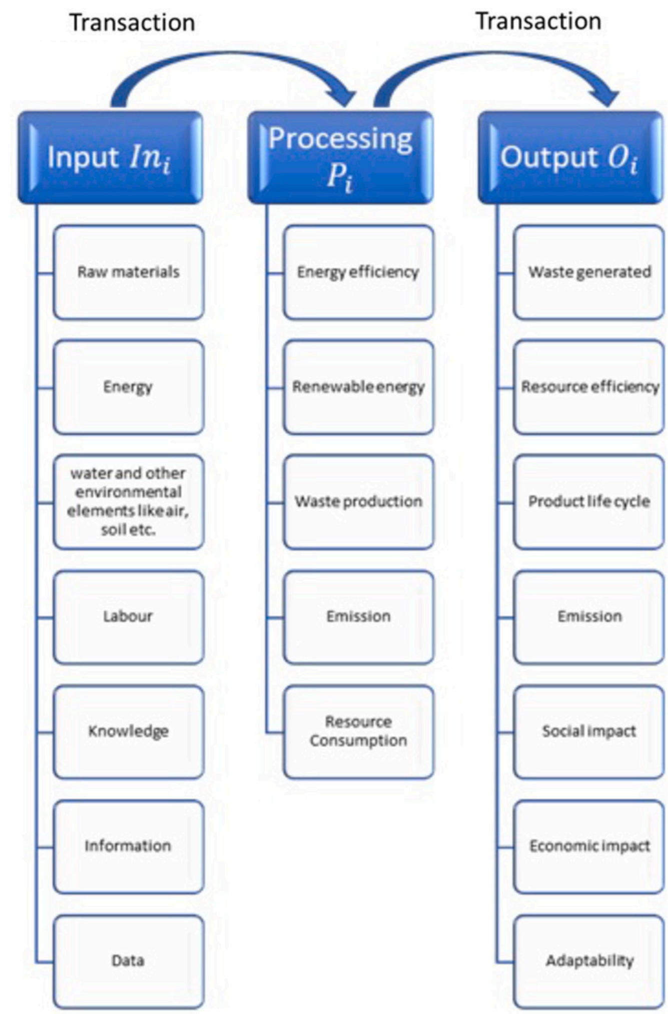

Fig. 2. Business process as an input-output system in an arbitrary functional boundary.

planning, deciding, changing plans, resolving disputes, and after-sales. Transaction costs affect a company's financial, social, and environmental performance. Improved information sharing and communication, streamlining processes, building strong relationships, and collaborating with stakeholders can help businesses reduce transaction costs while enhancing efficiency, transparency, compliance, and sustainability. By applying the TCT, companies can identify ways to improve their operations, reduce costs, and improve sustainability. This approach helps businesses achieve a more balanced triple bottom line (Pandiangan et al., 2022). To grasp the concept of the first phase, we will then move on to comprehending the lifecycle of the business process. Using TCT to understand the business process lifecycle from a sustainability perspective, we incorporate all sustainability elements depicted in Fig. 2. These elements are applied at a business process's input, processing, and output stages. This section is further divided into two subsections: the first details the methodology for integrating TCT with lifecycle analysis, and the second outlines the data requirements for executing the proposed method.

3.1. Methodology to integrate transaction cost theory and the process lifecycle analysis

This subsection explains the initial phase of the business process lifecycle, as well as how the entire lifecycle is assessed when integrating TCT.

3.1.1. Initial phase of the business process lifecycle

To comprehend the preliminary stage of the business process lifecycle, we examine a business process encompassing all components depicted in Fig. 2. This indicates that the business process incorporates seven inputs, five processing, and seven output elements, all tied to sustainability. Let's consider that the j^{th} input of the i^{th} business process results in the k^{th} processing factor. This likelihood culminates in a probability matrix denoted as $A_{jk} = P(ln_j|P_k)$. The dimensions of this matrix A_{jk} may measure 7×5. Likewise, the k^{th} processing factor of the i^{th} business process produces the l^{th} output. This likelihood culminates in another probability matrix denoted as $B_{kl} = P(P_k|O_l)$. The dimensions of B_{kl} may measure 5×7. In the same line, there would be an output matrix $C = P(ln_j|O_l)$ with dimension 7×7. These matrices showcase how TCT is applied to quantify sustainability likelihood. This quantification is crucial for improving sustainability integration within S-ERP systems. Thus, these matrices help answer RQ1, which was about integrating TCT in the business process lifecycle.

Next, we focus on the impact mechanism. In the context of TCT, the impact mechanism refers to how various elements of a transaction influence the total cost associated with that transaction. The impact mechanism in the TCT manages the interplay of asset specificity, uncertainty, and transaction frequency (Luo & Chen, 2023). Asset specificity concerns the degree to which the assets involved are specialised and unique to the transaction. Higher specificity can increase transaction costs due to difficulties in reallocating the assets if the transaction fails. Uncertainty refers to unpredictability in the business environment that can lead to increased information or monitoring costs. Transaction frequency affects the cost in terms of economies of scale; infrequent transactions might lack economies of scale, thus leading to higher per-transaction costs (Lameke et al., 2023). In the framework shown in Fig. 2, the asset specificity, uncertainty, and transaction frequency are applicable for B_i and C_i. As a result, the dimension of the impact matrix $(B_i \times C_i)$ will be 5×7. For the i^{th} business process, the impact matrix captures the influence of the k^{th} processing factor on the l^{th} output. The following matrix reflects the interplay between the five processing factors and the seven outputs:

$$I = \begin{bmatrix} i_{11} & i_{12} & i_{13} & i_{14} & i_{15} & i_{16} & i_{17} \\ i_{21} & i_{22} & i_{23} & i_{24} & i_{25} & i_{26} & i_{27} \\ .. & .. & .. & .. & .. & .. & .. \\ i_{51} & i_{52} & i_{53} & i_{54} & i_{55} & i_{56} & i_{57} \end{bmatrix} \tag{1}$$

Referring to the aforementioned impact matrix in equation (1), we initially delve into the evaluation within a singular phase before expanding it to encompass the entire life cycle. For a business process with an input-output system (like the one in Fig. 2), the process can be conceptualised as having three distinct layers. Once the output is generated, the coefficients associated with these layers become fixed. This leads us to formulate a set of equations that efficiently interconnects the layers of input, processing, and output, as demonstrated below:

$$\begin{cases} tc_{11} * in_1 + tc_{12} * in_2 + tc_{13} * in_3 + tc_{14} * in_4 + tc_{15} * in_5 + tc_{16} * in_6 \\ \quad +tc_{17} * in_7 = al_1 \\ tc_{21} * in_1 + tc_{22} * in_2 + tc_{23} * in_3 + tc_{24} * in_4 + tc_{25} * in_5 + tc_{26} * in_6 \\ \quad +tc_{27} * in_7 = al_2 \\ tc_{31} * in_1 + tc_{32} * in_2 + tc_{33} * in_3 + tc_{34} * in_4 + tc_{35} * in_5 + tc_{36} * in_6 \\ \quad +tc_{37} * in_7 = al_3 \\ tc_{41} * in_1 + tc_{42} * in_2 + tc_{43} * in_3 + tc_{44} * in_4 + tc_{45} * in_5 + tc_{46} * in_6 \\ \quad +tc_{47} * in_7 = al_4 \\ tc_{51} * in_1 + tc_{52} * in_2 + tc_{53} * in_3 + tc_{54} * in_4 + tc_{55} * in_5 + tc_{56} * in_6 \\ \quad +tc_{57} * in_7 = al_5 \\ tc_{61} * in_1 + tc_{62} * in_2 + tc_{63} * in_3 + tc_{64} * in_4 + tc_{65} * in_5 + tc_{66} * in_6 \\ \quad +tc_{67} * in_7 = al_6 \\ tc_{71} * in_1 + tc_{72} * in_2 + tc_{73} * in_3 + tc_{74} * in_4 + tc_{75} * in_5 + tc_{76} * in_6 \\ \quad +tc_{77} * in_7 = al_7 \end{cases} \tag{2}$$

In equation (2), al_i, where $1 \le i \le 7$ stands for the actual loss obtained from reality and in_i, where $1 \le i \le 7$ stands for the real likelihood of seven input elements. When TCT is applied to sustainability, the actual loss can be understood as the tangible and intangible costs resulting from unsustainable practices. Tangible costs might include penalties for non-compliance with environmental regulations, increased waste management costs, or higher resource usage. Intangible costs could involve damage to reputation, loss of customer trust, or decreased employee morale due to unsustainable practices. Therefore, actual loss signifies the totality of direct and indirect costs, both financial and reputational, associated with neglecting sustainable practices in business transactions.

Controlling actual loss in TCT is critical when applying the theory to sustainability. Actual losses, such as direct and indirect costs associated with unsustainable practices, can be substantial (Wichelns & Oster, 2006). These can include regulatory fines, increased operational costs due to inefficient resource use, and expenses associated with waste management. Moreover, indirect costs like reputation damage can negatively impact customer trust and stakeholder relationships, leading to potential revenue loss. Hence, by controlling actual losses, businesses can improve their financial performance and enhance their commitment to sustainability. This can result in long-term benefits like increased brand value, customer loyalty, and a competitive edge, further emphasising the importance of minimising actual losses in sustainable transactions (Wang et al., 2021). In equation (2), $T = (tc_{ij})_{(7\times7)}$ is transferring the coefficient matrix from input to processing. Based on the transactions, the dimensions of transferring a co-efficient matrix may vary. In the current phase, it is crucial to identify the values of al_i. The values of al_i can be computed as follows:

$$\begin{aligned} &(al_1, al_2, al_3, al_4, al_5, al_6, al_7) \\ &\quad = (in_1, in_2, in_3, in_4, in_5, in_6, in_7) \times \left[\left(A_{jk}\right)_{7\times5} \times \left(I_{kl}\right)_{5\times7} \right] \end{aligned} \tag{3}$$

In equation (3), we substitute the values $\left(A_{jk}\right)_{7\times5} \times \left(I_{kl}\right)_{5\times7} = T = \left(tc_{ij}\right)_{7\times7}$. In the present work, we consider vectors like $(in_1, in_2, in_3, in_4, in_5, in_6, in_7)$ as 1×7 matrix. Therefore, equation (3) will be:

$$\begin{aligned} &(in_1, in_2, in_3, in_4, in_5, in_6, in_7) \times \left(T_{ij}\right)_{7\times7} \\ &\quad = (al_1, al_2, al_3, al_4, al_5, al_6, al_7) \quad \dots \end{aligned} \tag{4}$$

As previously mentioned, the values for al_i can be established as fixed. Consequently, whether we obtain the values for in_i or not will hinge on the specified values within the $(T_i j)_{(7\times7)}$. The detailed analysis using the impact matrix I and equations (1) to (4) illustrate how TCT can be assessed and potentially improve sustainability in business processes managed by S-ERP systems. The impact matrix I and equations (1) to (4) answer RQ2, which is about using TCT to evaluate and improve business processes' sustainability within S-ERP systems. For $(T_i j)_{(7\times7)}$ there will be two assumptions:

Assumption-1: $(T_{ij})_{(7\times7)}$ is invertible:

If the $(T_{ij})_{(7\times7)}$ is invertible (meaning it has an inverse matrix), it allows us to solve equation (3) for the values of the vector $(in_1, in_2, in_3, in_4, in_5, in_6, in_7)$. Equation (4) is a linear matrix equation and resembles the format of $RX = S$ where R is similar to $(T_{ij})_{(7\times7)}$ and S is similar to $(al_1, al_2, al_3, al_4, al_5, al_6, al_7)$. If the $(T_{ij})_{(7\times7)}$, is reversible, one can multiply each side of the equation $RX = S$ with R^{-1}, i.e., $(T_{ij})^{-1}_{(7\times7)}$.

$$\begin{aligned} &RX = S \\ \Rightarrow\ &RX * R^{-1} = S * R^{-1} \\ &\Rightarrow X = S * R^{-1} \end{aligned}$$

Here, X corresponds to $(in_1, in_2, in_3, in_4, in_5, in_6, in_7)$ and by multiplying the inverse of $(T_{ij})_{(7\times7)}$ with $(al_1, al_2, al_3, al_4, al_5, al_6, al_7$, one can find the values for X. However, it's important to note that finding an inverse matrix is only possible for square matrices, and fortunately,

7×7 satisfies this condition. The invertibility further relies on the determinant of the matrix not being zero.

Assumption-2: $(T_{ij})_{(7\times7)}$ is not invertible:

Suppose $(T_{ij})_{(7\times7)}$ is not invertible; it means there is no inverse matrix for $(T_{ij})_{(7\times7)}$. This typically happens if the determinant of the matrix is zero or if the matrix is not full rank, meaning some rows or columns are linearly dependent on others. In such cases, solving the equation for $\left(in_1, in_2, in_3, in_4, in_5, in_6, in_7\right)$ becomes more challenging and may not have a unique solution. Depending on the specific properties of the $(T_{ij})_{(7\times7)}$ and $\left(al_1, al_2, al_3, al_4, al_5, al_6, al_7\right)$ vector, the system of equations could have:

1. No solution: This happens if the system of equations is inconsistent.
2. Infinite solutions: This typically happens if there's a dependency between rows/columns in the matrix.

Practically, one would need to use other mathematical techniques to find a solution or an approximation. Methods might include least squares for over-determined systems, using a pseudoinverse, or regularisation methods in the context of machine learning. The choice of method depends heavily on the specific context and properties of the matrix and vectors involved. For practical purposes, to improve the precision and efficiency of the evaluation, it would be prudent to refine the impact estimation process to guarantee that the $(T_{ij})_{(7\times7)}$ is invertible. Once $\left(in_1, in_2, in_3, in_4, in_5, in_6, in_7\right)$, is obtained, the real likelihood of the process is:

$$\left(pl_1, pl_2, pl_3, pl_4, pl_5\right) = \left(p_1, p_2, p_3, p_4, p_5\right) \times \left(B_{jk}\right)_{5\times7} \tag{5}$$

From equation (5), the real likelihood of m^{th} process is:

$$p_m = \sum_{n=1}^{7} p_{1n} \times b_{nm} \tag{6}$$

In equation (6), $b_{nm} \in (B)_{5\times7}$ and pl is the loss vector during processing. Similarly, the real likelihood of output is:

$$O_m = \sum_{n=1}^{5} \sum_{m=1}^{7} in_{1m} \times a_{mn} \times b_{nm} \tag{7}$$

In equation (7), $a_{mn} \in (A)_{7\times5}$ and $b_{nm} \in (B)_{5\times7}$. Once the real likelihood is calculated, the actual loss at the input and processing stages will be calculated. The actual loss at the input stage would be:

$$\begin{aligned}&\left(in_1, in_2, in_3, in_4, in_5, in_6, in_7\right)^{\text{loss}} \\ &\quad = \left(in_1, in_2, in_3, in_4, in_5, in_6, in_7\right) \times (\text{ Identity })_{7\times7} \times \left[(A)_{7\times5} \times I\right]\end{aligned} \tag{8}$$

In equation (8), $(\text{ Identity })_{7\times7}$ is an identity matrix having the dimension of 7×7, and I is the impact matrix shown in equation (1). Multiplying a vector by an identity matrix preserves its original values in linear algebra. An identity matrix is a square matrix with ones on the main diagonal and zeros elsewhere. The main diagonal runs from the matrix's top left to the bottom right. When one multiplies a vector by the identity matrix, each vector element is multiplied by the corresponding element on the main diagonal of the identity matrix. Since the main diagonal of the identity matrix consists of ones, the vector remains unchanged after the multiplication. Next, the actual loss during the processing is:

$$\left(p_1, p_2, p_3, p_4, p_5\right)^{loss} = \left(p_1, p_2, p_3, p_4, p_5\right) \times (\text{ Identity })_{5\times5} \times \left[(I)_{5\times7} \times A_{7\times5}\right] \tag{9}$$

3.1.2. *Assessment during all the phases of the business process lifecycle*

Building upon the previous equations (numbered one through nine), each interrelated operation depends on the specific structure of the given matrix. It's important to emphasise that these equations are not universally applicable but tailored to specific contexts. However, for illustrative purposes, we can represent the dynamic states of the 'n' phases of the lifecycle within a matrix. In this context, we'll assign the dynamic dimension to one of the matrix dimensions. Let's assume the likelihood solution for input constructs an $n \times 7$ matrix, denoted as In. The corresponding actual loss matrix Lm will also have the dimension $n \times 7$. Furthermore, the dimensions of the likelihood solution for the process matrix P will be $n \times 5$, and for the output matrix, it will be $n \times 7$. The equation representing these matrices is:

$$\text{In } \times T = Lm^T \tag{10}$$

Similarly, $P = In \times A$, where $p_{ij} = \sum_{m=1}^{7}\left(in_{im} \times a_{mj}\right)$. Likewise, the real likelihood of the output can be represented as $O = P \times B$ with $o_{ij} = \sum_{m=1}^{5}\sum_{k=1}^{7} in_{ik} \times a_{km} \times b_{mj}$. Further, the actual loss during i^{th} phase of the lifecycle for input will be:

$$\begin{aligned}&\left(in_{i1}, in_{i2}, in_{i3}, in_{i4}, in_{i5}, in_{i6}, in_{i7}\right)^{loss} \\ &\quad = \left(in_{i1}, in_{i2}, in_{i3}, in_{i4}, in_{i5}, in_{i6}, in_{i7}\right) \times (\text{ Identity })_{7\times7} \times \left[(A)_{7\times k} \times I_{k\times7}\right]\end{aligned} \tag{11}$$

The actual loss during i^{th} phase of the lifecycle processing stage will be:

$$\begin{aligned}&\left(p_{i1}, p_{i2}, p_{i3}, p_{i4}, p_{i5}\right)^{\text{loss}} \\ &\quad = \left(p_{i1}, p_{i2}, p_{i3}, p_{i4}, p_{i5}\right) \times (\text{ Identity })_{5\times5} \times \left[(I)_{5\times i} \times A_{i\times5}\right]\end{aligned} \tag{12}$$

A key point to note: While we're currently using dimensions of seven, five, and seven for inputs, processing elements, and outputs, respectively, the algorithm is remarkably flexible. It can handle any number of inputs, processing elements, and outputs as long as there's a way to connect them. This means that even if the number of inputs doesn't match the number of outputs, there's still a valuable approach. We can create a system of equations to explore the quantitative relationship between inputs and outputs. In cases where standard matrix multiplication isn't possible due to dimension mismatches, advanced techniques like tensor products (Kumar et al., 1995) or Kronecker products (Loan, 2000) can be useful. These methods, applicable in more general scenarios, can multiply matrices of any dimension. However, it's important to remember that the results might differ from those obtained using conventional matrix multiplication. We summarise the methodology and all the equations above into a formal algorithm:

Algorithm: Transaction cost theory to integrate sustainability with S-ERP and study the lifecycle of business process

Input: Input vector/matrix and transaction matrices A, B and C

1. Calculate the impact matrix by multiplying matrices B and C as described in equation (1).
2. Calculate process likelihood for i^{th} phase of the lifecycle with the following as shown in equation (6):

$$p_{im} = \sum_{n=1}^{\text{Total input factors}} in_n \times a_{(nm)_i}$$

3. Calculate output likelihood for the i^{th} phase of the lifecycle with

$$O_{im} = \sum_{n=1}^{\text{Total transaction factors}} \sum_{m=1}^{\text{Total input factors}} in_{im} \times a_{(mn)_i} \times b_{(nm)_i}$$

4. Calculate the total loss during the input stage of the i^{th} phase of the lifecycle with

$$\begin{aligned}&(in_{i1}, in_{i2}, in_{i3}, in_{i4}, in_{i5}, in_{i6}, in_{i7})^{\text{loss}} \\ &\quad = (in_{i1}, in_{i2}, in_{i3}, in_{i4}, in_{i5}, in_{i6}, in_{i7}) \times \text{Identity}_{7\times7} \times [A_{7\times k} \times I_{k\times7}]\end{aligned}$$

The number of input elements can vary from business process to business process.

5. Obtain processing vector from input vector by multiplying input vector with transferring co-efficient matrix (T_{ij}).
6. Obtain output vector from processing vector by multiplying processing vector with transferring co-efficient matrix (T_{ij}).
7. Calculate the total loss during the processing stage of the i^{th} phase of the lifecycle with

$$(p_{i1}, p_{i2}, p_{i3}, p_{i4}, p_{i5})^{\text{loss}} = (p_{i1}, p_{i2}, p_{i3}, p_{i4}, p_{i5}) \times \text{Identity}_{5\times5} \times [I_{5\times i} \times A_{i\times5}]$$

The number of input elements can vary from business process to business process.
8. Calculate the total loss during the output stage of the i^{th} phase of the lifecycle with

$$(o_{i1}, o_{i2}, o_{i3}, o_{i4}, o_{i5}, o_{i6}, o_{i7})^{\text{loss}} = (o_{i1}, o_{i2}, o_{i3}, o_{i4}, o_{i5}, o_{i6}, o_{i7}) \times \text{Identity}_{7\times7} \times [A_{7\times k} \times I_{k\times7}]$$

The number of input elements can vary from business process to business process.

Output: Likelihood of all the lifecycle phases related to the processing and output stage and total loss of all the phases of the lifecycle during input, processing and output stages.

The algorithm discussed above directly addresses RQ3, which concerns a sustainability matrix based on TCT. This matrix addresses the current limitations of S-ERP systems regarding holistic sustainability integration. We've implemented the aforementioned algorithm in Python to demonstrate its functionality. The code is provided in the supplementary materials for those interested in delving deeper. The algorithm takes an input vector or matrix and a transaction matrix as essential inputs. This aligns with TCT's emphasis on explicit costs associated with economic exchanges or transactions. This approach provides detailed information about inputs and the complexities of each transaction. However, TCT theory doesn't inherently offer predictions about potential losses and their likelihood. These are often influenced by unpredictable factors like market volatility, regulatory changes, or unforeseen events. Due to their indirect relationship with the transactional process, these elements are challenging to predict accurately. The strength of the proposed algorithm lies in its ability to generate these factors as output.

Typically, with S-ERP, sustainability assessment methods are executed in a 'clockwise' direction. At the beginning of each lifecycle phase, the organisation performs a risk assessment and formulates predictions based on prior experience and feedback. However, this approach inevitably introduces subjective bias, affecting sustainability assessments of past, present, and future scenarios. Contrary to this conventional methodology, the algorithm proposed in this research functions in a 'reverse' direction. In essence, the organisation evaluates sustainability factors at each phase's conclusion based on actual collected loss data, thereby enhancing the accuracy and reliability of the assessment. Traditional S-ERP or ERP systems typically assess sustainability using a cause-and-effect framework. However, the proposed algorithm links cause and effect through process elements, allowing forward (from cause to effect) and backward (from effect to cause) movements. This sophisticated approach quantifies the probability and aggregate loss associated with each phase of the business process—specifically the input, processing, and output stages.

3.2. Data requirements to execute the proposed method

To effectively execute the proposed method, a comprehensive data set is essential. This includes detailed input data encompassing various sustainability metrics, such as energy consumption, waste generation, resource usage, and emission levels. These metrics are crucial for assessing the environmental impact at different stages of the business process. Additionally, processing data, which includes information on operational procedures, asset specificity, and transaction frequencies, are required to evaluate the efficiency and sustainability of business operations. Output data, such as product quality, customer satisfaction, and environmental impact assessments, are also critical for understanding the end results of business processes. Furthermore, financial data, including cost information related to planning, implementation, dispute resolution, and after-sales services, are necessary to accurately calculate the total cost and transaction costs. Data on market trends, regulatory changes, and stakeholder expectations are also valuable for predicting potential losses and assessing overall sustainability. All these data must be accurate, up-to-date, and collected consistently across the entire lifecycle of business processes to enable a thorough analysis and application of the TCT. The integration of this diverse set of data within the S-ERP system is pivotal for achieving a holistic and robust sustainability integration, facilitating informed decision-making and policy formulation for sustainable business practices.

This integrated data within the S-ERP system serves as a powerful platform for advanced analytics and machine learning algorithms. By analysing correlations between input, processing, output, and financial data, businesses can glean valuable sustainability-related insights. Predicting the economic and environmental impacts of various strategic decisions becomes possible. This, in turn, can guide the development of targeted sustainability initiatives and optimise resource allocation for maximum impact.

The algorithm presented in the previous subsection has been successfully implemented in two significant case studies, which will be presented in the upcoming section. In Case Study 1, which focuses on Sustainable Product Design (SPD), the holistic approach encompasses various dimensions of sustainability throughout the product's lifecycle. The study meticulously integrates eco-friendly materials and energy-efficient manufacturing processes. It employs detailed input data, including methods of material extraction, environmental impact considerations in design, and knowledge of recyclability. These data points are essential in providing a comprehensive view of sustainability metrics, ensuring that the product's entire lifecycle is considered from a sustainability perspective. The process also delves into the operational side, considering factors like functionality, energy use, and costs associated with assembly and disassembly. This processing data is crucial for evaluating the efficiency and sustainability of the business operations. It enables a thorough analysis of operational procedures and their environmental impacts, a key aspect of transaction cost analysis in sustainable practices.

The case study also incorporates vital output data, such as emissions and the safety of humans and workers. These elements are crucial for assessing the environmental and social impacts at the end of the business process, providing a comprehensive picture of the outcomes associated with SPD practices. While the case study doesn't explicitly detail financial and market data, the SPD methodology inherently considers the economic viability and marketability of its practices. This suggests an underlying emphasis on these aspects, as they are integral for calculating total and transaction costs within sustainable practices. In essence, it highlights the importance of considering the practical applicability and economic feasibility of these sustainable approaches.

Case Study 2 investigates the sustainability of modular vs. conventional construction methods through a comparative analysis of various input factors. These factors include energy performance, material consumption, and site selection, all essential for a comprehensive environmental impact assessment throughout the construction process. The case study's approach to data collection ensures the availability of detailed input data, which is necessary for in-depth analysis. The study further examines processing elements such as using local and renewable materials and alternate transportation methods. This processing data is crucial for evaluating resource consumption and the efficiency of the construction methods being compared. By focusing on these aspects, the study fulfils the requirement for processing data that is vital for analysing the sustainability of these construction methods. Finally, the study incorporates important output data such as waste management, greenhouse gas emissions, and embodied energy consumption. This output data is integral to understanding the overall environmental impact of the construction methods, aligning with the need for comprehensive output data encompassing all critical environmental aspects.

Significantly, even though not explicitly detailed, the study implicitly considers financial aspects and cost preferences when comparing modular and conventional construction methods. This inclusion is crucial for a complete transaction cost analysis and adds depth to our understanding of these methods' cost-effectiveness and viability. Across both case studies, integrating such diverse data sets within the TCT and lifecycle analysis framework signifies a comprehensive approach to sustainability integration. This aligns with the data requirements for executing the proposed method and ensures the research is grounded in practical, real-world applications. This, in turn, enhances the studies' relevance and applicability across various industries, demonstrating a systematic approach to understanding and improving sustainability practices.

Data verification was a paramount concern in our case study selection. To ensure the credibility and accuracy of the data used, we meticulously selected information from reputable and widely recognised sources in the field for all external papers and databases. Additionally, the use of peer-reviewed data bolsters the credibility of our case study evaluations. The following section delves into these case studies, detailing the application of the proposed method and the resulting findings. These case studies directly address RQ4, which explores the practical implications of TCT within S-ERP systems.

4. Case studies

In the present section, we discuss two major case studies. Case studies about business processes and TCT hold significant importance as they provide real-world evidence of operational efficiencies or inefficiencies. The Global Reporting Initiative (GRI) (Initiative, 2012) advocates that scholarly investigations into sustainability ought to meticulously address distinct elements, encompassing organisational structure, operative activities, and quantifiable sustainability indicators. Such studies can either be integrated into a broader analytical framework or presented as distinct, standalone inquiries. The British Standards Institution (BSI) (Project, 2003) further emphasises the pivotal role of case studies in guiding business transformations towards sustainability. These case studies, serving as both instructional and directional tools, are instrumental in steering organisations toward sustainable practices and outcomes. To be effective, they should embody characteristics of flexibility, practical applicability, reliability, and comprehensive coverage, making them suitable for a broad spectrum of industrial applications. The development of these guidelines necessitates a thorough and strategic consideration of numerous critical steps ensuring the successful implementation of sustainable systems. In alignment with the guidelines set forth by GRI and BSI, our research methodologically selects two case studies that exemplify these principles. These cases have been chosen for their flexible, practical, reliable, and comprehensive nature, ensuring their relevance and applicability across a diverse range of industries. This selection is underpinned by a commitment to providing insightful, applicable, and broadly relevant sustainability solutions within the business context. There are limited case studies that follow GRI guidelines, (Brown et al., 2009, Chotruangprasert, 2013) and BSI guidelines (Holton et al., 2010, Chofreh & Goni, 2017).

Along with GRI and BSI standards, the chosen case studies allow for a detailed investigation of how the nature of transactions and related business practices influence costs. Furthermore, these case studies facilitate a comprehensive understanding of how strategic changes can minimise costs and optimise business performance. They also offer valuable insights that help to shape future decisions and strategies. In essence, they contribute significantly to theory validation and practical applications in business management. The first case study is about Sustainable Product Design (SPD).

4.1. Case study-1: Sustainable Product Design (SPD)

This case study focuses on the analysis, processing, and outcomes considered from the standpoint of Sustainable Product Design (SPD). SPD incorporates sustainability throughout the product's lifecycle - from product development to design configuration and evaluation phases. SPD aims to mitigate environmental impact by harnessing eco-friendly materials and energy-saving manufacturing processes by emphasising environmental stewardship, economic viability, and social equity. Concurrently, it ensures the economic practicability and marketability of the product's production. Moreover, social considerations are not overlooked; SPD encourages equitable labour practices and promotes community well-being. The overarching objective is to fulfil current demands without jeopardising the resource needs of future generations. There have been many approaches in the literature about SPD, such as identifying a product's environmental impact (Bajwa et al., 2019), using complementary sustainability strategies (He et al., 2020), collaborating with a broader innovation ecosystem (Abhari et al., 2022), and designing for an improved product lifecycle and ecodesign strategies (Kalita et al., 2021). However, these approaches have limitations like evaluating relevant sustainability aspects (Stark et al., 2017), risk of trying too many new approaches (Stark et al., 2017), difficulties of eco-design (Vilochani et al., 2023), and consumer preferences (Diaz et al., 2021). To avoid these issues and use the most advanced case study in the field of SPD, we use a case study presented by Hassan et al. (2016) associated with SPD.

Input-output-based business processes can be highly valuable for sustainable product development. These processes ensure a clear understanding of the resources consumed and waste generated, facilitating eco-efficiency. It allows for systematic tracking of materials, aiding in minimising waste and maximising resource utilisation. They aid in the design stage, helping to identify materials that can be replaced with sustainable alternatives. The transparency they offer can drive sustainability throughout the supply chain. By applying these models, businesses can make informed decisions promoting circular economy principles and significantly reduce their environmental footprint. In past explorations, notably, those conducted by Hassan et al. (2016), there was a palpable absence of a classification system for SPD elements in the spheres of input, output, and processing. In the scholarly endeavour, we now find ourselves, the method we propose will be dutifully applied, allowing us to categorize the SPD elements and their corresponding data into sections, namely input, processing, and output elements.

In the business process of SPD, we take into account materials and the methods used for their extraction, along with design specifics related to the environment and expertise in recyclability. These contributing factors may be classified into several categories, such as environmental aspects, raw materials and understanding thereof, along with information and data that align with the categories depicted in Fig. 2. Material and its extraction are key to assessing environmental impact and resource efficiency in sustainable product development. Environmental design information allows designers to make informed choices that enhance the product's lifecycle sustainability. Knowledge of recyclability aids in end-of-life planning, ensuring materials can be effectively reclaimed and reused, promoting circular economy principles. These inputs help create functional, economically viable, and environmentally friendly products, thus improving overall business sustainability.

During the processing or execution of the business process related to SPD, we consider functionality, energy, assembly, and disassembly costs. These factors may be categorized into several groups, such as energy, resource usage, and energy efficiency, which are among the five categories depicted in Fig. 2. Functionality is crucial in SPD as it ensures that products meet user requirements while promoting sustainability.

Table 1
Input, processing and output factors related to SPD.

Input Factors			
Sustainability criteria weight	Weight factor rating	Factor Rating	
Material and material extraction	0.136	0.007	0.275
Design information for the environment	0.125	0.007	0.253
Knowledge on recyclability	0.2	0.01	0.405
Processing Factors			
Sustainability criteria weight	Weight factor rating	Factor Rating	
Functionality	0.263	0.014	0.532
Energy cost	0.12	0.006	0.243
Assembly and dis-assembly cost	0.077	0.004	0.156
Output Factors			
Sustainability criteria weight	Weight factor rating	Factor Rating	
Emission	0.028	0.001	0.057
Human safety	0.147	0.008	0.298
Worker safety	0.045	0.002	0.091

Considering energy cost is integral to understanding the product's environmental footprint, enabling optimisation for efficiency. Assembly and disassembly costs inform the design for ease of production and end-of-life management, promoting resource circularity. Such considerations are essential for a business process aimed at SPD because they balance operational viability with sustainability, fostering environmentally friendly and commercially successful products.

As output elements of the business process related to SPD, we consider three elements, i.e., emission, human safety, and worker safety. These factors can be classified under categories like waste production and social impact, which are two of the seven categories illustrated in Fig. 2. Emissions are critical to consider because they reflect the environmental impact of a product, which SPD aims to minimize. Human safety, including consumer and public health, should be output because sustainable products should not harm the people they serve. Worker safety is another essential output; SPD should ensure safe manufacturing conditions and avoid exploitation. These outputs embody the holistic approach of SPD, which prioritizes not just environmental sustainability but also social equity and well-being. Therefore, businesses dedicated to SPD should ensure their processes result in safe, low-emission products and safe working conditions. The study by Hassan et al. (2016) employed twenty-six parameters. Yet, to minimize complexity and foster improved comprehension, our approach opts to utilize merely nine. The parameters, along with their corresponding data gleaned from Hassan et al.'s work, are succinctly summarized in Table 1.

We use possibility-probability transformation (Dubois et al., 2004) to deal with the sustainability weight, weight factor, factor rating and Likert scale data provided by Hassan et al. (2016). Thus, using Table 1, we derive matrices as follows:

$$A = \begin{bmatrix} 0.494545455 & 0.025454545 & 0.4800 \\ 0.494071146 & 0.027667984 & 0.47826087 \\ 0.49382716 & 0.024691358 & 0.481481481 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.494360902 & 0.026315789 & 0.479323308 \\ 0.49382716 & 0.024691358 & 0.481481481 \\ 0.493589744 & 0.025641026 & 0.480769231 \end{bmatrix}$$

$$C = \begin{bmatrix} 0.49122807 & 0.01754386 & 0.49122807 \\ 0.493288591 & 0.026845638 & 0.479865772 \\ 0.494505495 & 0.021978022 & 0.483516484 \end{bmatrix}$$

Building upon the aforementioned matrix, as detailed in the first step of the algorithm, we compute the impact matrix, denoted as I, as presented in Equation (1).

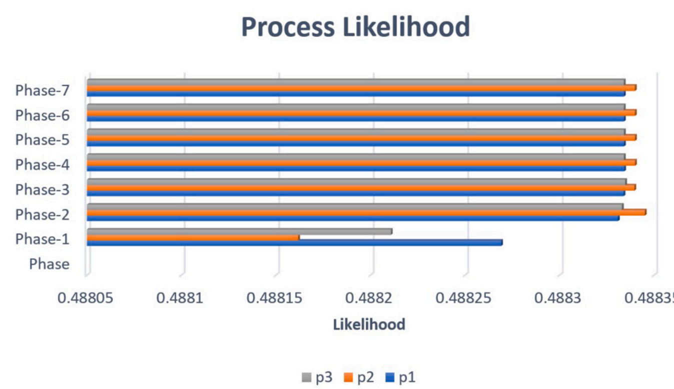

Fig. 3. Process likelihoods.

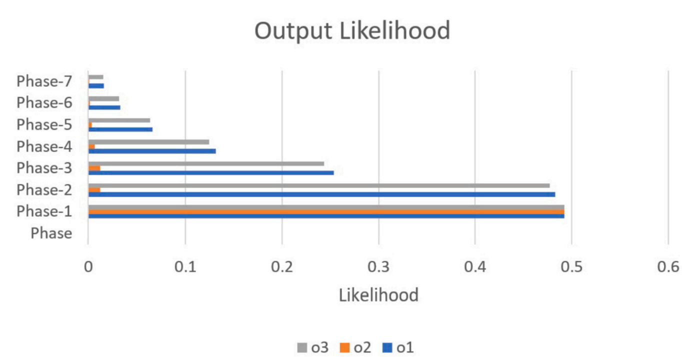

Fig. 4. Process likelihoods.

$$I = \begin{bmatrix} 0.484938529 & 0.01837751 & 0.485786378 \\ 0.48495333 & 0.017464428 & 0.485768544 \\ 0.484978512 & 0.01810722 & 0.485680399 \end{bmatrix}$$

With these matrices, the available input vector is as follows:

$$\mathbf{in}_n(\mathbf{in}_1, \mathbf{in}_2, \mathbf{in}_3) = (0.4941, 0.02593, 0.4799).$$

Based on step-3 of the algorithm and equations (6) and (7), we get the likelihood for the next seven phases. The likelihood for the next seven phases is shown in Table 2.

Figs. 3 and 4 illustrate the nearly consistent probability of maintaining sustainability throughout the process stage, while the likelihood of breaching sustainability norms diminishes in the output phase. This decrease stems from the growing social and competitive pressures that businesses confront in order to satisfy the market's

Table 2
Processing and output likelihood for seven phases based on the transaction cost theory.

Phase	p_1	p_2	p_3	o_1	o_2	o_3
Phase-1	0.488269113	0.488161759	0.488210799	0.49219645907	0.492139546138	0.492207850034
Phase-2	0.48833089	0.488345136	0.488333019	0.48272520260	0.012390724342	0.476939673888
Phase-3	0.488333894	0.488339616	0.488334739	0.25337533560	0.012202294304	0.243638021194
Phase-4	0.488334218	0.48833994	0.488334063	0.13165650999	0.006442674295	0.124682688394
Phase-5	0.48833412	0.488339942	0.488334066	0.06678765063	0.003294583848	0.063713073493
Phase-6	0.488334081	0.488339903	0.488334025	0.03280146206	0.001596076142	0.0316732375561
Phase-7	0.488334047	0.48833987	0.488334003	0.01606090687	0.000778848265	0.015493499872

Table 3
Loss during seven phases of the SPD lifecycle.

Phases	in_1^{loss}	in_2^{loss}	in_3^{loss}	p_1^{loss}	p_2^{loss}	p_3^{loss}	o_1^{loss}	o_2^{loss}	o_3^{loss}
Ph-1	0.47941156	0.012826301	0.47887369	0.48148570	0.01216612	0.48119529	0.484430730	0.01258618	0.48393327
Ph-2	0.47920240	0.012209247	0.47899308	0.47884264	0.01171737	0.47855488	0.481506742	0.01184840	0.48089488
Ph-3	0.47905108	0.012156501	0.47883508	0.47721252	0.01167485	0.47692625	0.478925889	0.01134057	0.47849387
Ph-4	0.47888415	0.012082732	0.47870360	0.47478173	0.01156393	0.47449411	0.476381120	0.01111746	0.47594122
Ph-5	0.47854351	0.011951849	0.47825281	0.47210010	0.01129436	0.47178242	0.473832011	0.01086026	0.47333235
Ph-6	0.47820678	0.011753742	0.47787670	0.46918397	0.01110276	0.46877523	0.471296105	0.01045397	0.47081045
Ph-7	0.47754877	0.011558378	0.47722941	0.46676930	0.01094617	0.46636548	0.468275989	0.01028864	0.46780419

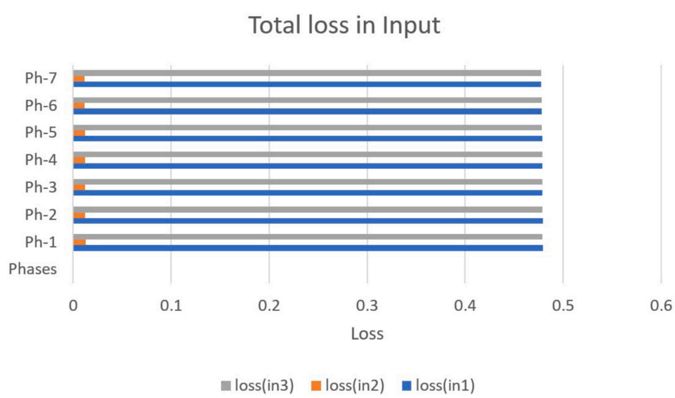

Fig. 5. Loss during the input stage for the seven phases of the SPD lifecycle.

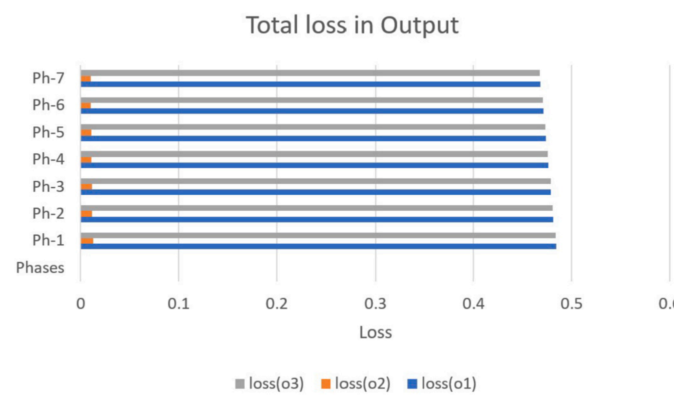

Fig. 7. Loss during the output stage for the seven phases of the SPD lifecycle.

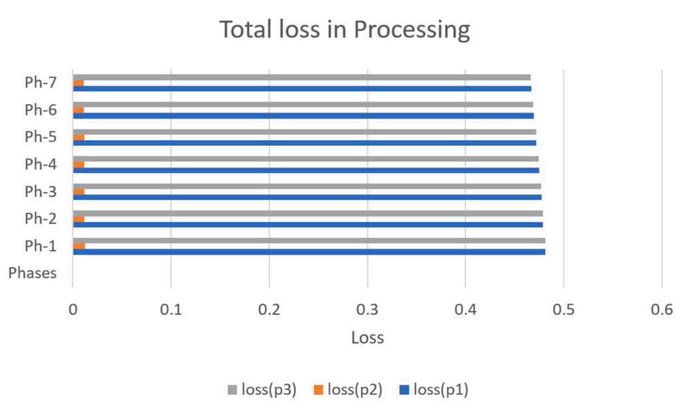

Fig. 6. Loss during the processing stage for the seven phases of the SPD lifecycle.

demand for sustainable products. Consequently, they are intensifying their scrutiny of the environmental footprint left by their products and processes. Next, we aim to calculate actual loss during the input, processing and output phases. First, with the help of equation (4), we obtained vectors $(0.493925935, 0.025549391, 0.480524674)$ and $(0.493007385, 0.022122506, 0.484870109)$ corresponding to processing and output, respectively. Based on the definition of the loss function, steps 7 and 8 of the algorithm and equations (11) and (12), we describe the loss function in Table 3.

Fig. 5 and Table 1 illustrate that losses at the input stage remain relatively constant across all phases. Furthermore, the input stage registers the highest losses due to materials and their extraction. As depicted by Fig. 6 and Table 1, these losses progressively decrease with each phase in the SPD lifecycle. During the processing stage, losses predominantly stem from the product's functionality, often requiring substantial investment. The reason for this is twofold: not only must sustainable products perform their intended functions effectively, but they must also do so in a manner that mitigates environmental impact. Such a requirement may involve using recyclable or biodegradable materials, extending the product's lifespan to curtail waste, or designing the product for enhanced energy efficiency. Accomplishing these objectives requires considerable research and development efforts, which can lead to substantial costs.

Conversely, energy costs tend to be lower than in traditional product development when the SPD process is executed efficiently. The emphasis here lies in employing energy-efficient techniques and tools, a common theme in sustainable product development. Finally, as indicated by Fig. 7 and Table 1, losses gradually decrease with each phase of the SPD lifecycle during the output stage. Here, losses are primarily due to emissions, which are the highest, while human safety-related losses are minimal. This aligns with the SPD's overarching goal of reducing emissions and maximizing human safety. The ultimate objective is to produce products that fulfil organisations' needs without jeopardising future generations' capacity to meet their own needs. Next, we discuss case study 2.

4.2. Case study 2: Sustainability evaluation of modular versus conventional construction methods

The present case study concerns the sustainability evaluation of modular versus conventional construction methods (Kamali & Hewage, 2017). Modular construction, often seen as more sustainable, leverages a factory-controlled environment that results in efficient material use and minimal waste. Leftover materials can be easily reused, reducing resource consumption. Conversely, conventional construction often generates more waste as materials are transported to and tailored on-site. Additionally, modular construction tends to lower energy consumption due to precision and controlled assembly, which reduce errors and rework. Conventional methods may consume more energy due to extended on-site work and potential rework. Both methods can result in durable structures, with the lifespan depending largely on the quality of construction, but the flexibility of modular structures can also extend their useful life. However, modular construction can increase transportation emissions due to the need to ship modules to the site. Ultimately, the sustainability of either method will depend on careful planning and execution. There have been many approaches in the literature about the sustainability evaluation of modular versus conventional construction methods, such as performance evaluation criteria (Jiang et al., (20), performance benchmarking (Kamali et al., 2023), and comparative analysis (Balasbaneh et al., 2021). However, these approaches have limitations like unavailability of complexity and diversity criteria (Liu & Qian, 2019), bureaucratic evaluation process, high cost of usage prevention, program delays (Adabre et al., 2022), skill gaps, reduced design flexibility (Liu & Qian, 2019), and lack of quantification differences (Razkenari et al., 2020). To avoid these issues and use the most advanced case study in the field, we used a case study by Kamali and Hewage (2017).

The input-output-based business process is pivotal in evaluating the sustainability of modular versus conventional construction methods as it provides a comprehensive and detailed perspective of the resources involved. It offers visibility into the quantity and type of inputs, such as raw materials and energy, and the outputs, including finished products, waste, and emissions. By quantifying these elements, businesses can identify inefficiencies, waste, and environmental impact. For modular construction, it might highlight benefits like material use efficiency and lower energy consumption in a controlled factory setting. Conventional construction can reveal areas of resource or energy waste that occur during on-site construction. This process also encourages an industry shift towards circular economy principles by enabling businesses to optimize resource use, reduce waste, and limit environmental impact, leading to more sustainable construction practices.

In the previous work done by Kamali and Hewage (2017), the exploration of the input-output system was missing for the development of performance criteria for sustainability evaluation of modular versus conventional construction methods. We divide the factors into input, processing and output-related factors to apply the proposed method. We have considered energy performance and efficiency strategy, material consumption and site selection as input factors. The elements can be classified into three primary categories - energy, raw materials, and knowledge. These categories are derived from the seven factors illustrated in Fig. 2. Energy performance and efficiency strategy, material consumption, and site selection are critical input factors in the sustainability evaluation of construction methods because they directly influence the environmental footprint. Energy performance and efficiency pertain to the energy required for construction and the energy efficiency of the final structure, which directly impacts greenhouse gas emissions. Material consumption impacts resource use and waste production. Sustainable practices aim to reduce material usage and increase recycling or reuse. Site selection is pivotal because it involves considerations about land use, local ecosystems, and transportation needs for workers and materials. In the case of modular construction, site selection also includes the factory location and the environmental implications of transporting the modules to the construction site. These factors are crucial to the evaluation as they provide a comprehensive understanding of the environmental impact of both construction methods.

We have considered local materials, renewable materials and alternate transportation as processing elements. These components can be sorted into three key categories - resource consumption, renewable energy, and energy efficiency. These groupings are part of the five categories depicted in Fig. 2. Local and renewable materials, along with alternative transportation, are processing elements significant to the sustainability evaluation of construction methods because they can drastically reduce a project's environmental impact. Using local materials minimizes the emissions and energy usage associated with long-distance transportation. Renewable materials, being replenishable over short periods, offer a sustainable option that reduces strain on non-renewable resources. Alternate transportation methods, especially those using cleaner fuels or more efficient logistics, can reduce the carbon footprint associated with moving materials or finished modules. Considering these processing factors in the evaluation allows for a complete understanding of the environmental implications associated with both modular and conventional construction methods.

We have considered waste management, greenhouse gas emissions, and embodied energy consumption as output elements. The components can be classified into three distinct categories - emission, waste generation, and adaptability. These categories originate from the seven groupings presented in Fig. 2. Waste management, greenhouse gas emissions, and embodied energy consumption are considered output factors in sustainability evaluations of construction methods because they represent the environmental impacts of a project after the construction process. Waste management pertains to handling waste materials, with sustainable practices focusing on reducing, reusing, or recycling waste. Greenhouse gas emissions reflect the project's carbon footprint, directly linking to climate change impacts. Embodied energy consumption relates to the total energy required to produce a building, from extraction and processing of raw materials to transportation and assembly. Assessing these output factors gives a comprehensive view of the ecological footprint of both modular and conventional construction methods, informing more sustainable decision-making. The study by Kamali and Hewage (2017) employed twelve parameters. Yet, to minimize complexity and foster improved comprehension, our approach utilises merely nine. The parameters and their corresponding data gleaned from Kamali and Hewage 's work are succinctly summarized in Table 4.

We use possibility-probability transformation (Dubois et al., 2004) to deal with the categorical weight, weight factor, factor rating and Likert scale data (Anjaria, 2022) provided by Kamali and Hewage (2017). Thus, using Table 4, we derive matrices as follows:

$$A = \begin{bmatrix} 0.344827586 & 0.517241379 & 0.137931034 \\ 0.32 & 0.52 & 0.16 \\ 0.285714286 & 0.428571429 & 0.285714286 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.375 & 0.25 & 0.375 \\ 0.272727273 & 0.590909091 & 0.136363636 \\ 0.166666667 & 0.666666667 & 0.166666667 \end{bmatrix}$$

$$C = \begin{bmatrix} 0.363636364 & 0.515151515 & 0.121212121 \\ 0.291666667 & 0.541666667 & 0.166666667 \\ 0.307692308 & 0.461538462 & 0.230769231 \end{bmatrix}$$

Building upon the matrices above, as detailed in the first step of the algorithm, we compute the impact matrix, denoted as I, as presented in Equation (1).

$$I = \begin{bmatrix} 0.27344354 & 0.33344086 & 0.152048 \\ 0.28623140 & 0.43841752 & 0.148350 \\ 0.21370967 & 0.35774193 & 0.136021 \end{bmatrix}$$

Table 4
Input, processing and output factors related to sustainability evaluation of modular versus conventional construction methods.

Factors	Categorical weight	Sustainability Performance Indicator	Environmental Importance
Input Factors			
Energy performance and efficiency strategy	10	29	4
Material consumption	8	25	4
Site selection	2	7	2
Processing Factors			
Local materials	3	8	3
Renewable materials	6	22	3
Alternate transportation	1	6	1
Output Factors			
Waste management	12	33	4
Greenhouse gas emissions	7	24	4
Embodied energy consumption	4	13	3

Table 5
Processing and output likelihood for seven phases based on the transaction cost theory.

Phase	p_1	p_2	p_3	o_1	o_2	o_3
Phase-1	0.320652043	0.5000201	0.1771906	0.3227373	0.4022880	0.2503216
Phase-2	0.321129341	0.4899252	0.1257914	0.3098242	0.3906156	0.2389468
Phase-3	0.110696369	0.2589710	0.0932604	0.2946153	0.3765850	0.2288662
Phase-4	0.078178714	0.1682412	0.0607728	0.3013440	0.3840057	0.2409875
Phase-5	0.081400932	0.1325596	0.0601947	0.3210394	0.4095324	0.2625020
Phase-6	0.064025668	0.1027467	0.0483920	0.3490645	0.4423774	0.2815033
Phase-7	0.066699896	0.1049910	0.0439463	0.3726913	0.4710889	0.2959042

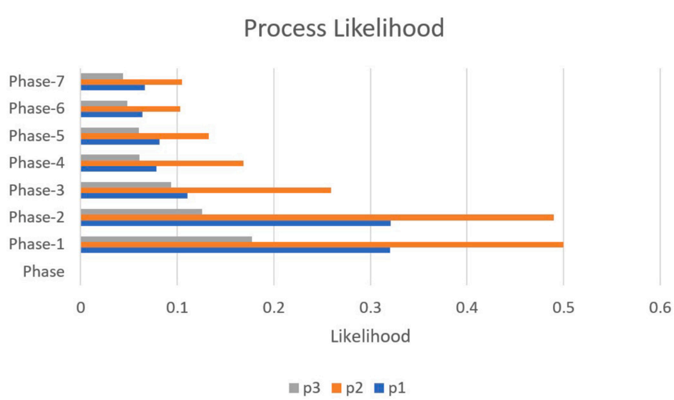

Fig. 8. Process likelihoods.

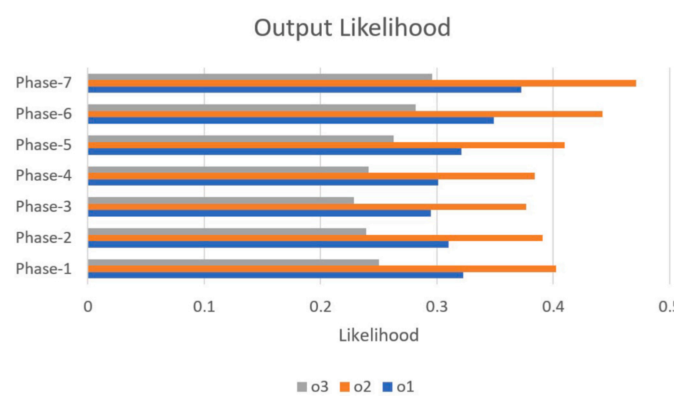

Fig. 9. Output likelihood.

With these matrices, the available input vector is as follows:

$$\mathbf{in}_n(\mathbf{in}_1, \mathbf{in}_2, \mathbf{in}_3) = (0.3168, 0.4886, 0.1945).$$

Based on step-3 of the algorithm and equations (6) and (7), we get the likelihood for the next seven lifecycle phases. The likelihood for the subsequent seven phases is shown in Table 5.

Fig. 8 and 9 show an interesting pattern. The figures show that during the processing phase, the likelihood related to sustainability decreases throughout the lifecycle of the business process, while in the output phase, the likelihood related to sustainability first decreases and then increases as the lifecycle of the business process progresses. The pattern can be attributed to the principles of the TCT and the inherent differences between modular and conventional construction business processes. In the processing phase, the decrease in likelihood related to sustainability is due to the efficiency gains of modular construction over conventional methods. Modular construction typically involves controlled, factory-like settings where pieces are pre-built, leading to less waste, fewer onsite errors, and lower transaction costs. This, in turn, reduces the overall environmental impact and increases sustainability throughout the business process lifecycle. As for the output phase, the initial decrease in sustainability likelihood is associated with the higher upfront costs and impacts of modular construction, such as the transportation of modules to the site. This fact leads to an initial drop in sustainability. However, as the project progresses, the benefits of modular construction—like reduced construction time, less waste, and better quality control—begin to outweigh these upfront impacts. This aspect explains the eventual increase in sustainability likelihood as the lifecycle of the business process advances. The facts mentioned above are discussed in detail by Kamali and Hewage (2016, 2017).

Next, we aim to calculate actual loss during the input, processing and output phases. First, with the help of equation (4), we obtained vectors $(0.271464646, 0.502525253, 0.226010101)$ and $(0.320998446, 0.506118881, 0.172882673)$ corresponding to processing and output, respectively. Based on the definition of the loss function, steps 7 and 8 of the algorithm and equation (11) and (12), we describe the loss function in Table 6.

Table 6
Loss during seven phases of SPD lifecycle with the classification of lifecycle phases in input, processing and output stages.

Phases	in_1^{loss}	in_2^{loss}	in_3^{loss}	p_1^{loss}	p_2^{loss}	p_3^{loss}	o_1^{loss}	o_2^{loss}	o_3^{loss}
Ph-1	0.291360009	0.4156511324	0.244401492	0.295183282	0.4322196099	0.253085588	0.26319258	0.37545266	0.2066740
Ph-2	0.284256189	0.3864223428	0.240997430	0.281855866	0.3898959304	0.227647308	0.25684920	0.36983472	0.2058903
Ph-3	0.273819089	0.3643633466	0.225686051	0.269478331	0.3742614786	0.217997217	0.24579999	0.35432260	0.2007808
Ph-4	0.252745509	0.3421477035	0.209416040	0.257767307	0.3559359575	0.207038791	0.23702440	0.34259043	0.1944451
Ph-5	0.247548824	0.3351072882	0.204209207	0.237218605	0.3269126448	0.191981722	0.22475342	0.32443303	0.1846360
Ph-6	0.239099309	0.3282036230	0.196254431	0.222199122	0.3054643310	0.179604905	0.21000240	0.30364115	0.1734993
Ph-7	0.243166982	0.3336624304	0.199013837	0.224392157	0.3090914004	0.182739128	0.20004750	0.28998105	0.1647488

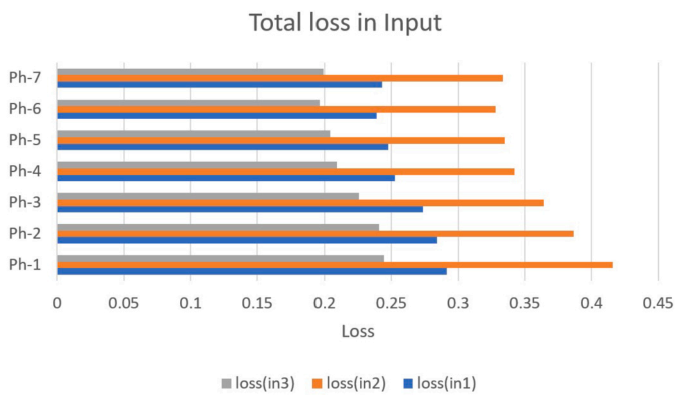

Fig. 10. Loss during the input stage for the seven phases of sustainability evaluation of modular versus conventional construction methods.

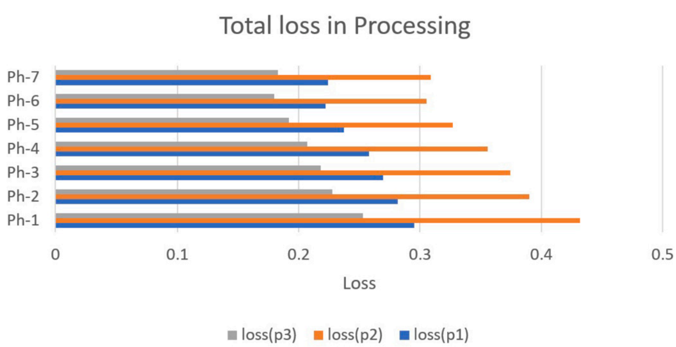

Fig. 11. Loss during the processing stage for the seven phases of sustainability evaluation of modular versus conventional construction methods.

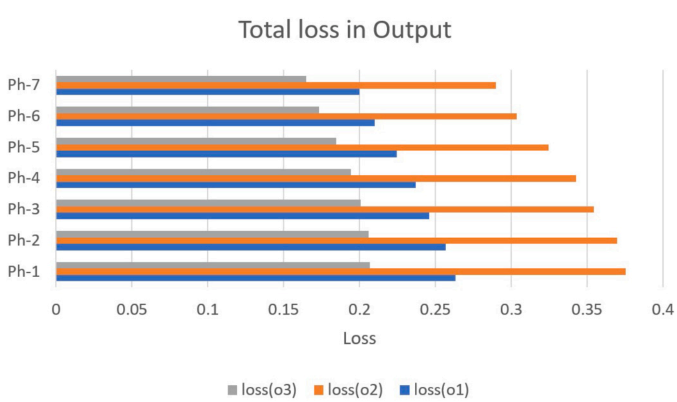

Fig. 12. Loss during the output stage for the seven phases of sustainability evaluation of modular versus conventional construction methods.

As depicted in Fig. 10, the most pronounced loss in the lifecycle phases of sustainability evaluation between modular and conventional construction methods is due to material consumption, while the smallest loss is attributed to site selection. Modular construction, with its reliance on controlled, off-site manufacturing, provides enhanced precision and efficiency, minimizing waste and promoting the effective use of materials. Conversely, conventional methods, due to on-site construction complexities and inaccuracies, lead to a higher loss through material consumption. While site selection plays a minimal role in determining the sustainability difference between the two approaches, modular construction offers some advantages. It reduces site disturbance and shortens construction duration, contributing to a lesser environmental footprint. Yet, these benefits are relatively trivial when compared to the substantial material efficiency that modular construction provides. Hence, losses associated with site selection are typically the least among lifecycle phases.

Fig. 11 elucidates that during the processing phase, the greatest loss in sustainability evaluation between modular and conventional construction methods is attributable to renewable materials, while the least loss is tied to alternate transportation methods. The pronounced loss in renewable materials is a result of their extensive consumption in modular construction, which, although environmentally considerate, leans heavily on renewable resources like timber. This accelerated consumption rate often surpasses the replenishment rate, leading to a notable short-term ecological impact. On the contrary, the loss from alternate transportation methods is minimized due to the streamlined logistics integral to modular construction. Modules are fabricated off-site and subsequently delivered to the construction site for assembly. This centralized production process reduces the need to ferry various raw materials to diverse sites, a common occurrence in conventional construction. Moreover, the delivery of completed modules can be optimized to decrease the number of transport trips and the resultant emissions. This method is more predictable, with modules being efficiently packed and transported, thereby lowering the environmental footprint compared to traditional construction techniques. Consequently, while the excessive use of renewable materials leads to substantial loss, proficient, optimized transportation curtails the loss in that category.

Fig. 12 shows that during the output stage of all the seven phases of the lifecycle related to the sustainability evaluation of modular versus conventional construction methods, loss due to greenhouse gas emission is the highest, and the loss due to embodied energy consumption is the lowest. In the output stage of the sustainability evaluation lifecycle, greenhouse gas (GHG) emissions present the highest loss because both modular and conventional construction methods involve activities that release significant amounts of these gases. These activities include the extraction and processing of raw materials, transportation of materials and modules, and on-site assembly operations. Even though modular construction tends to be more efficient and generate less waste, it is still associated with substantial GHG emissions. Conventional construction methods often require more on-site activity and longer construction times, both of which contribute to increased GHG emissions. Modular construction methods, though less emission-intensive, still contribute to GHG emissions during the manufacturing, transportation, and assembly of the modules. In contrast, the loss due to embodied energy consumption is typically the lowest in the output stage. Embodied energy refers to the total energy required to produce a product, including the extraction, manufacturing, and transportation of raw materials. Because modular construction is more efficient and generates less waste than conventional construction, it typically requires less energy, resulting in lower embodied energy. Moreover, modular construction allows for the efficient use of materials and more controlled manufacturing environments, which reduce the energy consumption associated with the production process. Consequently, despite the embodied energy involved in the production of building modules, it's lower than the energy consumed during conventional on-site construction. Therefore, while modular construction offers several environmental advantages over conventional construction, the output stage of the lifecycle sustainability evaluation highlights that GHG emissions are the largest loss and embodied energy consumption is the smallest loss in both methods.

In light of TCT, sustainable product development demonstrates a strategic advantage through reduced internal and external transaction costs, fostering collaborative innovation, and enhancing environmental stewardship. Similarly, the sustainability evaluation of modular versus conventional construction methods underlines the efficiency of modular techniques. They lower transaction costs by streamlining production, minimising waste, and mitigating greenhouse gas emissions. Both cases underscore the importance of sustainability not just as an ecological imperative but as a strategy to optimise transaction costs and drive competitive advantage. The following section discusses the proposed approach's advantages, limitations, and policy implications.

5. Discussion on the proposed methodology: advantages, limitations and policy implications

The advantages of TCT are manifold for business processes. Primarily, it provides an analytical structure that aids businesses in evaluating the cost-effectiveness of different operational strategies. By understanding and estimating the costs associated with various transactions, companies can determine whether conducting a process in-house is more cost-efficient or outsourcing it to a third-party provider (Vatiero, 2022). This is especially beneficial in strategic supply chain management, procurement, and manufacturing operations decisions. Understanding transaction costs can also help businesses optimise their contractual relationships (Troisi & Alfano, 2023). By designing contracts that minimise transaction costs, businesses can enhance the efficiency of their partnerships, leading to improved profitability. Furthermore, the theory provides insights into the ideal organisational structure and the nature of interfirm relationships under varying economic circumstances (Nygaard, 2022). Hence, it enables businesses to understand better and navigate market structures and dynamics, thus leading to improved strategic decision-making and performance.

In the context of lifecycle assessment, TCT provides several advantages. It facilitates a thorough analysis of costs associated with each stage of a product's lifecycle, from raw material acquisition to end-of-life disposal. This comprehensive cost analysis can guide decision-making about insourcing or outsourcing specific lifecycle stages based on their cost-effectiveness. Furthermore, TCT empowers businesses to identify inefficiencies and areas for cost optimisation throughout the product lifecycle, ultimately enhancing profitability. It also supports businesses in structuring contracts for each lifecycle stage to minimise transaction costs, fostering better relationships with suppliers, manufacturers, and waste management entities. The theory also offers valuable insights into how economic factors, such as market uncertainty and asset specificity, influence lifecycle management decisions. By understanding these influences, businesses can better navigate market dynamics, leading to more informed and strategic decisions about product lifecycle management.

Integrating TCT into S-ERP systems fosters a strategic approach to managing and enhancing business operations. S-ERP systems strive to align various business processes while prioritising sustainability seamlessly. By incorporating TCT, organisations can leverage a thorough transaction cost analysis to make informed decisions regarding internal operations or outsourcing. This analysis considers search and information costs, bargaining and decision costs, and enforcement and compliance costs. TCT enhances the flexibility of the S-ERP approach. It empowers businesses to adapt their strategies dynamically based on changing transaction costs. For instance, if market fluctuations are projected to increase transaction costs associated with a particular operation, the business can proactively bring that operation in-house to mitigate cost escalation.

Moreover, TCT contributes to optimising contractual relationships, a vital element within the S-ERP framework. By structuring contracts to minimise transaction costs, businesses can foster stronger relationships with suppliers and partners, ultimately leading to more efficient and sustainable operations. Furthermore, TCT aligns with a core objective of S-ERP: enabling companies to make decisions that enhance both economic efficiency and sustainability. By factoring in transaction costs, businesses can make strategic choices about sourcing, manufacturing, and other processes, ensuring alignment with sustainability goals. In essence, TCT strengthens the potential of S-ERP to integrate sustainability into every aspect of business operations, thus demonstrating its adaptability and practicality.

TCT is a powerful tool for designing environmentally focused and sustainable policies within S-ERP systems. By leveraging this theory, organisations can comprehensively understand the environmental and sustainability-related costs associated with each transaction. This information forms the bedrock for policy decisions, as organisations can then strategically decide whether to conduct these transactions internally or outsource them based on cost efficiency. For instance, consider an organisation contemplating implementing a new recycling program. TCT can assist in estimating the costs associated with sourcing recycling services, negotiating contracts, and enforcing compliance. These cost calculations can inform the company's decision-making. For example, the analysis might reveal that developing an in-house recycling operation proves more cost-effective and sustainable in the long run.

TCT also extends its benefits to contract design and relationships with external entities. By incorporating TCT principles, organisations can craft policies that minimise transaction costs in contracts with suppliers or partners, while simultaneously maximising environmental benefits. Furthermore, aligning transaction costs with sustainability goals ensures that environmental policies are not only ethically sound but also economically viable. This focus on economic viability strengthens the long-term viability of these policies by promoting sustainability within the constraints of the business environment. In essence, integrating TCT into S-ERP empowers organisations to design and implement environmentally sound, sustainable, and economically viable policies. This fosters a balanced approach that integrates environmental stewardship seamlessly with core business operations.

Despite its numerous advantages, TCT does have limitations. One key limitation lies in its emphasis on cost efficiency as the primary decision-making criterion. While cost-efficiency is undeniably crucial, other factors like quality, innovation, and strategic fit can be equally critical business considerations. Over-reliance on TCT could lead to an excessive focus on cost at the expense of these other factors. Another limitation is the theory's foundation on certain assumptions, such as rational decision-making and complete information availability. These assumptions may not always reflect real-world scenarios. In practice, decision-makers may operate with incomplete information, and their choices might be influenced by cognitive biases, emotions, or other non-rational factors. This can result in transaction costs that deviate from the theory's predictions, potentially exceeding or falling below the anticipated values.

Furthermore, TCT may not fully capture the dynamic nature of business environments. Market conditions, technologies, and consumer preferences can evolve rapidly, significantly impacting transaction costs. The theory does not always offer clear guidance on adapting to such changes. Lastly, TCT has limitations in comprehensively addressing the complexities of relationships and contracts. While it provides a framework for minimising transaction costs through contract design, it does not account for the trust, communication, and relational dynamics that are often essential for successful business relationships.

This limitation can hinder its usefulness in situations where relationship management is a critical factor.

6. Contributions

This study offers significant theoretical and experimental contributions by applying TCT to enhance S-ERP systems. Theoretically, it innovatively extends TCT to assess and quantify sustainability in business processes, providing a novel lens for understanding the integration of sustainability metrics. Experimentally, the study's validation through case studies in sustainable product design and modular versus conventional construction methods demonstrates the practical applicability of the approach. It addresses the gaps in S-ERP systems, particularly in fully integrating sustainability across all business functions, thereby advancing the knowledge and practice in this vital area. We discuss theoretical and practical contributions in

6.1. Theoretical contributions

From a methodological standpoint, this study enhances comprehension of business processes and their associated sustainability through the lens of S-ERP. The proposed approach specifically illuminates the probability and cost associated with a particular business process from a sustainability standpoint. Traditional S-ERP or ERP systems tend to evaluate sustainability based on a cause-and-effect paradigm. Our suggested methodology, however, creates a bridge between cause and effect via process elements, enabling movement both forwards (from cause to effect) and backward (from effect to cause). This advanced approach quantifies the likelihood and total loss associated with each phase of the business process, namely the input, processing, and output stages.

The proposed methodology effectively handles the intricacies of business processes. It delivers an extensive analysis of sustainability at the business process level, significantly beneficial within the S-ERP system. Rather than analysing in isolation, it thoroughly reviews the business process and its associated operations using a three-stage approach - input, processing, and output. This methodology allows the sustainability impact from the input to output phase to be measured and scrutinised. While existing S-ERP systems typically offer data only at the input and output stages, the suggested approach can generate detailed sustainability reports at the business process level. Moreover, the methodology serves as an effective mechanism to reduce subjective bias and enhance accuracy in sustainability assessment at the business process level. Although there is still a need for estimating transfer probabilities, impact, and sustainability values, the proposed algorithm leans more towards accurate data rather than personal judgment, which is inherently limited and inaccurate in a dynamic and complex environment. This methodology minimises subjective bias by applying the sustainability assessment at the business process level to actual data and case studies, enhancing its overall effectiveness and reliability.

From a theoretical standpoint, this study enhances comprehension of business processes and their associated sustainability through the lens of S-ERP. Building upon existing research highlighting the challenges of holistic sustainability integration in S-ERP (e.g., (Lothari et al., 2024)), our proposed method addresses this gap by quantifying the probability and cost associated with each phase of the business process. This innovative approach goes beyond the cause-and-effect paradigm of traditional S-ERP by enabling both forward and backward analysis, providing a more comprehensive understanding of sustainability impact. The effectiveness of this method is validated through its application in two case studies. These case studies demonstrate how our approach generates detailed sustainability reports at the business process level, confirming the theoretical advantages of reduced bias and expanded data analysis compared to existing S-ERP capabilities (Abobakr et al., 2023). Furthermore, the case study findings extend the theoretical understanding of TCT by showcasing its novel application to quantifying sustainability likelihood and losses within S-ERP systems (Marakulina & Murzin, 2023).

The research contributes to the theoretical understanding of how sustainability can be more comprehensively integrated into S-ERP systems. It addresses the identified gap in current S-ERP systems—namely, their potential inability to integrate sustainability metrics across all business functions holistically. The study adds to the knowledge of ERP systems and sustainability integration by proposing a method to leverage static input data for broader sustainability insights. This study innovatively applies TCT to sustainable business practices, particularly in S-ERP systems. By conceptualising business processes as input-output systems, the research provides a unique lens to assess and quantify sustainability likelihood and overall losses. This novel application extends the scope of TCT, contributing to the theoretical foundation for understanding the efficiency and sustainability of business processes.

6.2. Practical contributions

The suggested methodology stands to enhance the S-ERP system significantly. Once the S-ERP system supplies data regarding the input and the method of processing said input – that is, transaction data – all relevant conditions concerning sustainability factors are immediately presented to the management team and policy-makers. This eliminates the need to replicate conventional estimations at each stage of the business process, unquestionably boosting the efficiency of the assessment and overall management of sustainability and business processes. Generally, through S-ERP, sustainability assessment methods are carried out in a 'clockwise' manner. At the onset of each lifecycle phase, the organisation conducts a risk assessment and makes predictions based on their experience and feedback information. Consequently, subjective bias inevitably impacts past, present, and future sustainability assessments. In contrast to this traditional method, the algorithm proposed in this study operates in a 'reverse' manner. That is, the organisation will evaluate sustainability factors at the end of each phase based on actual loss data gathered, ensuring the accuracy and reliability of the assessment. Essentially, a more rational sustainability evaluation for the past paves the way for an improved assessment of the present and the future. Furthermore, this approach allows for 'attribution' to relative sustainability, enabling quicker and more precise identification of specific sources contributing to certain losses. This, in turn, allows for developing more effective measures to manage risk.

The study presents a practical, comprehensive framework for decision-makers in organisations employing S-ERP systems. This framework aids in making informed choices focusing on sustainable outcomes, facilitating more environmentally responsible and socially equitable business practices. Such a tool is invaluable for organisations balancing economic goals with sustainability considerations. Through detailed case studies on sustainable product design and modular versus conventional construction methods, this research offers a practical methodology for evaluating and implementing sustainability in various business processes. This aspect of the research provides a clear, actionable path for organisations to assess and improve their sustainability practices, especially in the context of S-ERP systems. The proposed research offers a robust framework for systematically tracking and assessing sustainability performance within S-ERP systems at the business process level. This enables organisations to improve continuously, ensuring their business processes align with evolving sustainability goals and standards. Such a framework is crucial for long-term sustainability and operational efficiency in contemporary business environments.

Beyond facilitating internal decision-making, our approach paves the way for increased transparency and stakeholder engagement surrounding sustainability efforts. By integrating transaction cost analysis directly into S-ERP systems, organisations can access readily available, quantifiable data on the environmental and social costs associated with their business processes. This information can be readily shared with stakeholders, including investors, regulators, and customers, fostering trust and demonstrating a commitment to responsible business practices. Furthermore, stakeholders can utilise this data to engage in informed dialogue with organisations, providing valuable feedback and encouraging continuous improvement in sustainability measures. This heightened transparency can strengthen trust and brand reputation, attracting ethically conscious consumers and investors while building stronger relationships with communities and regulatory bodies. In conclusion, the proposed methodology streamlines internal decision-making and empowers organisations to cultivate meaningful dialogue and collaboration with stakeholders, ultimately contributing to a more sustainable and inclusive business landscape.

Through detailed case studies on sustainable product design and modular versus conventional construction, this research offers a practical methodology for evaluating and implementing sustainability in various business processes. These case studies not only showcase the real-world applicability of our proposed method but also validate its effectiveness in addressing limitations identified by previous research on S-ERP sustainability integration, e.g., lack of process-level analysis (Olsen, 2023, Abobakr et al., 2023). For instance, by employing a 'reverse' evaluation approach, our method demonstrably reduced subjective bias compared to traditional 'clockwise' assessments, as observed in the product design case study (Stark et al., 2017). Furthermore, the ability to attribute losses to specific sustainability factors, as showcased in the modular construction case study (Shakeri & Azhar, 2021), aligns with and expands upon the theoretical understanding of TCT within S-ERP systems, originally proposed by (Marakulina & Murzin, 2023).

6.3. Future research directions

The TCT-based approach we've proposed for managing sustainability at the business process level for S-ERP systems has opened several promising avenues for future research. Firstly, while the approach shows potential, additional empirical studies using real-world data could help to validate the model further and refine its assumptions. Such studies could also provide more detailed insights into how transaction costs vary across different industries and types of business processes. Additionally, future research could explore how to integrate other relevant factors into the approach. While transaction costs are certainly important, there are other factors, such as the strategic importance of a process or potential impacts on customer satisfaction, which could also affect the decision on how to manage a process. Another promising direction could be to explore how to use this approach in conjunction with other management theories or frameworks (Sent & Kroese, 2022). For instance, researchers could look into how this approach could be integrated with risk management or quality management practices. Finally, as technologies and business environments continue to evolve, future research should also investigate how emerging trends, such as digital transformation or the increasing importance of corporate social responsibility, could impact transaction costs and the optimal management of business processes in S-ERP systems. In the end, while the proposed approach represents a significant step forward, future research has many exciting directions to develop further and refine the method, thereby contributing to more effective and sustainable business process management.

Building upon the potential of our approach, future research can delve deeper into its practical integration and customisation. One crucial aspect is the development of user-friendly interfaces within S-ERP systems that seamlessly integrate transaction cost analysis capabilities for real-time decision-making at the process level (Gandhi et al., 2023). Additionally, exploring industry-specific adaptations of the transaction cost framework would enhance its practical applicability for various corporate contexts. Furthermore, investigating the potential for dynamic adjustments of transaction cost calculations based on real-time data feeds and changing environmental regulations could significantly amplify the approach's responsiveness and effectiveness. By embracing these research avenues, we can bridge the gap between theoretical advancements and practical implementation, ultimately guiding organisations towards a future where S-ERP systems not only optimise efficiency but also empower informed decisions for a more sustainable business landscape.

7. Conclusion

This paper embarked on an exploratory journey to enhance sustainability integration within S-ERP systems, guided by Transaction Cost Theory (TCT) and supported by empirical evidence from case studies. We addressed the critical need for holistic integration of sustainability metrics across all business functions and offered a methodological framework to achieve this goal. Recognising the inherent challenges in existing S-ERP systems, particularly regarding the difficulty of integrating diverse ESG metrics, we applied TCT as a robust foundation for analysing and optimising the resources, efforts, and time involved in sustainable business practices. TCT provided valuable insights into the complexities of sustainability integration and offered a unique perspective on managing trade-offs and efficiencies associated with various sustainability initiatives. Our methodology centred around implementing a sustainability matrix across business processes. This matrix facilitated informed decision-making regarding resource allocation and long-term sustainability by identifying, evaluating, and prioritising objectives and risks. The case studies in sustainable product design and modular construction methods exemplified our approach's practical application and versatility across different industry sectors.

Embedding sustainability criteria and performance indicators directly into S-ERP systems demonstrated their potential to reduce manual efforts, minimise errors, and enhance the visibility of sustainability information. However, limitations such as adapting S-ERP systems to accommodate unique processes, modelling complex sustainability elements, and the ongoing refinement of processes warrant further exploration. The present research contributes to understanding S-ERP systems and their potential for integrating sustainability into business processes. It paves the way for future research, particularly in advanced sustainability metrics integration, customisation of S-ERP systems for sector-specific needs, and exploration of sustainability challenges and opportunities unique to various industries. Ultimately, this work emphasises the potential for informed, sustainable, and efficient business practices, reinforcing the idea that technological advancement and environmental stewardship can progress in tandem.

CRediT authorship contribution statement

Kushal Anjaria: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used GPT4 to polish the language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jjimei.2024.100243.

References

Abhari, K., Davidson, E. J., & Xiao, B. (2022). Modeling social product development process, technology, and governance. *IEEE Transactions on Engineering Management*, *69*(2), 409–422. https://doi.org/10.1109/TEM.2020.2973234.

Abobakr, M. A., Abdel-Kader, M., & Elbayoumi, A. F. (2023). Integrating s-erp systems and lean manufacturing practices to improve sustainability performance: An institutional theory perspective. *Journal of Accounting in Emerging Economies*, *13*(5), 870–897. https://doi.org/10.1108/JAEE-10-2020-0255.

Adabre, M. A., Chan, A. P., Edwards, D. J., & Mensah, S. (2022). Evaluation of symmetries and asymmetries on barriers to sustainable housing in developing countries. *Journal of Building Engineering*, *50*, Article 104174. https://doi.org/10.1016/j.jobe.2022.104174.

Afshar Jahanshahi, A., Al-Gamrh, B., & Gharleghi, B. (2020). Sustainable development in Iran post-sanction: Embracing green innovation by small and medium-sized enterprises. *Sustainable Development*, *28*(4), 781–790. https://doi.org/10.1002/sd.2028.

Agafonow, A., & Perez, M. (2023). How a social enterprise wanes: The transaction costs of credible commitments at Etsy.com. *Journal of Interdisciplinary Economics*, *35*(1), 83–107. https://doi.org/10.1177/02601079211038239.

Akbar, Y. H., & Tracogna, A. (2018). The sharing economy and the future of the hotel industry: Transaction cost theory and platform economics. *International Journal of Hospitality Management*, *71*, 91–101. https://doi.org/10.1016/j.ijhm.2017.12.004.

Al-Othman, A., Tawalbeh, M., Martis, R., Dhou, S., Orhan, M., Qasim, M., & Ghani Olabi, A. (2022). Artificial intelligence and numerical models in hybrid renewable energy systems with fuel cells: Advances and prospects. *Energy Conversion and Management*, *253*, Article 115154. https://doi.org/10.1016/j.enconman.2021.115154.

Ali, Y., Pretaroli, R., Socci, C., & Severini, F. (2018). Carbon and water footprint accounts of Italy: A multi-region input-output approach. *Renewable & Sustainable Energy Reviews*, *81*, 1813–1824. https://doi.org/10.1016/j.rser.2017.05.277.

Amjith, L., & Bavanish, B. (2022). A review on biomass and wind as renewable energy for sustainable environment. *Chemosphere*, *293*, Article 133579. https://doi.org/10.1016/j.chemosphere.2022.133579.

Anjaria, K. (2022). Knowledge derivation from Likert scale using z-numbers. *Information Sciences*, *590*, 234–252. https://doi.org/10.1016/j.ins.2022.01.024.

Anjaria, K., & Mishra, A. (2017a). Quantitative analysis of information leakage in service-oriented architecture-based web services. *Kybernetes*, *46*(3), 479–500. https://doi.org/10.1108/K-07-2016-0178.

Anjaria, K., & Mishra, A. (2017b). Information leakage analysis of software: How to make it useful to it industries? *Future Computing and Informatics Journal*, *2*(1), 10–18. https://doi.org/10.1016/j.fcij.2017.04.002.

Anjaria, K., & Mishra, A. (2017c). Relating Wiener's cybernetics aspects and a situation awareness model implementation for information security risk management. *Kybernetes*, *47*(1), 58–79. https://doi.org/10.1108/K-06-2017-0226.

Anjaria, K., & Patel, N. (2021). Attainment of green computing in cloudlet-based mobile cloud computing model using squirrel search algorithm. In R. P. Mahapatra, B. K. Panigrahi, B. K. Kaushik, & S. Roy (Eds.), *Proceedings of 6th international conference on recent trends in computing* (pp. 457–470). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-33-4501-0_42.

Antràs, P., & Chor, D. (2022). Chapter 5 - Global value chains. In G. Gopinath, E. Helpman, & K. Rogoff (Eds.), *Handbook of international economics*. *Handbook of international economics: International trade: Vol. 5* (pp. 297–376). Elsevier. https://doi.org/10.1016/bs.hesint.2022.02.005.

Ardanza, A., Moreno, A., Segura, Á., De La Cruz, M., & Aguinaga, D. (2019). Sustainable and flexible industrial human machine interfaces to support adaptable applications in the Industry 4.0 paradigm. *International Journal of Production Research*, *57*(12), 4045–4059. https://doi.org/10.1080/00207543.2019.1572932.

Babber, G., & Mittal, A. (2023). Achieving sustainability through the integration of lean, agile, and innovative systems: Implications for Indian micro small medium enterprises (msmes). *Journal of Science and Technology Policy Management*. https://doi.org/10.1108/JSTPM-05-2023-0087.

Backer, C. R., Slaman, M., Haddara, M., & Langseth, M. (2023). Towards sustainable erp systems: Bridging the gap between current capabilities and future potential. In *Proceedings of the future technologies conference* (pp. 216–242). Springer. https://doi.org/10.1007/978-3-031-47448-4_16.

Bahli, B., & Rivard, S. (2005). Validating measures of information technology outsourcing risk factors. *Omega*, *33*(2), 175–187. https://doi.org/10.1016/j.omega.2004.04.003.

Bajwa, D., Pourhashem, G., Ullah, A., & Bajwa, S. (2019). A concise review of current lignin production, applications, products and their environmental impact. *Industrial Crops and Products*, *139*, Article 111526. https://doi.org/10.1016/j.indcrop.2019.111526.

Bakarich, K. M., Castonguay, J. J., & O'Brien, P. E. (2020). The use of blockchains to enhance sustainability reporting and assurance*. *Accounting Perspectives*, *19*(4), 389–412. https://doi.org/10.1111/1911-3838.12241.

Balasbaneh, A. T., Yeoh, D., & Juki, M. I. (2021). *Life cycle sustainability assessment study of conventional and prefabricated construction methods: MADM analysis*. Singapore: Springer Singapore (pp. 179–201). https://doi.org/10.1007/978-981-16-4562-4_8.

Benkler, Y. (2017). Peer production, the commons, and the future of the firm. *Strategic Organization*, *15*(2), 264–274. https://doi.org/10.1177/1476127016652606.

Bigelow, L., Nickerson, J. A., & Park, W.-Y. (2019). When and how to shift gears: Dynamic trade-offs among adjustment, opportunity, and transaction costs in response to an innovation shock. *Strategic Management Journal*, *40*(3), 377–407. https://doi.org/10.1002/smj.2996.

Bradač Hojnik, B., & Huđek, I. (2023). Small and medium-sized enterprises in the digital age: Understanding characteristics and essential demands. *Information*, *14*(11). https://doi.org/10.3390/info14110606.

Broccardo, L., Zicari, A., Jabeen, F., & Bhatti, Z. A. (2023). How digitalization supports a sustainable business model: A literature review. *Technological Forecasting & Social Change*, *187*, Article 122146. https://doi.org/10.1016/j.techfore.2022.122146.

Brown, H. S., de Jong, M., & Lessidrenska, T. (2009). The rise of the global reporting initiative: A case of institutional entrepreneurship. *Environmental Politics*, *18*(2), 182–200. https://doi.org/10.1080/09644010802682551.

Buchmayr, A., Verhofstadt, E., Van Ootegem, L., Thomassen, G., Taelman, S. E., & Dewulf, J. (2022). Exploring the global and local social sustainability of wind energy technologies: An application of a social impact assessment framework. *Applied Energy*, *312*, Article 118808. https://doi.org/10.1016/j.apenergy.2022.118808.

Bui, Q. N., Leo, E., & Adelakun, O. (2019). Exploring complexity and contradiction in information technology outsourcing: A set-theoretical approach. *Journal of Strategic Information Systems*, *28*(3), 330–355. https://doi.org/10.1016/j.jsis.2019.07.001.

Burke, A. Z. H., & Wang, J. X. (2023). Integrating product design and supply chain management for a circular economy. *Production Planning & Control*, *34*(11), 1097–1113. https://doi.org/10.1080/09537287.2021.1983063.

Cámara, Ã., & Llop, M. (2021). Defining sustainability in an input–output model: An application to Spanish water use. *Water*, *13*(1). https://doi.org/10.3390/w13010001.

Castiglione, C., Pastore, E., & Alfieri, A. (2022). Technical, economic, and environmental performance assessment of manufacturing systems: The multi-layer enterprise input-output formalization method. *Production Planning & Control*, 1–18. https://doi.org/10.1080/09537287.2022.2054743.

Cazcarro, I., Duarte, R., Choliz, J. S., & Sarasa, C. (2011). Water rates and the responsibilities of direct, indirect and end-users in Spain. *Economic Systems Research*, *23*(4), 409–430. https://doi.org/10.1080/09535314.2011.611794.

Cevikparmak, S., Celik, H., Adana, S., Uvet, H., Sauser, B., & Nowicki, D. (2022). Scale development and validation of transaction cost economics typology for contracts: A systems thinking approach. *Journal of Purchasing and Supply Management*, *28*(3), Article 100769. https://doi.org/10.1016/j.pursup.2022.100769.

Chari, A., Stahre, J., Bärring, M., Despeisse, M., Li, D., Friis, M., Mörstam, M., & Johansson, B. (2023). Analysing the antecedents to digital platform implementation for resilient and sustainable manufacturing supply chains - an idef0 modelling approach. *Journal of Cleaner Production*, *429*, Article 139598. https://doi.org/10.1016/j.jclepro.2023.139598.

Chen, W., & Kamal, F. (2016). The impact of information and communication technology adoption on multinational firm boundary decisions. *Journal of International Business Studies*, *47*, 563–576. https://doi.org/10.1057/jibs.2016.6.

Chen, W., Botchie, D., Braganza, A., & Han, H. (2022). A transaction cost perspective on blockchain governance in global value chains. *Strategic Change*, *31*(1), 75–87. https://doi.org/10.1002/jsc.2487.

Cheng, J., Mao, C., Huang, Z., Hong, J., & Liu, G. (2022). Implementation strategies for sustainable renewal at the neighborhood level with the goal of reducing carbon emission. *Sustainable Cities and Society*, *85*, Article 104047. https://doi.org/10.1016/j.scs.2022.104047.

Chiu, M.-L., & Lin, C.-N. (2022). Developing supply chain open innovation capability: The mediating role of the knowledge creation process, governance mechanism and technology as a driver. *Journal of Innovation & Knowledge*, *7*(4), Article 100264. https://doi.org/10.1016/j.jik.2022.100264.

Chofreh, A. G., & Goni, F. A. (2017). Review of frameworks for sustainability implementation. *Sustainable Development*, *25*(3), 180–188. https://doi.org/10.1002/sd.1658.

Chofreh, A. G., Goni, F. A., Shaharoun, A. M., Ismail, S., & Klemeš, J. J. (2014). Sustainable enterprise resource planning: Imperatives and research directions. *Journal of Cleaner Production*, *71*, 139–147. https://doi.org/10.1016/j.jclepro.2014.01.010.

Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2017b). Development of a framework for the implementation of Sustainable Enterprise Resource Planning. *Chemical Engineering Transactions*, *61*, 1543–1548. https://doi.org/10.3303/CET1761255.

Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2017a). Development of a roadmap for Sustainable Enterprise Resource Planning systems implementation (part II). *Journal of Cleaner Production*, *166*, 425–437. https://doi.org/10.1016/j.jclepro.2017.08.037.

Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2018a). A roadmap for Sustainable Enterprise Resource Planning systems implementation (part III). *Journal of Cleaner Production*, *174*, 1325–1337. https://doi.org/10.1016/j.jclepro.2017.10.285.

Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2018b). Sustainable enterprise resource planning systems implementation: A framework development. *Journal of Cleaner Production*, *198*, 1345–1354. https://doi.org/10.1016/j.jclepro.2018.07.096.

Chofreh, A. G., Goni, F. A., & Klemeš, J. J. (2018c). Evaluation of a framework for sustainable enterprise resource planning systems implementation. *Journal of Cleaner Production*, *190*, 778–786. https://doi.org/10.1016/j.jclepro.2018.04.182.

Chofreh, A. G., Goni, F. A., Klemeš, J. J., Malik, M. N., & Khan, H. H. (2020). Development of guidelines for the implementation of sustainable enterprise resource planning systems. *Journal of Cleaner Production*, *244*, Article 118655. https://doi.org/10.1016/j.jclepro.2019.118655.

Chotruangprasert, K. (2013). Global reporting initiative indicator selection decisions: A case study. In *CAAA annual conference*.

Chung, H.-M. (2014). The role of family management and ownership on semi-globalization pattern of globalization: The case of family business groups. *International Business Review*, *23*(1), 260–271. https://doi.org/10.1016/j.ibusrev.2013.04.005.

Cong, G., & Chen, T. (2015). A novel dynamic algorithm for IT outsourcing risk assessment based on transaction cost theory. *Discrete Dynamics in Nature and Society*, *2015*, Article e325890. https://doi.org/10.1155/2015/325890.

Corallo, A., Del Vecchio, V., Lezzi, M., & Luperto, A. (2022). Model-based enterprise approach in the product lifecycle management: State-of-the-art and future research directions. *Sustainability*, *14*(3), 1370. https://doi.org/10.3390/su14031370.

Cordelia, A. (2006). Transaction costs and information systems: Does it add up? *Journal of Information Technology*, *21*(3), 195–202. https://doi.org/10.1057/palgrave.jit.2000066.

Cuypers, I. R. P., Hennart, J.-F., Silverman, B. S., & Ertug, G. (2021). Transaction cost theory: Past progress, current challenges, and suggestions for the future. *Academy of Management Annals*, *15*(1), 111–150. https://doi.org/10.5465/annals.2019.0051.

d'Aquino, P., & Bah, A. (2013). A participatory modeling process to capture indigenous ways of adaptability to uncertainty: Outputs from an experiment in West African drylands. *Ecology and Society*, *18*(4). Retrieved from https://www.jstor.org/stable/26269397.

Davenport, T. H., & Short, J. E. (1990). The new industrial engineering: Information technology and business process redesign. *MIT Sloan Management Review*. Retrieved from https://sloanreview.mit.edu/article/the-new-industrial-engineering-information-technology-and-business-process-redesign/.

De Felice, F., & Petrillo, A. (2021). An interdisciplinary framework to define strategies for digitalization and sustainability: Proposal of a 'digicircular' model. *IET Collaborative Intelligent Manufacturing*, *3*(1), 75–84. https://doi.org/10.1049/cim2.12013.

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. https://psycnet.apa.org/record/2010-00924-039.

Diaz, A., Schöggl, J.-P., Reyes, T., & Baumgartner, R. J. (2021). Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management. *Sustainable Production and Consumption*, *26*, 1031–1045. https://doi.org/10.1016/j.spc.2020.12.044.

Domenech, T., & Bahn-Walkowiak, B. (2019). Transition towards a resource efficient circular economy in Europe: Policy lessons from the EU and the member states. *Ecological Economics*, *155*, 7–19. https://doi.org/10.1016/j.ecolecon.2017.11.001.

Dubois, D., Foulloy, L., Mauris, G., & Prade, H. (2004). Probability-possibility transformations, triangular fuzzy sets, and probabilistic inequalities. *Reliable Computing*, *10*(4), 273–297.

Dumitru, V. F., Ionescu, B-È., Rîndașu, S.-M., Barna, L.-E-L., & Crîjman, A.-M. (2023). Implications for sustainability accounting and reporting in the context of the automation-driven evolution of erp systems. *Electronics*, *12*(8). https://doi.org/10.3390/electronics12081819.

Dwivedi, R., Nerur, S., & Balijepally, V. (2023). Exploring artificial intelligence and big data scholarship in information systems: A citation, bibliographic coupling, and co-word analysis. *International Journal of Information Management Data Insights*, *3*(2), Article 100185. https://doi.org/10.1016/j.jjimei.2023.100185.

Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, P. V., Janssen, M., Jones, P., Kar, A. K., Kizgin, H., Kronemann, B., Lal, B., Lucini, B., … Williams, M. D. (2021). Artificial intelligence (ai): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *57*, Article 101994. https://doi.org/10.1016/j.ijinfomgt.2019.08.002.

Elahi, E., & Khalid, Z. (2022). Estimating smart energy inputs packages using hybrid optimisation technique to mitigate environmental emissions of commercial fish farms. *Applied Energy*, *326*, Article 119602. https://doi.org/10.1016/j.apenergy.2022.119602.

Fatimah, Y. A., Govindan, K., Murniningsih, R., & Setiawan, A. (2020). Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia. *Journal of Cleaner Production*, *269*, Article 122263. https://doi.org/10.1016/j.jclepro.2020.122263.

Gandhi, S., Kiwelekar, A., Netak, L., & Shahare, S. (2023). A blockchain-based data-driven trustworthy approval process system. *International Journal of Information Management Data Insights*, *3*(1), Article 100162. https://doi.org/10.1016/j.jjimei.2023.100162.

Gatto, A. (2020). A pluralistic approach to economic and business sustainability: A critical meta-synthesis of foundations, metrics, and evidence of human and local development. *Corporate Social-Responsibility and Environmental Management*, *27*(4), 1525–1539. https://doi.org/10.1002/csr.1912.

Ge, T. (2023). Rising energy inequity and its driving factors to approach a just energy transition in China. *Environmental Impact Assessment Review*, *103*, Article 107231. https://doi.org/10.1016/j.eiar.2023.107231.

Ghobakhloo, M., Iranmanesh, M., Mubarak, M. F., Mubarik, M., Rejeb, A., & Nilashi, M. (2022). Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values. *Sustainable Production and Consumption*, *33*, 716–737. https://doi.org/10.1016/j.spc.2022.08.003.

Gholamzadeh Chofreh, A., Goni, F. A., Ismail, S., Mohamed Shaharoun, A., Klemeš, J. J., & Zeinalnezhad, M. (2016). A master plan for the implementation of sustainable enterprise resource planning systems (part I): Concept and methodology. *Journal of Cleaner Production*, *136*, 176–182. https://doi.org/10.1016/j.jclepro.2016.05.140.

Guo, Z., Li, T., Shi, B., & Zhang, H. (2022). Economic impacts and carbon emissions of electric vehicles roll-out towards 2025 goal of China: An integrated input-output and computable general equilibrium study. *Sustainable Production and Consumption*, *31*, 165–174. https://doi.org/10.1016/j.spc.2022.02.009.

Gupta, S., Motlagh, M., & Rhyner, J. (2020). The digitalization sustainability matrix: A participatory research tool for investigating digitainability. *Sustainability*, *12*(21). https://doi.org/10.3390/su12219283.

Hahn, T., Pinkse, J., Preuss, L., & Figge, F. (2015). Tensions in corporate sustainability: Towards an integrative framework. *Journal of Business Ethics*, *127*, 297–316. https://doi.org/10.1007/s10551-014-2047-5.

Hammer, M. (2014). What is business process management? In *Handbook on business process management 1: Introduction, methods, and information systems* (pp. 3–16). Springer.

Hasan, M. M., Nekmahmud, M., Yajuan, L., & Patwary, M. A. (2019). Green business value chain: A systematic review. *Sustainable Production and Consumption*, *20*, 326–339. https://doi.org/10.1016/j.spc.2019.08.003.

Hassan, M. F., Saman, M. Z. M., Sharif, S., & Omar, B. (2016). Sustainability evaluation of alternative part configurations in product design: Weighted decision matrix and artificial neural network approach. *Clean Technologies and Environmental Policy*, *18*(1), 63–79. https://doi.org/10.1007/s10098-015-0990-1.

He, B., Li, F., Cao, X., & Li, T. (2020). Product sustainable design: A review from the environmental, economic, and social aspects. *Journal of Computing and Information Science in Engineering*, *20*(4), Article 040801. https://doi.org/10.1115/1.4045408.

Herrera, J., & de las Heras-Rosas, C. (2020). Corporate social responsibility and human resource management: Towards sustainable business organizations. *Sustainability*, *12*(3). https://doi.org/10.3390/su12030841.

Holton, I., Glass, J., & Price, A. D. (2010). Managing for sustainability: Findings from four company case studies in the UK precast concrete industry. *Journal of Cleaner Production*, *18*(2), 152–160. https://doi.org/10.1016/j.jclepro.2009.09.016.

Initiative, G. R. (2012). Global reporting initiative. Retrieved from https://www.globalreporting.org/Pages/default.aspx [20 Dec 2012].

Jiang, Y., Zhao, D., Wang, D., & Xing, Y. ((20). Sustainable performance of buildings through modular prefabrication in the construction phase: A comparative study. *Sustainability*, *11*(20). https://doi.org/10.3390/su11205658.

Kalita, H., Kumar, K., & Davim, J. P. (2021). Chapter one - current tools and methodology for a sustainable product life cycle and design. In K. Kumar, D. Zindani, & J. P. Davim (Eds.), *Woodhead publishing reviews: Mechanical engineering series. Sustainable manufacturing and design* (pp. 3–17). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-822124-2.00001-9.

Kamal Abdelbasset, W., Elkholi, S. M., Jade Catalan Opulencia, M., Diana, T., Su, C.-H., Alashwal, M., Zwawi, M., Algarni, M., Abdelrahman, A., & Nguyen, H. C. (2022). Development of multiple machine-learning computational techniques for optimization of heterogenous catalytic biodiesel production from waste vegetable oil. *Arabian Journal of Chemistry*, *15*(6), Article 103843. https://doi.org/10.1016/j.arabjc.2022.103843.

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable & Sustainable Energy Reviews*, *62*, 1171–1183. https://doi.org/10.1016/j.rser.2016.05.031.

Kamali, M., & Hewage, K. (2017). Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *Journal of Cleaner Production*, *142*, 3592–3606. https://doi.org/10.1016/j.jclepro.2016.10.108.

Kamali, M., Hewage, K., Rana, A., Alam, M. S., & Sadiq, R. (2023). Environmental sustainability assessment of single-family modular homes using performance benchmarks of conventional homes: Case studies in British Columbia, Canada. *Clean Technologies and Environmental Policy*, 1–26. https://doi.org/10.1007/s10098-023-02495-2.

Ketokivi, M., & Mahoney, J. T. (2020). Transaction cost economics as a theory of supply chain efficiency. *Production and Operations Management*, *29*(4), 1011–1031. https://doi.org/10.1111/poms.13148.

Kouriati, A., Moulogianni, C., Kountios, G., Bournaris, T., Dimitriadou, E., & Papadavid, G. (2022). Evaluation of critical success factors for enterprise resource planning implementation using quantitative methods in agricultural processing companies. *Sustainability*, *14*(11), 6606. https://doi.org/10.3390/su14116606.

Kumar, B., Huang, C.-H., Sadayappan, P., & Johnson, R. W. (1995). A tensor product formulation of Strassen's matrix multiplication algorithm with memory reduction. *Scientific Programming*, *4*(4), 275–289. Retrieved from https://content.iospress.com/articles/scientific-programming/spr4-4-04.

Lameke, A. A., Nkuku, A. M., Sánchez de la Sierra, R., Tanutama, V., & Titeca, K. (2023). On the governance of corrupt exchange: How citizens and officials build social ties to reduce corruption's transaction costs, https://doi.org/10.3386/w31286.

Leclère, D., Obersteiner, M., Barrett, M., Butchart, S. H. M., Chaudhary, A., De Palma, A., DeClerck, F. A. J., Di Marco, M., Doelman, J. C., Dürauer, M., Freeman, R., Harfoot, M., Hasegawa, T., Hellweg, S., Hilbers, J. P., Hill, S. L. L., Humpenöder, F., Jennings, N., Krisztin, T., … Young, L. (2020). Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature*, *585*(7826), 551–556. https://doi.org/10.1038/s41586-020-2705-y.

Leimona, B., Bingham, L. R., Jarungrattanapong, R., & van Noordwijk, M. (2023). Auctions in payments for ecosystem services and the plural values of nature. *Current Opinion in Environmental Sustainability*, *64*, Article 101334. https://doi.org/10.1016/j.cosust.2023.101334.

Li, C.-Y., & Fang, Y.-H. (2022). The more we get together, the more we can save? A transaction cost perspective. *International Journal of Information Management*, *62*, Article 102434. https://doi.org/10.1016/j.ijinfomgt.2021.102434.

Li, H., Ravey, A., N'Diaye, A., & Djerdir, A. (2019). Online adaptive equivalent consumption minimization strategy for fuel cell hybrid electric vehicle considering power sources degradation. *Energy Conversion and Management*, *192*, 133–149. https://doi.org/10.1016/j.enconman.2019.03.090.

Lim, J., Lee, H., Cho, H., Shim, J. Y., Lee, H., & Kim, J. (2022). Novel waste heat and oil recovery system in the finishing treatment of the textile process for cleaner production with economic improvement. *International Journal of Energy Research*, *46*(14), 20480–20493. https://doi.org/10.1002/er.7803.

Liu, S., & Qian, S. (2019). Towards sustainability-oriented decision making: Model development and its validation via a comparative case study on building construction methods. *Sustainable Development*, *27*(5), 860–872. https://doi.org/10.1002/sd.1946.

Loan, C. F. V. (2000). The ubiquitous Kronecker product. *Journal of Computational and Applied Mathematics*, *123*(1), 85–100. https://doi.org/10.1016/S0377-0427(00)00393-9.

Lothary, D., Tomov, P., & Dimitrov, L. (2024). Combination of an ERP system with other technological approaches to increase sustainability in discrete manufacturing. *AIP Conference Proceedings*, *3063*(1). https://doi.org/10.1063/5.0195806.

Luo, Y., & Chen, Y. (2023). Understanding the relationship between asset specificity and governance choices in construction projects: Moderating role of uncertainty. *Journal of Construction Engineering and Management*, *149*(3), Article 04022178. https://doi.org/10.1061/JCEMD4.COENG-12729.

Lutfi, A. (2023). Factors affecting the success of accounting information system from the lens of delone and mclean is model. *International Journal of Information Management Data Insights*, *3*(2), Article 100202. https://doi.org/10.1016/j.jjimei.2023.100202.

Lutfi, A., Alshira'h, A. F., Alshirah, M. H., Al-Okaily, M., Alqudah, H., Saad, M., Ibrahim, N., & Abdelmaksoud, O. (2022). Antecedents and impacts of enterprise resource planning system adoption among jordanian SMEs. *Sustainability*, *14*(6), 3508. https://doi.org/10.3390/su14063508.

Mach, K. J., Lemos, M. C., Meadow, A. M., Wyborn, C., Klenk, N., Arnott, J. C., Ardoin, N. M., Fieseler, C., Moss, R. H., Nichols, L., Stults, M., Vaughan, C., & Wong-Parodi, G. (2020). Actionable knowledge and the art of engagement. *Current Opinion in Environmental Sustainability*, *42*, 30–37. https://doi.org/10.1016/j.cosust.2020.01.002.

Mantravadi, S., Srai, J. S., & Møller, C. (2023). Application of mes/mom for industry 4.0 supply chains: A cross-case analysis. *Computers in Industry*, *148*, Article 103907. https://doi.org/10.1016/j.compind.2023.103907.

Marakulina, Y. N., & Murzin, A. D. (2023). *The role of transaction costs in the concept of sustainable enterprise development*. Singapore: Springer Nature Singapore (pp. 411–419). https://doi.org/10.1007/978-981-19-4005-7_45.

Marín-Rodríguez, N. J., Gonzalez-Ruiz, J. D., & Botero, S. (2023). Assessing fiscal sustainability in the landscape of economics research. *Economies*, *11*(12). https://doi.org/10.3390/economies11120300.

Meglin, R., Kytzia, S., & Habert, G. (2022). Regional circular economy of building materials: Environmental and economic assessment combining material flow analysis, input-output analyses, and life cycle assessment. *Journal of Industrial Ecology*, *26*(2), 562–576. https://doi.org/10.1111/jiec.13205.

Melao, N., & Pidd, M. (2000). A conceptual framework for understanding business processes and business process modelling. *Information Systems Journal*, *10*(2), 105–129. https://doi.org/10.1046/j.1365-2575.2000.00075.x.

Mezquita, A., Monfort, E., Ferrer, S., & Gabaldón-Estevan, D. (2017). How to reduce energy and water consumption in the preparation of raw materials for ceramic tile manufacturing: Dry versus wet route. *Journal of Cleaner Production*, *168*, 1566–1570. https://doi.org/10.1016/j.jclepro.2017.04.082.

Mitra, A. (2022). How can we enhance reputation in blockchain consensus for industry 4.0–a proposed approach by extending the pagerank algorithm. *International Journal of Information Management Data Insights*, *2*(2), Article 100138. https://doi.org/10.1016/j.jjimei.2022.100138.

Mittal, A., Raheja, K., Raut, R., & Deshpande, A. (2023). Fostering perceived wealth among smes through green business: Unveiling the mediating influence of consumers' green attitude. *Management of Environmental Quality: An International Journal*. https://doi.org/10.1108/MEQ-06-2023-0167.

Mölder, F., Jablonski, K., Letcher, B., Hall, M., Tomkins-Tinch, C., Sochat, V., Forster, J., Lee, S., Twardziok, S., Kanitz, A., Wilm, A., Holtgrewe, M., Rahmann, S., Nahnsen, S., & Köster, J. (2021). Sustainable data analysis with snakemake [version 2; peer review: 2 approved]. *F1000Research*, *10*(33). https://doi.org/10.12688/f1000research.29032.2.

Mookwon Jung, M. T. E., & Yayla, A. (2023). Investigating the interaction effect between it-enabled innovation and corporate social responsibility on firm performance. *Information Systems Management*, *40*(1), 70–89. https://doi.org/10.1080/10580530.2022.2031352.

Ncube, L. K., Ude, A. U., Ogunmuyiwa, E. N., Zulkifli, R., & Beas, I. N. (2020). Environmental impact of food packaging materials: A review of contemporary development from conventional plastics to polylactic acid based materials. *Materials*, *13*(21), 4994. https://doi.org/10.3390/ma13214994.

Nygaard, A. (2022). From linear to circular economy: A transaction cost approach to the ecological transformation of the firm. *Circular Economy and Sustainability*, *2*(3), 1127–1142. https://doi.org/10.1007/s43615-022-00158-w.

Okorie, D. I. (2021). The energy use of capital inputs: Towards cleaner production in Nigeria. *Environmental Challenges*, *4*, Article 100104. https://doi.org/10.1016/j.envc.2021.100104.

Olsen, C. (2022). An overview of key sustainability theories, regulations and s erp for business education, business research and digital business practitioners. In A. M. A. Musleh Al-Sartawi (Ed.), *Artificial intelligence for sustainable finance and sustainable technology* (pp. 584–592). Cham: Springer International Publishing.

Olsen, C. (2023). Toward a digital sustainability reporting framework in organizations in the industry 5.0 era: An accounting perspective. In A. M. A. Musleh Al-Sartawi, A. Razzaque, & M. M. Kamal (Eds.), *Lecture notes in networks and systems*. *From the Internet of Things to the Internet of Ideas: The role of Artificial Intelligence* (pp. 463–473). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-17746-0_37.

Pandiangan, S. M. T., Oktafiani, F., Panjaitan, S. R., Shifa, M., & Jefri, R. (2022). Analysis of public ownership and management ownership on the implementation of the triple bottom line in the plantation sector listed on the Indonesia stock exchange. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal)*, *5*(1), 3489–3497. https://doi.org/10.33258/birci.v5i1.4016.

Paris, B., Vandorou, F., Balafoutis, A. T., Vaiopoulos, K., Kyriakarakos, G., Manolakos, D., & Papadakis, G. (2022). Energy use in open-field agriculture in the EU: A critical review recommending energy efficiency measures and renewable energy sources adoption. *Renewable & Sustainable Energy Reviews*, *158*, Article 112098. https://doi.org/10.1016/j.rser.2022.112098.

Patalas-Maliszewska, J., & Kłos, S. (2019). The methodology of the s-erp system employment for small and medium manufacturing companies. *IFAC-PapersOnLine*, *52*(10), 85–90. https://doi.org/10.1016/j.ifacol.2019.10.004.

Piluso, C., Huang, Y., & Lou, H. H. (2008). Ecological input-output analysis-based sustainability analysis of industrial systems. *Industrial & Engineering Chemistry Research*, *47*(6), 1955–1966. https://doi.org/10.1021/ie061283s.

Potoski, M., Petersen, O. H., & Brown, T. L. (2023). Same product, different price: Experimental evidence on the transaction cost expenditures of selling to governments and firms. *Public Administration Review*, *83*(3), 623–638. https://doi.org/10.1111/puar.13551.

Project, S. (2003). The sigma guidelines: Putting sustainable development into practice-a guide for organizations.

Quito, B., del Río-Rama, M. d. l. C., Álvarez García, J., & Durán-Sánchez, A. (2023). Impacts of industrialization, renewable energy and urbanization on the global ecological footprint: A quantile regression approach. *Business Strategy and the Environment*, *32*(4), 1529–1541. https://doi.org/10.1002/bse.3203.

Rani, G. M., Wu, C.-M., Motora, K. G., & Umapathi, R. (2022). Waste-to-energy: Utilization of recycled waste materials to fabricate triboelectric nanogenerator for mechanical energy harvesting. *Journal of Cleaner Production*, *363*, Article 132532. https://doi.org/10.1016/j.jclepro.2022.132532.

Raut, R. D., Mangla, S. K., Narwane, V. S., Gardas, B. B., Priyadarshinee, P., & Narkhede, B. E. (2019). Linking big data analytics and operational sustainability practices for sustainable business management. *Journal of Cleaner Production*, *224*, 10–24. https://doi.org/10.1016/j.jclepro.2019.03.181.

Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020). Perceptions of offsite construction in the United States: An investigation of current practices. *Journal of Building Engineering*, *29*, Article 101138. https://doi.org/10.1016/j.jobe.2019.101138.

Rutz, P., Kotthaus, C., Pinatti de Carvalho, A. F., Randall, D., & Pipek, V. (2023). The relevance of kes-oriented processes for the implementation of erp systems: Findings from an empirical study in German smes. *Proceedings of the ACM on Human–Computer Interaction*, *7*(CSCW2). https://doi.org/10.1145/3610104.

Saidani, I., Ouni, A., Mkaouer, M. W., & Saied, A. (2019). Towards automated microservices extraction using muti-objective evolutionary search. In S. Yangui, I. Bouassida Rodriguez, K. Drira, & Z. Tari (Eds.), *Lecture notes in computer science*. *Service-oriented computing* (pp. 58–63). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-33702-5_5.

Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. *Journal of Purchasing and Supply Management*, *25*(4), Article 100552. https://doi.org/10.1016/j.pursup.2019.100552.

Scuri, S., Ferreira, M., Jardim Nunes, N., Nisi, V., & Mulligan, C. (2022). Hitting the triple bottom line: Widening the hci approach to sustainability. In *Proceedings of the 2022 CHI conference on human factors in computing systems, CHI '22*. New York, NY, USA: Association for Computing Machinery. https://doi.org/10.1145/3491102.3517518.

Sent, E.-M., & Kroese, A. L. J. (2022). Commemorating Oliver Williamson, a founding father of transaction cost economics. *Journal of Institutional Economics*, *18*(2), 181–193. https://doi.org/10.1017/S1744137421000606.

Sgroi, F., & Sciancalepore, V. D. (2022). Dynamics of structural change in agriculture, transaction cost theory and market efficiency: The case of cultivation contracts between agricultural enterprises and the food industry. *Journal of Agriculture and Food Research*, *10*, Article 100396. https://doi.org/10.1016/j.jafr.2022.100396.

Shakeri, R., & Azhar, S. (2021). Modular versus conventional construction: An analysis of cost and benefits via a case study. In S. M. Ahmed, P. Hampton, S. Azhar, & A. D. Saul (Eds.), *Collaboration and integration in construction, engineering, management and technology* (pp. 613–618). Cham: Springer International Publishing.

Stark, R., Buchert, T., Neugebauer, S., Bonvoisin, J., & Finkbeiner, M. (2017). Benefits and obstacles of sustainable product development methods: A case study in the field of urban mobility. *Design Science*, *3*, Article e17. https://doi.org/10.1017/dsj.2017.20.

Subhan, S., Budiman, K., & Efrilianda, D. A. (2021). Business process re-engineering to support the sustainability of the construction industry and sales commodities in large scale transaction during COVID-19 with integrating ERP and quotation system. *Scientific Journal of Informatics*, 84–91. Retrieved from https://garuda.ristekbrin.go.id/documents/detail/2035245.

Taylor, N. (2020). Already monstrous: A dietary response to existential crisis, https://doi.org/10.25918/THESIS.145.

Tian, G., Xia, Q., Wu, Z., & Fu, T. (2022). Ecological network analysis of industrial wastes metabolism based on input-output model for Jiangsu, China. *Waste Management*, *143*, 23–34. https://doi.org/10.1016/j.wasman.2022.02.011.

Troisi, R., & Alfano, G. (2023). Proximity and inter-firm corruption: A transaction cost approach. *Small Business Economics*, *60*(3), 1105–1120. https://doi.org/10.1007/s11187-022-00649-y.

Unal, E., Lin, B., & Managi, S. (2023). Co2 emissions embodied in bilateral trade in China: An input-output analysis. *Environmental Impact Assessment Review*, *103*, Article 107218. https://doi.org/10.1016/j.eiar.2023.107218.

Vatiero, M. (2022). Smart contracts vs incomplete contracts: A transaction cost economics viewpoint. *Computer Law & Security Review*, *46*, Article 105710. https://doi.org/10.1016/j.clsr.2022.105710.

Vieira, L. C., Longo, M., & Mura, M. (2023). From carbon dependence to renewables: The European oil majors' strategies to face climate change. *Business Strategy and the Environment*, *32*(4), 1248–1259. https://doi.org/10.1002/bse.3185.

Vilochani, S., McAloone, T. C., & Pigosso, D. C. A. (2023). Management practices for sustainable product development: Insights from a systematic literature review. *Proceedings of the Design Society*, *3*, 2505–2514. https://doi.org/10.1017/pds.2023.251.

Wang, H., Ko, E., Woodside, A., & Yu, J. (2021). SNS marketing activities as a sustainable competitive advantage and traditional market equity. *Journal of Business Research*, *130*, 378–383. https://doi.org/10.1016/j.jbusres.2020.06.005.

Wang, N., Cui, D., & Dong, Y. (2023). Study on the impact of business environment on private enterprises' technological innovation from the perspective of transaction cost. *Innovation and Green Development*, *2*(1), Article 100034. https://doi.org/10.1016/j.igd.2023.100034.

Weber, P., Gabriel, R., Lux, T., & Menke, K. (2022). Business process management. In P. Weber, R. Gabriel, T. Lux, & K. Menke (Eds.), *Basics in business informatics* (pp. 175–206). Wiesbaden: Springer Fachmedien. https://doi.org/10.1007/978-3-658-35859-4_8.

Weske, M. (2019). *Business process management: Concepts, languages, architectures*. Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-59432-2.

Wichelns, D., & Oster, J. D. (2006). Sustainable irrigation is necessary and achievable, but direct costs and environmental impacts can be substantial. *Agricultural Water Management*, *86*(1), 114–127. https://doi.org/10.1016/j.agwat.2006.07.014.

Wong, W. P., Sinnandavar, C. M., & Soh, K.-L. (2021). The relationship between supply environment, supply chain integration and operational performance: The role of business process in curbing opportunistic behaviour. *International Journal of Production Economics*, *232*, Article 107966. https://doi.org/10.1016/j.ijpe.2020.107966.

Wu, J., Guo, S., Li, J., & Zeng, D. (2016). Big data meet green challenges: Big data toward green applications. *IEEE Systems Journal*, *10*(3), 888–900. https://doi.org/10.1109/JSYST.2016.2550530.

Xia, H., Liu, Z., Efremochkina, M., Liu, X., & Lin, C. (2022). Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and building information modeling integration. *Sustainable Cities and Society*, *84*, Article 104009. https://doi.org/10.1016/j.scs.2022.104009.

Yang, J., Wu, R., & Ynag, H. (2023). Digital transformation and enterprise sustainability: The moderating role of regional virtual agglomeration. *Sustainability*, *15*, Article 9. https://doi.org/10.3390/su15097597.

Yoshikuni, A. C., Dwivedi, R., Zhou, D., & Wamba, S. F. (2023). Big data and business analytics enabled innovation and dynamic capabilities in organizations: Developing and validating scale. *International Journal of Information Management Data Insights*, *3*(2), Article 100206. https://doi.org/10.1016/j.jjimei.2023.100206.

Zabukovšek, U., Tominc, P., & Bobek, S. (2023). Business it alignment impact on corporate sustainability. *Sustainability*, *15*(16). https://doi.org/10.3390/su151612519.

Zhang, A., Tay, H. L., Alvi, M. F., Wang, J. X., & Gong, Y. (2023). Carbon neutrality drivers and implications for firm performance and supply chain management. *Business Strategy and the Environment*, *32*(4), 1966–1980. https://doi.org/10.1002/bse.3230.

Zhang, D., & Xie, Y. (2022). Customer environmental concerns and profit margin: Evidence from manufacturing firms. *Journal of Economics and Business*, *120*, Article 106057. https://doi.org/10.1016/j.jeconbus.2022.106057.

Zhang, W., Luo, Q., & Liu, S. (2022). Is government regulation a push for corporate environmental performance? Evidence from China. *Economic Analysis and Policy*, *74*, 105–121. https://doi.org/10.1016/j.eap.2022.01.018.

Zhang, Y., Zhao, S., & Xu, X. (2016). Business model innovation: An integrated approach based on elements and functions. *Information Technology and Management*, *17*(3), 303–310. https://doi.org/10.1007/s10799-015-0225-5.

Zhou, B., Li, Y., Ding, Y., Huang, G., & Shen, Z. (2023). An input-output-based Bayesian neural network method for analyzing carbon reduction potential: A case study of Guangdong province. *Journal of Cleaner Production*, *389*, Article 135986. https://doi.org/10.1016/j.jclepro.2023.135986.

Zhu, G., Xie, Z., Xu, H., Wang, N., Zhang, L., Mao, N., & Cheng, J. (2022). Oil spill environmental risk assessment and mapping in coastal China using Automatic Identification System (AIS) data. *Sustainability*, *14*(10), 5837. https://doi.org/10.3390/su14105837.

Zoppelletto, A., & Bullini Orlandi, L. (2022). Cultural and digital collaboration infrastructures as sustainability enhancing factors: A configurational approach. *Technological Forecasting & Social Change*, *179*, Article 121645. https://doi.org/10.1016/j.techfore.2022.121645.