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Industry 4.0 impacts on responsible environmental and societal management in the family business

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ABSTRACT

Technological innovations are critical for businesses to sustain a competitive advantage in an increasingly competitive globalised environment. Amongst other advances, Industry 4.0 (I4.0) technologies are having a growing impact on society; they have become a significant part of family business resources to create more sustainable environments and exploit new opportunities. However, few studies have analysed the impacts of I4.0 on responsible environmental management and society in the context of a family business. To take a step toward filling this gap, this study has employed a system dynamics model to evaluate the impacts of I4.0 on the clean production processes of family businesses in an emerging economy and to describe I4.0 practices on determinants of ethical behaviour and environmental management. Implementation is conducted in the packaging sector to analyse the impacts of I4.0 on CO_2 emissions, total packaging waste recovery and societal responsibilities on family businesses in Turkey. The results show that ethical business development contributes toward enhancing corporate social responsibility and environmental management systems in an I4.0 context. The findings can inform the efforts of managers, governments and decision-makers to analyse and manage the societal and environmental impacts of their activities to create a more sustainable environment for family businesses.

1. Introduction

The new industrial revolution, commonly called Industry 4.0 (I4.0), is altering contemporary business eco-systems. The term I4.0 is used to define the transformation from machine dominant production to digital manufacturing. Developments in I4.0 technologies reveal promising opportunities for sustainable manufacturing (Stock and Seliger, 2016), as cleaner production, sustainable manufacturing and circular economies are becoming necessary elements of business survival and growth as well as environmental sustainability and societal change.

Along with I4.0, cleaner production techniques have emerged during the past two decades as a means for industries to promote sustainable development through minimising the waste of natural resources. However, cleaner production approaches often carry benefits for economic performance as well as environmental conditions, business ethics and society in general (Hens et al., 2018). From this perspective, it is highly related to two other important concepts that shape manufacturing environments: a circular economy and sustainable business development (Ferasso et al., 2020).

Cleaner production supports sustainable manufacturing through more effective management of resources and efficient environmental processing while continuing high-quality production (Chakraborty, 2017). Hens et al., 3326) defined cleaner production as a business strategy that 'addresses the three sustainability dimensions individually and synergistically'. Cleaner production is a central concept in a circular economy based on closed-loop production systems which consistently aim to increase resource efficiency and thereby minimise waste (Ghisellini et al., 2016; Bala et al., 2020).

Authors have defined the relationship between these terms from different perspectives. For instance, De Sousa Jabbour et al. (2018a) described I4.0 and sustainability as two major, inextricably linked trends in the current manufacturing system; Garcia-Muiña et al. (2018) identified the relationship between I4.0 and the circular economy as

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List of abbreviations

I4.0	Industry 4.0

"two sides of the same coin". Similarly, de Sousa Jabbour et al. (2018b) argued that I4.0 technologies have the capability to promote circular economy principles and in the same vein, decisions in sustainable operations can contribute toward implementing the connection between the circular economy and I4.0 principles.

I4.0 contributes toward corporate social responsibility and environmental management (Johnstone, 2020), both of which are integral elements of ethical business development (Bassi et al., 2020). Summarising the impacts of I4.0 on environmental and social sustainability in the manufacturing context, Varela et al. (2019) correlated decreases in industrial waste, energy and resource consumption with increases in the practice of circular economy and production of renewable energy for environmental sustainability as well as enhanced social sustainability due to improvements in working and wider societal conditions, greater employee participation in decision-making and stakeholder collaboration and reduced workplace accidents. Therefore, sustainable business models in the current manufacturing environment can be achieved through the integration of I4.0 and cleaner production approaches to achieve ethical and environmental goals.

Cleaner production has become an important aspect of the management, planning, design and operation processes of industrial sectors; continuous monitoring of environmental and societal impacts is essential to progress to more sustainable systems (Klemeš et al., 2012). Each sector has specific stakeholders, barriers, geography and powers that develop sustainable practices (Depken and Zeman, 2018). Although various studies have analysed the environmental and social impacts of cleaner production practices (De Sousa Jabbour et al., 2018a; Varela et al., 2019; Kamble et al., 2020), to the best of our knowledge, a systematic approach for analysing the effects of I4.0 on cleaner production remains relatively unexplored. In the current manufacturing environment, integrating the technological developments of I4.0 with the United Nations sustainability goals is essential for business organisations to fulfil their environmental and social responsibilities (Luthra et al., 2020). Therefore, organisations must develop ethical business values and practices that are harmonised with the new industrial revolution in order to manage an increasingly complex and dynamic environment (Gregori and Holzmann, 2020; Mas-Tur et al., 2020).

As is the case for other businesses, the long-term sustainable competition of family firms is related to how much they predict and respond to change. As the new industrial revolution advances, businesses need to take on responsible roles in developing the social and environmental impacts of their activities in order to achieve sustainable competitive advantages (Barbosa et al., 2020; Xiang et al., 2020b). The process of developing sustainable practices requires significant resources, including the skills and abilities of employees, business owners and managers (Depken and Zeman, 2018). Investment in innovation is another important resource to help small and medium enterprises create new opportunities and enhance performance and growth (Yu, 2013; Memili et al., 2014). Globalisation has enhanced the ability of smaller or medium-sized companies to engage in wide-ranging, intensive knowledge-building as well as research and development activities to introduce new products (Camps and Marques, 2014; Hatak et al., 2016).

However, it is necessary to determine parameters of how I4.0 influences family business operations and outcomes and to evaluate the impacts of I4.0 on responsible environmental management and societal impacts within cleaner production practices in order to contribute toward increasing sustainability in family businesses (Aiello et al., 2020; Rovelli et al., 2021). Few studies have examined the impacts of I4.0 on family business operations and outcomes. To contribute toward addressing this gap, this research conducted a case study of the impacts of CO_2 emissions and total packaging waste recovery on family businesses in the packaging sector in Turkey.

Accordingly, this study aims to answer the following research questions:

RQ1: How has I4.0 impacted the responsible environmental management of family businesses?

RQ2: What are the social impacts of sustainable I4.0 in the context of family businesses?

Family businesses' resources are unusually complex, rich and dynamic; their internal characteristics, stakeholders and performance are substantially inter-related (Bichler et al., 2021). Family businesses must operate within highly dynamic and variable environments to ensure long-term sustainability and growth (Xiang et al., 2020a). Moreover, as Isensee et al. (2020) demonstrated, organisational culture, environmental sustainability and digitalisation have significant impacts on small and medium enterprises. Therefore, analysing the impacts of I4.0 on family businesses' responsible environmental management and related economic and social outcomes requires a holistic, systematic approach capable of integrating multiple components and inter-relating them with causal relationships. In order to deal with the complex nature of a family business and to investigate societal dynamic relations within this environment, holistic approaches are needed (Khanzode et al., 2021). From this point of view, a systems dynamics approach is used as the methodology. The system dynamics model is used in order to analyse possible impacts of I4.0 on sustainable family businesses considering environmental and societal dimensions that require a holistic approach to investigate the dynamic behaviour of the system.

Therefore, the main contribution of this study is to address the parameters and their effects within the scope of environmental sustainability and digitalization with a holistic approach in a family business which is affected by various inter-related parameters due to the complexity of cleaner production processes in the business; the aim is to predict how each of these components affects the behaviour of the system over time. This study makes a unique contribution to existing literature to deal with various parameters and investigate the effects of I4.0 on the clean production processes and societal responsibility of family businesses in the context of an emerging economy simultaneously.

This study is organised as follows. Section 2 elaborates the theoretical background of this work followed by a description of the methodology in Section 3. A case study and review of the analysis and findings are presented in Section 4. Section 5 presents discussions and implications while conclusions are drawn up in section 6.

2. Theoretical background

I4.0 has great potential to promote the development of sustainable business models in the manufacturing industry where the integration of cleaner production practices with digital technologies is essential (Li et al., 2020). Studies that cover the relationship between I4.0 and inter-related concepts such as cleaner production, sustainable production and circular economy are becoming more frequent; authors have utilised varying approaches to contribute to building theoretical and practical knowledge in this area. However, despite some differences in the definitions and ideas proposed across literature, they share many commonalities in terms of their integration of I4.0 and cleaner production, sustainable production, circular economy, green production and reverse logistics.

In their discussion of macro and micro opportunities of I4.0 in sustainable manufacturing, Stock and Seliger (2016) classified the former into business models and value creation networks and the latter into human, organisational, process and product opportunities. De Man and Strandhagen (2017) elaborated a sustainable I4.0 model comprised of four main components, i.e. value proposition, supply chain management, customer loyalty and relations plus financial justification; potential scenarios such as smart laptops, serviced wardrobes and smart kitchens were identified. Kamble et al. (2018) suggested that a sustainable I4.0 framework should include three critical components, namely sustainable outcomes, process integration and I4.0 technologies. Similarly, Machando et al. (2020) conducted a detailed study that included a systematic review of the links between I4.0 and sustainable manufacturing, with a proposed research agenda that covers research gaps and opportunities for developing the field.

The integration of sustainable manufacturing, lean manufacturing and I4.0 is another trending topic related to cleaner production practices. For instance, Varela et al. (2019) analysed correlations between lean manufacturing, sustainable manufacturing, I4.0 and contributed to existing literature by proposing ideas for industry decision supports. Kamble et al. (2020) showed that I4.0 technologies can be used as enablers of lean manufacturing practices, thereby contributing to sustainable organisational performance.

Nascimento et al. (2019) proposed a business model to explore the impacts of I4.0 technologies on the circular economy in the context of reuse and recycling activities. Similarly, Rosa et al. (2020) conducted a systematic literature review of I4.0 technologies that enable a circular economy; their resulting model identified several key technology areas: a) additive manufacturing for recycling of products and materials; b) cyber-physical systems to support the development of innovative sustainable services; c) simulation to support the remanufacturing of complex products and better management of complex supply chains and e) big data management and the Internet of things (IoT) to improve the efficient use of natural resources. Rajput and Singh (2019) conducted an exploratory factor analysis and DEMATEL modelling to highlight artificial intelligence, service and policy framework and a circular economy as the most forceful enablers of I4.0 to effectively manage a closed-loop supply chain; elsewhere interface designing to adapt the necessary components of circular economy and automated synergy model to maximise efficiency and accuracy were found to be the main potential barriers (Luthra and Mangla, 2018). Yadav et al. (2020) considered the integration of I4.0 and circular economy to deliver sustainable outputs whereby I4.0 focuses on cyber-physical systems to build smart factories for sustainable practices, while the circular economy emphasises the adoption and implementation of end of life strategies.

Tsai (2018) discussed using a combination of I4.0 and mathematical programming to achieve green production planning and control practices. Dev et al. (2019) modelled reverse logistics activities in I4.0 to examine green product diffusion dynamics that affect the balance between environmental and economic performance and found that tradeoffs are negatively impacted by operational parameters and their related costs as well as the size of the end-user market and collection investment. Wang and Wang (2019) focused on the more specific issue of I4.0-based solutions to the waste electrical and electronic equipment (WEEE) industry from design to recovery. Lin (2018) proposed a smart production system based on I4.0 technologies that explores product decision-making information systems in the glass recycling industry under a circular economy. Kerin and Pham (2019) investigated the applicability of I4.0 technologies, including the IoT, virtual reality and augmented reality in end-of-life activity, recommending the need to integrate IoT and cyber-physical systems to support smart remanufacturing.

In the context of small and medium businesses, Graafland (2020) analysed the family business relations with cleaner production and found that larger, non-family owned businesses evinced a weaker relationship than family businesses and that the performance gap between family-owned and non-family companies was greatest for small firms managed by a combination of family members and non-family members. Barbosa et al. (2020) developed an integrated 'sustainable strategic management' model, which aims to provide a competitive advantage by incorporating sustainability into the activities of small businesses in a holistic, applicable and controllable manner. Isensee et al. (2020) carried out a literature review to investigate how green digitalisation approaches can lead to fundamental transformations of organisational culture, environmental sustainability or business models in family businesses. Li et al. (2020) investigated how digital technologies influence economic and environmental performance in the new era of I4.0. They state that digital supply chain platforms mediate the effects of digital technologies on both economic and environmental performance. Finally, Gregori and Holzmann (2020) developed a sustainable business model to explore how sustainable entrepreneurs adopt digital technologies in their business models to create social and environmental value. Table 1 presents a summary of the works contributing to the theoretical background, the main concepts covered and how they relate to the aims of this study.

As Table 1 indicates, the above-discussed literature mostly contributes general theoretical knowledge. This analyses the impacts of I4.0 on cleaner production practices with a special focus on the societal impacts of responsible environmental management in the context of family businesses in an emerging economy. The significance of sustainability for the improvement of society needs businesses to make significant efforts to achieve this goal. In this context, family businesses need to take responsible leading roles to develop the social and environmental effects in order to continue maintaining or creating competitiveness. However, due to the rapidly changing business environment and technological improvements such as I4.0, cleaner production processes have become more complex (Chen et al., 2020). In this study, we consider family businesses engaged in cleaner production as systems, which in turn are integrated into highly dynamic and variable environments in order to ensure long-term sustainability (Olson et al., 2003; Barbosa et al., 2020; Marques et al., 2020). Therefore, cleaner production processes within businesses are affected by various inter-related parameters; it is difficult to predict how each of these components influences the system's behaviour over time. As such, environmental sustainability and digitisation in family businesses should be addressed through a holistic approach by revealing the relationships between these parameters and their respective impacts (Isensee et al., 2020). Therefore, the system dynamics model is suggested as a research methodology in this paper.

3. Research methodology

System dynamics were introduced by Forrester (1961) as industrial dynamics in the mid-1950s as an approach to understanding complex macroeconomic dynamics. In later years Collins (1974) and Sterman (1991, 2001) applied their principles to various types of systems such as marketing, management and supply chains. System dynamics is a method to assess complexity and changes over time. It enables observing the results of long-term complex interactions and gaining insight into these relations. This method is useful for dealing with many parameters that affect the system. However, when the number of parameters is increased, the system becomes even more complex. Therefore, understanding and analysing the system become difficult.

From a system thinking perspective, it is necessary to see the big picture when planning any changes due to the non-linear structure of systems; even small changes in individual components can have major consequences on the whole (Ekinci et al., 2020; Ruutu et al., 2017). Some advantages of this approach include the ability to take a holistic perspective to analyse the long-term behaviour and interactions of complex, constantly changing components within the system to assess future impacts (Forrester 1961; Sterman, 2001; Kreng and Wang, 2013). Besides, system dynamics modelling enables investigating the behaviour of constantly changing constituents of the system, analysing the system with a holistic view and systems perspective by presenting and explaining the possible long-term effects of the system behaviours.

In the context of this study, a system dynamics approach provides an understanding of a business's external and internal relations. System dynamics deal with complex models by investigating the dynamic nature of innovation management and focusing more on processes (Kreng and Wang, 2013). Hence, the insights gained through the analysis increase performance and capture opportunities outside the firm to foster competitive advantage (Wang and Lai, 2020).

Table 1
Summary of the Theoretical Background.

Author(s)	*Key Concept(s)*	*Study Aims*	*Key Findings*
Stock and Seliger (2016)	Sustainable manufacturing and I4.0	Presenting opportunities of I4.0 in sustainable manufacturing	Opportunities of sustainable manufacturing in I4.0 are presented for macro and micro perspective. Macro perspective includes business models and value creation networks. Micro perspective includes human, organization, process and product aspects.
De Man and Strandhagen (2017)	Sustainable business models and I4.0	Proposing a research agenda for how I4.0 can be used to develop sustainable business models	A research agenda that includes topics including delivering a value proposition, supply chain management, customer and financial justification for a sustainable business model is proposed.
De Sousa Jabbour et al. (2018a)	Sustainable manufacturing and I4.0	Presenting arguments and a framework for integration of I4.0 and environmentally sustainable manufacturing	An integrative framework that includes twelve research ideas and explains the synergy between I4.0 and sustainable manufacturing is presented.
De Sousa Jabbour et al. (2018b)	Circular economy and sustainable operations and I4.0	Revealing the potential benefits of I4.0 technologies for circular economy strategies by addressing sustainable operations	The relationship between I4.0, circular economy and sustainable operations management is presented by the ReSOLVE model. In addition, the research agenda for integration of I4.0 and circular economy is developed.
Kamble et al. (2018)	Sustainable manufacturing and I4.0	Proposing a sustainable I4.0 framework	A sustainable I4.0 framework that includes technologies of I4.0, process integrations between human-machine and shop floor-equipment, sustainable outcomes and I4.0 principles is presented.
Lin (2018)	Recycling, circular economy and I4.0	Proposing a smart production approach to empower I4.0 in the glass recycling industry	The customer experience-based product design approach in the glass recycling industry is developed to support the circular economy in I4.0.
Nascimento et al. (2019)	Circular economy and I4.0	Exploring the integration of I4.0 technologies and circular economy practices	A circular model for reusing scrap electronic devices that integrate web technologies, reverse logistics and additive manufacturing is recommended.
Tsai (2018)	Green production planning and control and I4.0	Discussing I4.0 technologies to achieve green production planning and control	A mathematical decision model with constraints of activity-based costing and theory of constraints is developed and integrated with I4.0; it can be used for evaluating environmental impacts.
Dev et al. (2019)	Green products and reverse logistics and I4.0	Modelling reverse logistics and examining green product diffusion dynamics under I4.0	An information technology framework for reverse supply chain management under a dynamic green product diffusion environment is developed.
Kerin and Pham (2019)	Remanufacturing and I4.0	Reviewing the applicability of I4.0 technologies in remanufacturing	Twenty-nine research ideas are presented to explore the relationship between I4.0 technologies and smart remanufacturing.
Rajput and Singh (2019)	Circular economy and I4.0	Connecting I4.0 and the circular economy in the context of the supply chain by presenting enablers and barriers	Artificial Intelligence, Service and Policy Framework and Circular Economy are identified as important enablers; the most important challenge is found to be Interface Designing and Automated Synergy Model
Varela et al. (2019)	Lean manufacturing and sustainability and I4.0	Measuring effects of lean manufacturing and I4.0 on sustainability	Results of the survey indicated that I4.0 has a strong correlation with sustainability pillars; on the other hand, lean manufacturing does not have such a correlation.
Wang and Wang (2019)	Recycling, recovery and remanufacturing and I4.0	Introducing I4.0 enablers in the WEEE remanufacturing industry	In order to support manufacturing and remanufacturing processes throughout the life cycle, a novel digital twin-based system for WEEE is developed.
Kamble et al. (2020)	Sustainable manufacturing, lean manufacturing and I4.0	Investigating the indirect effects of I4.0 technologies on sustainable organisational performance with lean manufacturing practices as the mediating variable	Significant direct and indirect effects of I4.0 on sustainable organisational performance are suggested and the existence of lean manufacturing process as a strong mediating variable is confirmed.
Machado et al. (2020)	Sustainable manufacturing and I4.0	Identifying how sustainable manufacturing research contributes to develop an I4.0 agenda and understanding the link between the two concepts	Developing sustainable business models, sustainable and circular production systems, sustainable supply chains, sustainable product design and policy development are presented in the I4.0 agenda to achieve sustainable goals.
Rosa et al. (2020)	Circular economy and I4.0	Investigating how I4.0 affects the circular economy and presenting an innovative framework for classifying this relationship	A framework for highlighting the links between I4.0 and circular economy; introducing future research directions is developed.
Yadav et al. (2020)	Sustainable supply chain and circular economy and I4.0	Developing a framework for overcoming sustainable supply chain management challenges through I4.0 and a circular economy	Twenty-eight sustainable supply chain management challenges and twenty-two solutions are identified for the I4.0 environment. Results showed that managerial, organizational, and economic challenges are the most critical in sustainable supply chain adoption.
Graafland et al. (2020)	Cleaner Production	Analysing the impacts of cleaner production and investigating family business relations with cleaner production	The difference in environmental performance between family-owned and non-family-owned enterprises; it increases for small companies managed by a combination of family and non-family members.
Barbosa et al. (2020)	Sustainable Strategic Management Model	Creating a management model for small businesses' sustainable activities	Sustainable Strategic Management - GES model is developed, with support of strategic management, triple bottom line and balanced scorecard for small businesses.
Isensee et al. (2020)	Environmental Sustainability, Organisational Culture and Digitalisation	Investigating the relationship between environmental sustainability, organisational culture and digitalisation via systematic review	The Belief-Action-Outcome framework is presented with key dimensions and links between concepts revealed.
Li et al. (2020)	Environmental sustainability in the era of Industry 4.0	Exploring how digital technologies influence economic and environmental performance in the new era of I4.0	

(*continued on next page*)

Table 1 (*continued*)

Author(s)	*Key Concept(s)*	*Study Aims*	*Key Findings*
			Digital supply chain platforms mediate the effects of digital technologies on both economic and environmental performance.
Gregori and Holzmann (2020)	Digitalization Business model	Investigating how sustainable entrepreneurs embed digital technologies in their business models to leverage social and environmental value creation	Sustainable business models are developed; investigation of how digital technologies enable novel configurations of sustainable business model components.

System dynamics modelling begins with a description of the system under study and a determination of its boundaries and components. After defining system parameters, the inter-relationships between these parameters is presented via causal loop diagrams (di Nola et al., 2018). Interactions between elements within the system are presented by negative or positive feedback loops, the analysis of which demonstrates the overall behaviour of the system (Yuan and Wang, 2014; Ricciardi et al., 2020). Following this stage, the causal loop diagram is converted into a stock and flow diagram, with Stella software used to estimate parameter values. In the next section, the case study and steps of implementation are discussed.

4. Investigating impacts of I4.0 on responsible environmental and societal management in the packaging industry: a case study

Implementation is conducted in the packaging sector to analyse the impacts of CO_2 emissions and total packaging waste recovery on family businesses in the packaging sector in Turkey. Analysis has been carried out in the packaging sector since in general, family businesses dominate in this sector. Family can be considered as very important for both the societal and economical systems in Turkey. The rate of family business rises up to 95% in Turkey, significantly higher than the world average (Arman, 2001). Family plays a significant role in the Turkish economy and is also considered to be an important factor in society (Cetin, 2020). Therefore, analysing family characteristics and dynamics is vital to determine family firms' effectiveness and technological developments. Besides, recycling of packaging waste plays a significant role in providing a circular economy; packaging should be reused, recovered and recycled; sustainable solutions should be developed in the packaging sector (Hahladakis et al., 2018; Abejón et al., 2020). Moreover, the packaging sector needs effective ways to reduce environmental impacts and to increase societal impacts. GHG emissions and waste material after package use need to be tackled. New innovations and new design are needed to adapt to creating circular economy solutions in the packaging sector (Escursell et al., 2021).

Thus, this study proposes a system dynamics approach to evaluate the impacts of I4.0 on responsible environmental management and societal impacts within cleaner production practices in order to contribute to sustainable family businesses in the packaging sector. While the secondary data source is used for the sector macro values such as Global Competitive Index, Quality of Scientific Research Institutions etc., the packaging sector data is used for the sector-specific micro values, such as CO_2 emissions and total packaging waste recovered. These parameters are discussed in Section 4.2. In the following sections, steps of system dynamics modelling, which include determining model parameters and their scores and developing system dynamics model and results, are presented.

4.1. Model parameters

The primary aim of the model presented in this study is to evaluate the impacts of I4.0 on responsible environmental management and societal impacts within cleaner production practices in order to contribute toward increasing the sustainability of family businesses. The SD model has been developed to observe the behaviour of key variables over time by examining the current cause-effect relationships between them and identifying the determinants of ethical behaviour and I4.0 practices on environmental management. Various parameters were used to analyse societal and economic impacts of I4.0 within cleaner production practices, with levels of CO_2 emissions and total packaging waste recovered observed for the years 2013–2018. Parameters and data were obtained from the World Economic Forum's annual Global Competitiveness Reports (Klaus, 2016; Sala-i-Martín and Schwab, 2014; Schwab and Sala-i-Martín, 2016; Schwab et al., 2016; Schwab et al., al.,2018).

Moreover, productivity level, a significant indicator of the level of economic welfare, is the main driving force of growth and development. In other words, high productivity levels are required for countries and businesses to sustain more competitive economic growth (World Economic Forum, 2017–2018). Therefore, the global competitive index of countries has become an important indicator. Besides, each country's global competition index is influenced by multiple interacting variables. For instance, strong innovation capacity depends on healthy, skilled and well-educated employees; the quality of institutions is influenced by the extent of staff training and the development of strategies and policies, while absorbing new technologies is necessary to enhance the capacity for innovation (Prasetyoa and Siswantarib, 2020; Strobl et al., 2020). Therefore, variables discussed in the context of cleaner production and I4.0 implementation need to be analysed with a dynamic approach that includes inter-relationships rather than presenting them separately.

Besides, countries and companies are increasingly adapting I4.0 to move their processes and products toward sophisticated, innovation-driven approaches. Business sophistication can increase with the help of a successful network of companies and countries. To effectively manage a complex network, it is necessary to consider local supplier quality; this plays a substantial role in enhancing innovation in the production and business processes (Calabrò et al., 2019). In addition, countries aim to achieve a competitive advantage by implementing cleaner production practices that reduce CO_2 emissions and total waste amounts.

Therefore, technological innovation plays an important role in the survival of family companies in the I4.0 era. As the entrepreneurship environment becomes more complex, supply chains must be well-designed and efficient so that they can be managed effectively (Youssef et al., 2021; Kraus et al., 2020). In addition, a company needs a trained workforce that can quickly analyse and evaluate changes in the external environment and seize opportunities to benefit the firm (Wu et al., 2010). Moreover, company spending on R&D is increased by developing investment decisions on the innovation of process and product using I4.0 technologies. The implementation of I4.0 in production processes increases firm-level technology absorption due to increasing company spending on R&D (Prasetyo and Siswantari, 2020; Švarcová et al., 2019).

The ethical behaviour of firms is another significant social indicator of I4.0; it has been related to fatal work accidents in this study. The parameters used in the model are listed and defined in Table 2.

Based on the parameters proposed, the next section discusses the scores of these parameters to evaluate the impacts of I4.0 on responsible environmental management and societal responsibility within cleaner production practices in the context of the family business.

Table 2
Proposed parameters in the model.

Parameters	*Descriptions*
Global Competitive Index:	According to Global Competitiveness Reports, competitiveness can be defined as a set of factors that determine the productivity of a country. This concept includes varying static and dynamic components such as education and training, technological progress, production sophistication and market efficiency, all of which influence each other (World Economic Forum, 2012–2013).
Quality of scientific research institutions:	The quality of institutions has a strong influence on competitiveness and growth, as research contributes toward improving production processes and developing policy and strategies (World Economic Forum, 2012–2013).
Extent of staff training:	Well-trained personnel who can carry out complicated tasks and rapidly adapt to changing environments are needed due to increasing competition and developing technologies (Ramingwong et al., 2019).
Labour market efficiency:	Efficient labour markets can be achieved by increasing workplace incentives and ensuring equality between men and women in the work environment (Pereira and Romero, 2017).
Technological readiness:	This is amongst the most important I4.0 parameters. The importance of technology is increasing in today's globalising world. Businesses need to adopt and integrate advanced production processes in order to increase their productivity and gain a competitive advantage (Lin et al., 2018).
Production process sophistication:	In order to achieve high efficiency in the production of goods and services, firms should effectively manage their production processes and all business networks in their market. Businesses should have quality supply networks to deal with these complex production processes (Salas-Velasco, 2018).
Local supplier quality:	Local supplier quality is a very important parameter to manage production process sophistication (Zhang et al., 2019).
Capacity for innovation:	Innovations consist of both training for qualified personnel and investments in new technologies (Müller et al., 2020).
Company spending and R&D:	This refers to the expenditures that a company devotes to research and development in order to realise technological cooperation between universities and industry and create high-quality scientific research institutions to develop new technologies that can produce basic information (Svarcova et al., 2019). R&D spending, technological innovation and investment in innovation are important targets of family firms' resources (De Massis et al., 2013).
Availability of latest technologies:	Perception and technological readiness depend on the availability of new technologies (Dalenogare et al., 2018; Kearney, 2018).
University-industry R&D collaborations:	Transferring solutions from industry to the academy by providing research and training (Scandura, 2016).
Local availability of specialised training services:	Keeping up with changing dynamics and increasing productivity is only possible with employees who constantly improve themselves; this is realised by specialised training (Ramingwong et al., 2019).
Fatal work accidents:	This refers to accidents occurring during work that result in death. This parameter is directly impacted by firms' ethical behaviour in ensuring adequate protection for their workers (Kahraman et al., 2019).
Transparency of government policymaking:	Government policies are transparent, understandable and enforceable and should be presented in an accessible structure (Relly and Sabharwal, 2009).
Pay and productivity:	It is necessary to analyse the resources and capabilities of the company to ensure sustainability in terms of productivity and performance. (Parker and Lawrence, 2020). As measured in the Global Competitiveness Reports (World Economic Forum, 2012–2013), competitiveness is directly related to a country's productivity index.
Foreign direct investment (FDI) and technology transfer:	FDI decisions of family businesses, the growth of their firms and their strategies to achieve competitive advantage should be taken into account. To achieve this, technology transfers are a very significant indicator to cope with the complexity of foreign businesses (Wei et al., 2020).
Ethical behaviour of firms:	One of the most important parameters amongst the social indicators, ethical behaviour refers to honesty and transparency in relations with stakeholders (Crossan et al., 2013). Family businesses aim to investigate the effects of their activities both on the individual firm and on the wider community (Astrachan et al., 2020). Therefore, environmental responsibility and environmental process are directly related to the ethical behaviours of companies (Singh et al., 2019).

4.2. Parameter scores

The above-defined parameters were used to analyse indicators for global competitiveness in Turkey from 2013 to 2018. The scores of individual firms were incorporated to measure national competitiveness. The key data for the report was obtained through the Executive Opinions Survey conducted with more than 160 Partner Institutes at the national level around the world. In order to determine country scores, variable scores were converted to a 1–7 scale by taking the survey results into consideration. Fatal work accident parameter values from 2013 to 2018 were collected from Sustainable Development Indicators from the Presidency of Strategy and Budget of Turkey database (2020) and the Turkish Statistical Institute (TUIK, 2019;Sustainable Development Indicators, 2018). Table 3 presents Turkey's scores for all social and economic parameters.

Table 3
Parameter scores for Turkey from 2013 to 2018.

YearsParameters	2013	2014	2015	2016	2017	2018
Quality of scientific research institutions	3.4	3.7	3.9	3.6	3.3	3.3
Local availability of specialised training services	4	4.2	4.4	4.2	4	4
Extent of staff training	4	4	3.8	3.6	3.5	3.5
Firm-level technologies absorption	5.3	5.3	5.2	5.2	4.8	4.8
Company spending on R&D	3.2	3.1	2.9	3.1	3.3	3.3
University-industry R&D collaborations	3.6	3.9	3.7	3.7	3.5	3.5
Technological readiness	4.3	4.1	4.3	4.1	4.2	4.4
Transparency of government policymaking	4.7	4.6	4.4	4.4	4.5	4.5
Ethical behaviour of firms	4	4.2	4	3.6	3.6	3.6
Capacity of innovation	3.4	3.8	3.7	3.8	4.1	4.1
Labour market efficiency	3.8	3.7	3.5	3.5	3.4	3.4
Local supplier quality	4.7	4.7	4.7	4.5	4.6	4.6
Production process sophistication	4.4	4.6	4.5	4.3	4.2	4.2
Pay and productivity	4.2	4.1	3.8	3.8	3.7	3.7
FDI and technology transfer	4.7	4.9	5.1	4.7	4.5	4.5
Global competitive index	4.5	4.5	4.5	4.4	4.4	4.4

Table 4
Fatal work accidents.

YearsParameters	2013	2014	2015	2016	2017	2018
Fatal work accidents (Frequency rate per 100,000 employees)	8.3	9.4	6.9	7.5	8.2	7.9

fatal work accidents, technological readiness, local supplier quality and firm-level technology absorption indicators were included as social variables; CO_2 emissions and total packaging waste recovered were used as environmental responsibility indicators. Figs. 2, 3 and 4 illustrate the impacts of ethical behaviour of firms, innovation and social impacts of technological readiness, respectively.

Table 5
Total packaging waste recovered.

YearsParameters	2013	2014	2015	2016	2017	2018
Total packaging waste recovered (tonnes)	2300,345	2422,521	2530,664	2226,273	2198,845	2375,518

Tables 4, 5 and 6 summarise data on fatal work accidents and Turkey's CO_2 emissions; this was obtained from the European Commission's statistics database; data on total packaging waste was obtained from the Official Statistics Program Report (2017–2021) published by TUIK (2019).

After obtaining parameter values in the system, a causal loop diagram is created to indicate relationships between parameters.

4.3. Causal loop diagram of model

After defining system boundaries and parameters, a causal loop diagram was created to analyse the reinforcing and balancing loops between related variables and to develop the system dynamics model (Cernev and Fenner, 2020). The causal loop diagram is based on the variables described in Section 4.1 and is presented in Fig. 1. While black arrows indicate reinforcing effect of variables, the red arrows indicate balancing loops in the diagram.

4.4. Results and findings

CO_2 emissions and total packaging waste recovered from 2013 to 2021 were calculated using a STELLA model. Ethical behaviour of firms,

Table 6
Total CO_2 emissions.

YearsParameters	2013	2014	2015	2016	2017	2018
CO2 emissions (thousand tonnes)	47,065	48,58	51,492	51,628	50,738	54,644

In Fig. 2, it can be observed that when ethical behaviour decreased from 0.85 to 0.55 from 2013 to 2015, fatal work accidents increased from 6.5 to 9.5. In contrast, when companies increased their ethical behaviours from 2015 to 2017, it can be seen that fatal work accidents substantially decreased. Similarly, when the ethical behaviour variable decreased from 2013 to 2017, CO2 emissions increased by 50%; there was also a substantial rise in total packaging waste. With the increase in ethical behaviours from 2015 to 2017, we see a corresponding decrease in total packaging waste; however, CO2 emissions continued to rise, although this variable is again inversely correlated with ethical behaviours from 2017 onward. Overall, we see a trend of fluctuating ethical behaviour that is inversely correlated with fatal work accidents, whereas total packaging waste has remained stable since 2018. CO2 emissions have remained essentially stable since 2019 following a more-or-less steady rise.

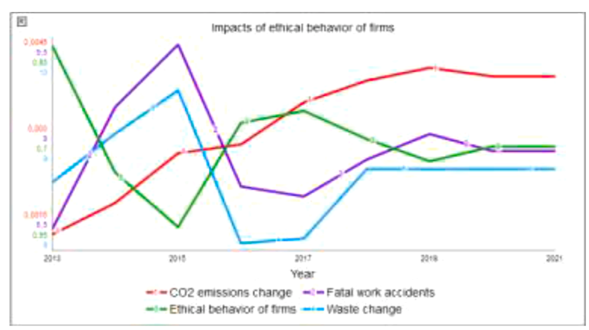

Fig. 2. Impacts of ethical behaviour of firms.

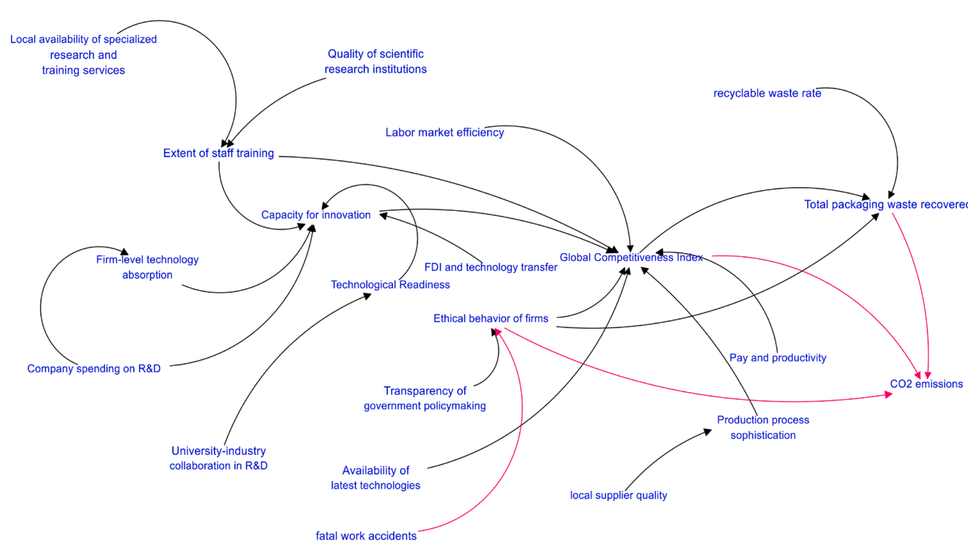

Fig. 1. Causal loop diagram of the model.

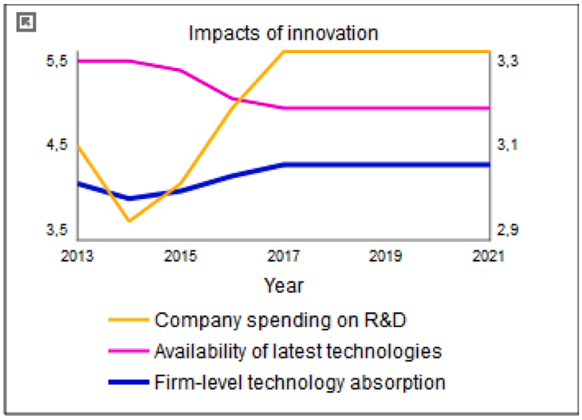

Fig. 3. Impacts of innovation.

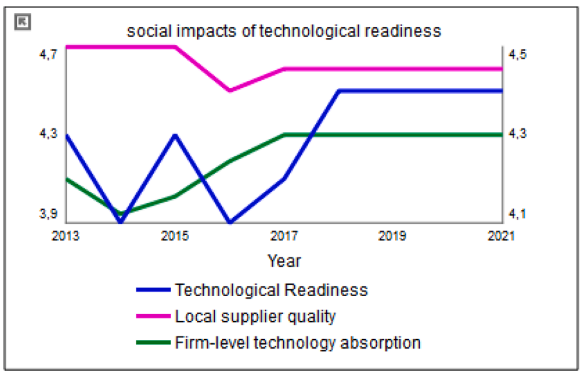

Fig. 4. Social impacts of technological readiness.

In order to evaluate the impacts of innovation, company spending on R&D, availability of the latest technologies and firm-level technology absorption, indexes are analysed in Fig. 3. As expected, firm-level technology absorption increased by 6.97% from 2015 to 2017; R&D investments rose by 9.27% during the same period. However, we see an inverse correlation between technological availability and firm-level technology absorption from 2013 to 2017. All three variables appear to have remained at steady levels since 2017.

Fig. 4 illustrates the social impacts of technological readiness. From 2015–2017, we see a generally positive correlation between technological readiness and local supplier quality; however, the relationship between these variables and firm-level technology absorption, which rose steadily from 2015 to 2017, is less clear. Following some fluctuations, technological readiness began rising from 2016 to 2018 before remaining steady in the years since, whereas the other two variables appear to have plateaued since 2017.

5. Discussions and implications

The main aim of this study was to analyse the impacts of I4.0 on responsible environmental management within cleaner production practices with a specific focus on CO_2 emissions and total packaging waste recovered. Examination has also been made of the societal impacts of I4.0 with a focus on ethical behaviour of firms, fatal work accidents, technological readiness, local supplier quality and firm-level technology absorption indicators. The results indicate that ethical business development contributes to the effective management of corporate social responsibility and environmental management systems. Besides, the model results evince a clear positive correlation between technological readiness and local supplier quality. Improving local supplier quality is critical in dealing with complex production processes; coping with these production processes can be achieved with a strong technological infrastructure. However, the apparent inverse correlation between the availability of new technologies and firm-level technology absorption requires more attention.

This study advocated that the continued survival of family firms in the packaging industry in the current production environment depends on the integration of I4.0 and cleaner production approaches while maintaining ethical and environmental principles for sustainable business models. In line with our results, Gregori and Holzmann (2020) stated that digitalization and the logics of sustainability clarify and advance the link between these concepts in an entrepreneurial context. The findings show that awareness and education on sustainability issues need to be increased in order to create sustainable businesses. Similar to this study, Li et al. (2020) analysed how digital technologies influence economic and environmental performance in the new era of I4.0 with results showing that digital technologies improved quality of environmental and economic performance. Moreover, Singh et al. (2019) found that environmental ethics have an effect on environmental training and performance to gain competitive advantage. In order to implement sustainable environmental management practices, organisations should embrace environmental ethics by providing benefits for the wider society. Similarly, Painter et al. (2019) suggested that the three main dimensions of the concept of sustainability, namely economic, social and environmental balance, can be achieved with the implementation of more ethical and sustainable practices.

Such arguments are partly reflected in the findings of this study, which show a correlation between reduced ethical behaviour and increases in fatal work accidents and total packaging waste and vice-versa. However, the relationship between ethical behaviour and CO_2 emissions was mixed; although, an inverse correlation between these two variables was observed from 2013 to 2015 and 2017–2021.

Several implications can be derived from the findings. As theoretical implications, academia can use this study in the analysis of sustainability and the analysis of environmental and social effects of I4.0. Besides, this structure can be examined for other sectors and can be used in sector-based studies. To enhance the impact of I4.0 on responsible environmental management within cleaner production practice, policymakers and managers should make long-term strategic decisions while considering both environmental and social responsibility. Policymakers can use the model presented as a tool to analyse the impacts of I4.0 on sustainability. Policymakers can use the structure that we offer in sectors dominated by family businesses. In companies dominated by family businesses, regulators should make comprehensive guidelines and take measures in matters related to reducing CO_2 emissions and waste management. Occupational accidents, one of the social impacts, stand out in this sector and urgent intervention is required. Policymakers should focus on regulations aimed at preventing occupational accidents. Besides, policymakers can offer training on environmental pollution, waste management and social responsibility to make improvements on these issues.

Moreover, family companies need to examine the effects of I4.0 on sustainability. Ethical business development has become a very important issue for managers and decision-makers. When firms and countries implement decisions and policies aimed at reducing CO_2 emissions and packaging waste, we can interpret that they have fulfilled their social responsibilities by increasing their ethical behaviour. When policymakers and managers fulfil their responsibilities towards the environment, they can also analyse firms' ethical business development behaviour by evaluating the impacts of various policies on the ethical behaviour of firms as reflected in CO_2 emissions and total recyclable waste. Social impacts can be analysed by observing correlations between ethical behaviour and fatal work accidents. Companies dominated by family members can examine their structures using the suggested process. Efforts should be made to reduce CO_2 emissions and ensure waste management. Managers can analyse the effects of I4.0 on sustainability with similar structures.

Technological investment and infrastructure are other important resources for family businesses. In the context of family businesses, employee skills and know-how should be developed through educational programs or training. Therefore, managers should implement policies with training on various topics such as environmental pollution, waste management, providing technological infrastructure and social responsibility to improve the skills and wellbeing of their employees.

6. Conclusions

Increasing I4.0 applications and investment in innovation have become critical for the survival and growth of family businesses. As a way of managing environmental problems, cleaner production involves responsibilities in the economic, environmental and social spheres. This study analysed the impacts of I4.0 on long-term environmental management, business ethics and social impacts related to cleaner production practices in family businesses in the packaging sector in Turkey. The results have shown that ethical business development and innovation management contributes to the establishment of corporate social responsibility and environmental management systems, thereby promoting sustainable family businesses in the context of I4.0.

Globalisation has led to an acceleration in companies' research and development and new product development activities. The resources of family businesses are complex and dynamic, and firms' internal characteristics and performance are significantly inter-related. Due to the increasing prevalence of I4.0 applications, cleaner production processes have become more complex, affected by various parameters. As a theoretical contribution of this study, we expanded the use of system theory and system dynamics approach to an analysis of sectors in the area where family businesses are concentrated. In addition, we expanded the analysis of the effects of I4.0 on sustainability by applying the system dynamics model and system theory approach. This framework can also be applied in other sectors, apart from the packaging sector, dominated by family companies. This study has shown the utility of analysing the dynamic relationships within cleaner production and their possible effects with a holistic systems-based approach. The model presented here is a useful tool to inform long-term strategic decisions of policymakers and managers.

A significant limitation of this study relates to the parameter determination stage of the system dynamics model; the societal impacts of I4.0 within cleaner production practices are not obvious; previous studies have not been able to explore them in-depth. Therefore, it was difficult to define the relationships between variables. Besides, different stakeholders with different points of view may introduce different assumptions in the models and therefore, a quite different picture can be created.

In future work, the proposed model can be applied to different sectors or countries. The model can be expanded by adding comparative analyses of different countries using a range of scenarios. In addition, the model can be improved by using different variables to extend the scope of cleaner production practices. The number of parameters covering social indicators can be increased. Comparisons between countries could also be researched in future work. Finally, the effects of specific digital technologies such as blockchain and big data can be investigated.

CRediT authorship contribution statement

Yigit Kazancoglu: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. **Muruvvet Deniz Sezer:** Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Yesim Deniz Ozkan-Ozen:** Conceptualization, Data curation, Visualization, Writing – original draft. **Sachin Kumar Mangla:** Writing – original draft, Writing – review & editing. **Ajay Kumar:** Writing – original draft, Writing – review & editing.

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