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Enabling the Circular Economy transition: a sustainable lean manufacturing recipe for Industry 4.0

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Abstract

Over the past 10 years, the concepts and objectives of circular economy have been increasingly detailed and become strategic issues of international, European, and national policies. However, the transition towards circular production models continues to be affected by several barriers and critical factors that make the transition difficult to achieve. The paper tries to design a relationship between sustainable production and lean production, highlighting the opportunity to invest in reverse-logistics and how Industry 4.0 system represents a breeding ground for circular economy targets application. The aim of the current study is to examine the relationships among sustainable production, lean production, and Industry 4.0 in order to evidence the need to adopt a lean methodology and Industry 4.0 technologies in a sustainable development perspective for companies. Following a holistic vision, the authors summarize the production principles and formulas, which, although in parallel, lead to similar results and therefore represent the pillars of a competitive and sustainable business. In conclusion, exploring the circular economy principles and production chain model, challenges, opportunities, and future outlooks are formulated.

KEYWORDS

business strategy, circular economy, environmental policy, Industry 4.0, stakeholder engagement, sustainable development, sustainable lean production

1 | INTRODUCTION

Pollution and the limited availability of natural resources to satisfy people's needs are causing increasingly alarming pressure upon the global ecosystem and, at the same time, dramatically determine different impacts on the costs of material and energy commodities and on the volatility of their market prices. Here emerges a critical condition to be managed by any companies involved in planning and programming of the materials, energies, and fuels flowing throughout its productive system. In this competitive business scenario, the question arises as to whether it is possible or even necessary to manage the adverse effects of consumption of unsustainable resources and production models?

The concept of sustainable production is not so new and dates back to quite some time by now. It was, indeed, Elkington (1994, 1998a, 1998b)—one of the first scientists encouraging companies to reconsider their value creation activities in a multidimensional perspective, that integrates economic aspects, for example, profit, revenues, and economic returns on capital invested, that are a classic in the economic management of industries, with the environmental and social dimensions in an integrated framework called “triple bottom line” (TBL). Sustainability exists only when those three dimensions are

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holistically accomplished. In this sense, companies should carry out environmental life-cycle and socioeconomic assessments of their production systems, according to the TBL model. Doing so, this will allow them to improve the quality and sustainability of products they deliver and, in turn, of the downstream phases in which those products are utilized to produce more complex commodities, in an industrial symbiosis perspective. However, even today, companies have difficulty in having a clear and complete vision of the impact of their sustainable policies and strategies because there is no single and universal standard for calculating TBL performance (Helleno et al., 2017; Henao et al., 2019; Slaper & Hall, 2011).

In the last decade, in March 2010, the European Commission presented its "Europe 2020" strategy, with the main aim of putting an end to the excessive exploitation of natural resources, and to the disparity in the availability of those resources in different geographical areas. "Europe 2020" was a 10-year strategic plan aimed at a structural transformation of the economic system and capable of facing the European economic crisis (European Commission, 2010).

Later, between September 25 and 27, 2015, the platform, "Transforming our world: the 2030 Agenda for sustainable development", was launched for the creation of a global action to favor sustainable development for people and the entire planet, while assuring the necessary prosperity conditions. This is also known as the "3P Agenda" and represents the document adopted by the Heads of State and Government, which establish the commitments for sustainable development to be achieved by 2030, identifying 17 goals (SDGs) and 169 related targets (United Nations, 2015).

In recent years, sustainable production has been strongly linked to circular economy (CE) principles that have taken a guiding role for the formulation of sustainable policies. According to Geng and Doberstein (2008), this concept brings together different strategies and approaches aimed at the following:

- increasing economic efficiency;
- adding value to businesses by maximizing energy, materials, and other resources;
- reducing the environmental impact of anthropic activities (in terms of exploitation of resources and emission of pollutants).

CE can be considered as an industrial economy that is oriented to sustainability (Ghisellini et al., 2016). Several key actions aimed at improving the economic and environmental performance of used resources are related to introducing CE on an industrial scale through adoption of closed loops for valorization of wastes and their recovery into material and energy commodities (Kalmykova et al., 2017).

In this sense, the research gives an attempt in expanding the lean production (LP) theory including environmental aspects and in contributing to highlighting the positive role of Industry 4.0 (I. 4.0) as an essential environment where redesign flows, processes, and targets. Therefore, the goal of the present paper is to represent sustainable supply chain as a product of the simultaneous engagement of lean strategies and emerging technologies, using reverse logistics (RL) as a mean to achieve circularity and sustainability.

Indeed, I. 4.0 represents the manufacturing scenario where various sustainable production strategies are being developed.

Hence, in this scenario, we introduce the research question Q1: *How to rethink the production model in a circular economy-oriented perspective at micro level*, also compliant with the goals of the UN Agenda 2030 (United Nations, 2015)?

This study was conducted to explore CE principles in a way to point out a practical business-oriented strategy that helps implement sustainable production paths.

The study reports upon findings from a theoretical work designed to attempt formulating key questions that need to be addressed to drive production competitiveness and sustainability in a way that they face the current challenges of satisfying the needs and the demands for food of an ever-growing population.

The article is divided into six sections. After Section 1, there is an overview of the strategies and tools to achieve satisfactory levels of application of CE models. In Section 2, CE principles and sustainable production policy are addressed. Moreover, the focus has been set upon the LP theory and tools, as one valid methodological support for a new strategy of competitive eco-business. Section 3 highlights ways for RL to answer the urgent need to translate the CE principles into actions. As for conclusions, Sections 4 and 5 carry out challenges, opportunities, and future outlooks within the emerging I. 4.0 environment.

2 | THEORETICAL FRAMEWORK

The manufacturing sector plays multiple key roles, from introducing innovation in production process and in terms of new or improved products, to the change in knowledge, job skills, market/consumer behaviors, as well as in worldwide adoption and promotion of sustainable production strategies and practices (Shankar et al., 2017; Tan et al., 2011). The concept of sustainability—expressed in the production model—incorporates objectives such as the reduction of consumption of resources and energy, selection of production processes with low environmental impact, and the development of eco-friendly products (Govindan et al., 2015; Schrader & Thøgersen, 2011).

In order to summarize the definitions elaborated by the notable scholars, a table has been built, in which definitions of circular economy, lean production, Industry 4.0, Reverse Logistics, and Sustainable Lean Production are gathered Table 1.

It is crucial to highlight that sustainable production promotes sustainability throughout supply chain and, through the launch of sustainable products, the development of a community of sustainability-oriented end users (Gupta, 2016; Gupta et al., 2016; Smith & Ball, 2012) that could be representatives of a new socio-technical system, becoming the leading infrastructure to support a green interaction between people and technology (Geels, 2011). Governments around the world promote financial and tax initiatives to accelerate the transition towards sustainable production practices and, subsequently, to favor increase of global growth and competitiveness (Moktadir et al., 2018; Sheldon, 2014).

TABLE 1 Circular Economy, Lean Production (LP), Industry 4.0 (I.4.0), Reverse Logistics (RL) and Sustainable Lean Lroduction (SLP) definitions, extracted from reference list

Topic	Definition	Reference
Circular economy	CE implies the implementation of closed loops of materials that generates the achievement of an increased economic efficiency, adds value to businesses, and reduces the environmental impact.	Geng & Doberstein, 2008
	By considering CE as closed-loop supply chains, it has to be viewed as an innovative path to create value over the whole life cycle of the product. Furthermore, reverse logistics processes, through redesigning and dematerializing of products, valorize process flows.	Guide & Van Wassenhove, 2009
	CE is focused on the redefinition of growth. It implies the decoupling of economic activity from the consumption of finite resources.	Ellen MacArthur Foundation, 2013a, 2013b, 2013c (Circular Economy Overview)
	CE is a way to optimize the use of resources, add value and regenerate wastes, and increase both corporate and consumers' responsability. In other words, it accomplishes the goal of sustainability.	Ghisellini et al., 2016
	The CE notion embraces optimization of natural resources, reusing and recycling them in production processes, eco-design of products, waste minimization, and the extension of their end of life.	Kalmykova et al., 2017
	CE concept concerns an "economic system that replaces the concept of "end of life" with the reduction, reuse, recycling and recovery of materials in the production/distribution and consumption processes. It operates at the micro level (products, companies, and consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond), with the aim of achieving sustainable development, simultaneously creating environmental quality, economic prosperity, and social equity, for the benefit of current generations and future. It is empowered by new business models and responsible consumers."	Kirchherr et al., 2017
	The incipit of the European «Circular Economy Action Plan» states that «*Building on the single market and the potential of digital technologies, the circular economy can strengthen the EU's industrial base and* ***foster business creation*** *and entrepreneurship among SMEs. Innovative models based on a closer relationship with customers,* ***mass customisation****, the* ***sharing and collaborative economy****, and powered by* ***digital technologies****, such as the internet of things, big data, blockchain and artificial intelligence, will not only accelerate circularity but also the* ***dematerialisation*** *of our economy and make Europe* ***less dependent on primary materials***».	European Commission, 2010. Europe 2020: A strategy for smart, sustainable and inclusive growth.

(Continues)

TABLE 1 (Continued)

Topic	Definition	Reference
	CE can be considered as an enabler of economic, environmental, societal benefits. This is due to the adoption of recovery, reuse, recycling, sharing and collaboration practices which redefine the corporate business model.	Moktadir et al., 2020
Lean production	The definition of LP evolved through three stages. In the first one, it was considered a set of tools (like Kanban; in the second one, a manufacturing method (like JIT); in the third, it is assumed to be a general management philosophy based on the reduction of wastes and lead times.	Koskela, 1992
	Lean production is a strategy based on 5 key elements, value, value flow, flow, pull and perfection. It aims at the elimination of waste, satisfaction of customer needs, generation of value and value flows, striving for excellence, guarantee of reliability in all production phases and continuous improvement in all processes	Womack & Jones, 1996
	The concept of LP is intended as lean transformation and means to do more with less. For the first time, beside the eight wastes (defects, excess processing, overproduction, waiting, inventory, transportation, motion, and nonutilized talent), energy is addressed as the ninth waste.	Sciortino et al., 2009
	LP is based on Toyota production system principles and is a strategy or philosophy that aims at minimizing waste and improving the company's performance.	Ioppolo et al., 2014
Industry 4.0	Industry 4.0 contributes to forecast customer requests and manages the entire supply chain. Technological innovation has a key role in developing competitive companies' skills to remain on the market.	Flint et al., 2005
	Industry 4.0 has tremendous potential. It enables dynamic businesses and flexible engineering processes. New technologies gain continuous resource productivity and efficiency, help to manage complexity and provide and guarantee transparency.	Kagermann et al., 2013
	Industry 4.0 represents the fourth industrial revolution and has significant impact on the production and operation management. In fact, it allows real-time planning of production plans and focuses on their optimization and flexibility.	Sanders et al., 2016
	Industry 4.0 provides in depth analysis of autonomous systems and cutting-edge design of human-machine interactions.	Klumpp, 2017
	Industry 4.0 represents an integrated system of information and knowledge that improves productivity, enables	Garcia-Muiña et al., 2019

TABLE 1 (Continued)

Topic	Definition	Reference
	sustainability, and optimizes management of process flows.	
	LP paradigm is a management approach that focuses on the elimination of wastes and the improvement of production and quality.	Taddeo et al., 2019
	Industry 4.0 entails digital transformation of companies and end user market.	Ghobakhloo, 2020
Sustainable lean production	"Green" or sustainable supply chain operates in sociotechnical systems. To evaluate their positive impacts and sustainability transition, they need to be empirically assessed.	Papachristos, 2014
	The implementation of sustainability in supply chain management plays a key role in keeping up with corporate competitiveness. Furthermore, the integration of a lean approach could contribute to the competitive advantage of companies.	Brandenburg & Rebs, 2015
	The implementation of sustainability principles in LP leads to an environmental improvement in enterprises process flows. SLP is the result of interaction between lean principles and sustainability paradigm.	Zhang et al., 2020
	A SLP featured as lean-green manufacturing is a new practice that lack a clear research definition. Despite this, there is unanimous consensus on the fact that a lean-green approach improves performances in the triple bottom line perspective simultaneously.	Abualfaraa et al., 2020
Reverse logistics	RL succeeds in achieving the minimization of waste through eco-effectiveness and "cradle to cradle" design of products.	Braungart et al., 2007
	In RL, waste is reintroduced into the same or another production cycle as a second raw material to create regenerative and circular systems.	Howard et al., 2018
	RL implies recovery operations and plays a key role in the sustainability paradigm. It includes measuring environmental impacts in order to minimize waste and reduce the use of energy in distribution strategies. RL should be focused on circular supply chain designed in such a way to restore and regenerate resources in industrial process flows and produce zero waste.	Farooque et al., 2019
	RL is perceived as an environmentally friendly practice. It is due to the outstanding reduction of sourcing costs of used materials in comparison with new ones.	Pushpamali et al., 2021

Source: authors' elaboration.

Indeed, promoting industrial-scale sustainability has become a central goal for national governments worldwide. In this regard, managers are facing the one big challenge to expand the concept of CE to productive company networks, so contributing to creating efficient interconnection models within a symbiotic industrial ecosystem and optimizing the market supply with a sustainable orientation of economies of scale (Simboli et al., 2015).

It is essential to consider that policies supporting the development of industrial sustainability must necessarily combine certain aspects of sustainable production that relate to different European strategies, for example, Horizon 2020, the 9th Framework Program-FP9 and other sectoral policies (European Parliament and Council of the EU, 2019).

Therefore, the implementation of adequate governmental policies plays a strategic role as a support to eco-innovation, promoting continuous pro-active collaborations between industrial companies (Aquilani et al., 2018).

In the last decade, the new vision of sustainability is represented and developed through the "CE" (Ellen MacArthur Foundation, 2013a, 2013b, 2013c). Starting from the concept of closed loop, based upon the "cradle-to-cradle" approach, Andersen (2007) proposed the first scientific study to attempt defining the CE, through an analysis of the main principles and approaches that integrate environmental economics and sustainability. Specifically, from the policy maker's point of view, the first environmental policies that formally introduced the CE on a national scale were the Japanese and Chinese ones (Flynn et al., 2019). Then, it was the European Union's turn with countries like Denmark, Germany, the Netherlands, and United Kingdom setting relevant initiatives, policies, and guidelines to introduce the CE principles on the productive and societal system (McDowall et al., 2017; Reike et al., 2018).

In December 2019, European Commission launched the "Green New Deal" challenge, through an investment plan, which aims at an ecological transition model that sees the whole of Europe taking leadership roles. The goal is to become the first climate-neutral continent by 2050, supporting the competitiveness and sustainability of European industry towards an ecologically and socially equitable transition. In particular, with the New Circular Economy Action Plan, European Commission proposed a plan to shift towards a transformation of products, using a sustainable way to make it and empowering consumers. The new proposal actually seeks to leverage on sectors considered strategic in the first Action Plan, such as batteries and vehicles; electronics and plastic; and extending the priority to new sectors, for example, textiles, construction and buildings, and food. Therefore, attention is focused not only on the final phase of the production system, which concerns waste management, but on the pre-production related to design and in particular eco-design (European Commission, 2020).

I. 4.0 represents the new bridge between human and machine interactions; named also the "the fourth industrial revolution", I. 4.0 is a smart manufacturing environment based on cyber-physical systems, which combines technologies, IoT solutions within a powerful horizontal and vertical system integration model. In this regard, the Internet of Things (IoT) embraces organizations in an intelligent environment. The technology backbone involves key elements as additive manufacturing, augmented reality, big data and analytics, cybersecurity, and cloud computing.

At the same time, I. 4.0 incorporates and enhances sustainability performance (Ghobakhloo, 2020).

The approaches adopted by I. 4.0 allow the linkage between sustainable production and CE, demonstrating a certain complementarity; indeed, I. 4.0 could be considered as a synergic environment essential

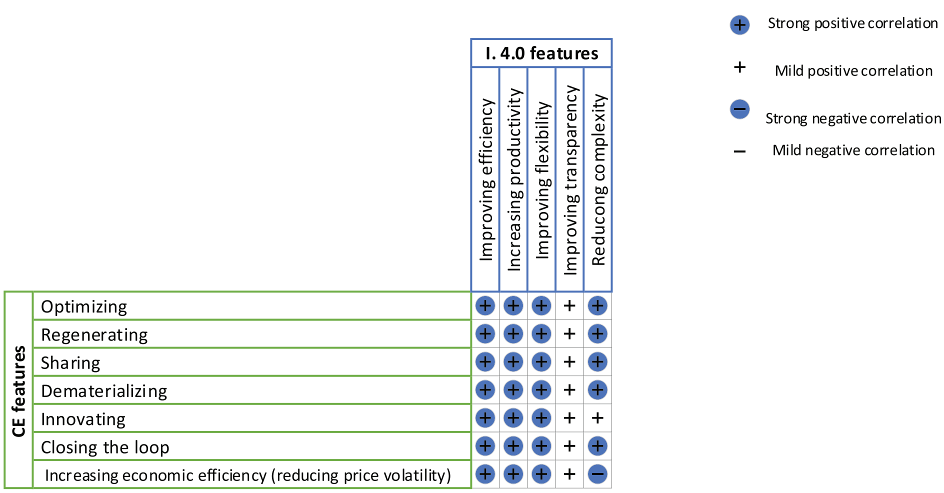

FIGURE 1 Matrix combining circular economy principles, taken from the "Circular Economy Action Plan", elaborated by European Commission, 2010, *Europe 2020: A strategy for smart, sustainable and inclusive growth. and features of the environment I. 4.0*, with features of the environment I. 4.0, gathered from the literature considered in the study. Source: authors' elaboration. The only strong negative correlation is placed between an increase of economic efficiency and the reduction of complexity in technological process flows because complexity is still viewed as a "measure of uncertainty" due to the fact that it has to manage a high number of data and variables in companies and its reduction represents a challenge for them (Mourtzis et al., 2019) [Colour figure can be viewed at wileyonlinelibrary.com]

to achieve holistic, integrated sustainability in production systems. Many studies in literature have indicated CE and I. 4.0 as the future of the organization (Kristoffersen et al., 2020; Yadav et al., 2020; Zhong et al., 2017).

Furthermore, their interaction is catching the attention of different topics from strategic management to technological and operations management. The reason lays in the fact that companies need to redesign their business model focused on their sustainable development (Centobelli et al., 2020). In this regard, such a closed-loop production systems can be improved through the implementation of I. 4.0 technologies (Awan et al., 2021). Thus, elaborating such a CE-based business model would mean to try to fill the existing gap in literature regarding the possibility to adopt CE principles for building new business models as a strategic management tool (Lüdeke-Freund et al., 2019).

Figure 1 shows a matrix that indicates strong correlation and complementarity between the bases and main characteristics of CE principles and I. 4.0. Each of the considered CE models positively influences the improvement of those that are objectives of I. 4.0.

By matching CE models with the attributes of I. 4.0 in this matrix, the results reveal the previous ones make a significant contribution to the achievement and improvement of all technological goals that could be achieved through the implementation of new technologies and vice versa. This implies I. 4.0 technologies can better improve economic and quality performance of an organization, whether or not they are implemented in a CE perspective.

It is noteworthy to notice that the only strong negative correlation is placed between an increase of economic efficiency and the reduction of complexity in technological process flows. This because, differently from the other combinations taken into consideration, which combine a kind of CE model and a potential benefit deriving from the implementation of I. 4.0 technologies, in the last case an economic benefit (the increase of economic efficiency) is linked to the reduction of complexity in process flows within a company. It is true that digitalizing and automated processes would mean meeting customers' demand and the reduction of complexity. But this kind of correlation should be represented through a strong negative correlation, because complexity is still viewed as a "measure of uncertainty" due to the fact that it has to manage a high number of data and variables in companies and its reduction represents a challenge for them (Mourtzis et al., 2019).

It must be said that I. 4.0 and CE, although sharing the same objectives to improve efficiency, productivity, and flexibility, present completely different operative approaches (Garcia-Muiña et al., 2019). CE models operate through the implementation of best practices aimed at resource productivity and process efficiency, through waste stream valorization, with a sustainability perspective. Meanwhile, I. 4.0 improves process performance through the integrated use of smart technologies.

To better explore the mainframe of the sustainable production, it is first necessary to highlight the CE principles, recognizing the complex concept and main aspects covered by the meaning of CE.

Guide and Van Wassenhove (2009) defined closed-loop supply chain as: "*the design, control and operation of a system to maximize the creation of value during the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time*". In this regard, some researchers have compared these loops with manufacturing metabolism (Ellen MacArthur Foundation, 2013a, 2013b, 2013c; McDonough & Braungart, 2002). Moreover, thanks to Kirchherr et al. (2017), a clear definition of CE exists today and that is "*economic system that replaces the concept of 'end of life' with the reduction, reuse, recycling, and recovery of materials in the production/distribution and consumption processes. It operates at the micro level (products, companies, and consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond), with the aim of achieving sustainable development, simultaneously creating environmental quality, economic prosperity and social equity, for the benefit of current generations and future. It is empowered by new business models and responsible consumers*."

To sum up, circular economy re-evaluates the concept of waste in economic and environmental terms, reconsidering all phases of the production chain. In this way, closed flows of recycled resources can be designed through a circular economy principles-based value chain.

Hence, CE can be considered as generating economic, environmental, and societal benefits that results from adopting recovery, reuse, recycling, sharing, and collaboration practices that redefine the corporate business model (Moktadir et al., 2020). These results are beneficial and strongly related to environmental conditions, as well as cultural, political, and technological skills. So far, the main barriers have resulted from: (a) low technological density and lack of homogeneous diffusion of digital infrastructures; (b) gaps in poorly integrative and unrepresentative governance models and the rigidity and fragmentation often characterizing supply chains; (c) difficulty in abandoning the traditional linear model of the economy as it is still too deeply embedded in people's behavior; (d) lack of widespread knowledge and the ability to make conscious choices; (e) policy being influenced by priority environmental issues; (f) the market and competition being not completely eco-friendly; and, finally, (g) traditional, non-proactive, and innovative management formulas.

In addition, CE model transition needs a legal framework support. In this matter, the mandatory system plays a critical role in promoting circular bio-based models within a more sustainable business (Batista et al., 2018).

Finally, in CE assessment, there is still lack of standard methods (Kristensen & Mosgaard, 2020; Sassanelli et al., 2019). Only few scholars have examined this topic, for example, Vinante et al. (2021), who has identified a large number of CE metrics at micro, meso, and macro level according to different sectors.

In the light of the above, the transition from traditional, linear systems to CE-based sustainable production models (see Figure 2) is very difficult. If at the country level (macro) or in a general industrial system such as industrial parks (meso), it would be easier to find applications and relevant outcomes, but at the micro level, data lack, and a fragmented culture of sustainable production reduces the broad and

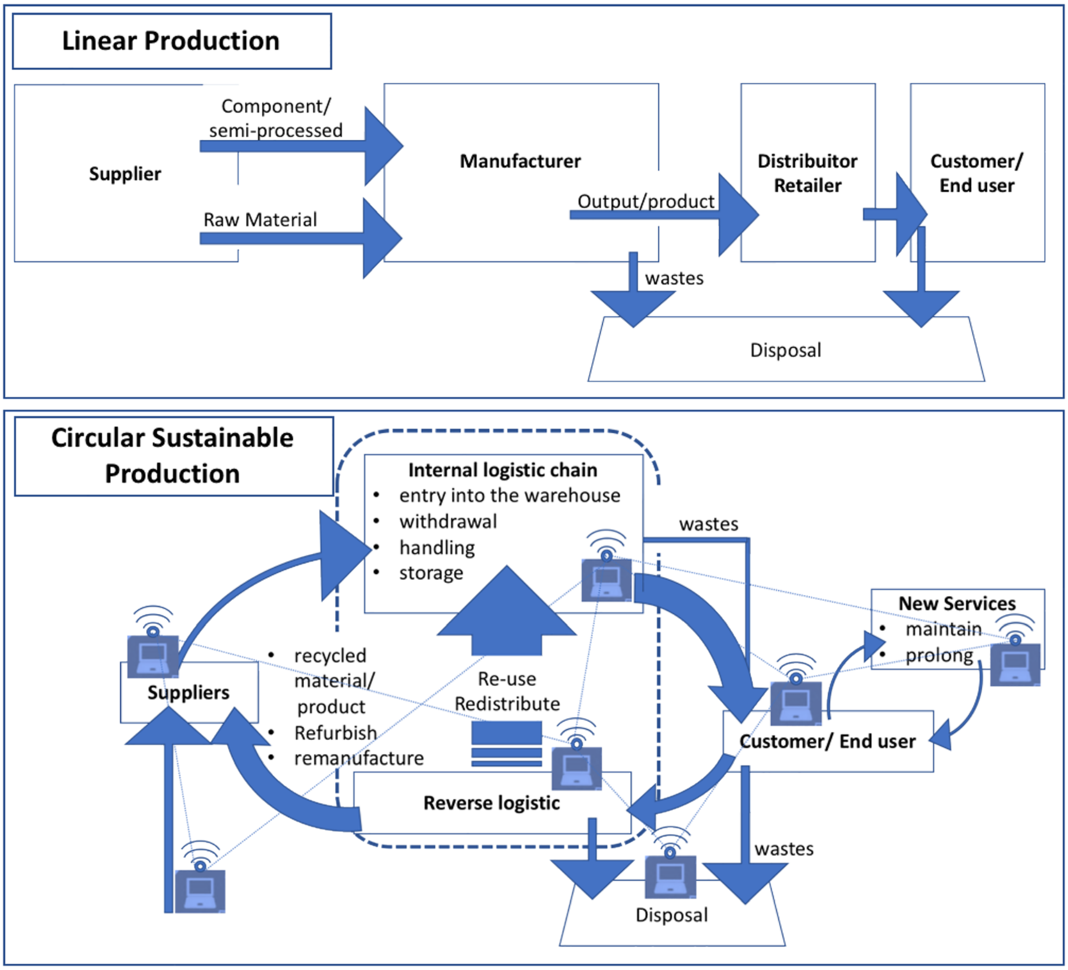

FIGURE 2 Production and reverse logistics within circular economy cycle. Source: authors' elaboration [Colour figure can be viewed at wileyonlinelibrary.com]

general development that remains only as a best practice or a limited experience. According to Savaskan et al. (2004), the entire manufacturing sector should be reconfigured to focus, as much as possible, on reusing waste and process residues as a zero-burden resource for reprocessing to produce secondary raw materials, which then feed into the production of new goods (Angelis-Dimakis et al., 2016; Jia et al., 2020; Svensson, 2007). At the same time, it should have the ability to avoid rebound effects (see, e.g., Hertwich, 2008), which can have counterproductive effects for the whole process.

Furthermore, as clarified by Geissdoerfer et al. (2017), the main beneficiaries of CE activities are the same economic actors who, as supply chain partners and system implementers, receive benefits and have returns from their investments.

The main contribution that CE can make to the strategic transition towards a sustainable production model covers the entire life cycle of products, which then become waste after use and are recycled to feed the same or different life cycles. The positive effect of this innovative approach is the increase in material circulation, that is, the relationship between secondary raw materials derived from waste and used materials. European countries that lead the ranking in terms of this indicator are as follows: the Netherlands (29.9%), France (18.6%), Belgium (17.8%), and United Kingdom (17.8%), followed by Italy (17.7%) (Circular Economy Network, ENEA, 2020). Despite the strategies implemented, the results obtained so far are still unsatisfactory and require significant efforts to improve performance both as single country and together as the whole European system.

A transition towards a CE model in the industrial sector would imply the application of appropriate sustainable production principles that focus on:

- increasing productivity through efficient usage of raw materials, by-products, waste, and energy;
- reducing emissions of pollutants from industrial processes.

Hence, it is understood that the holistic application of the environmental, economic, social, and technological principles of a CE model would represent the essential element to pursue sustainable development in the Industry.

2.1 | Methodological support: The LP philosophy

The selection of a management model, especially in the manufacturing sector, becomes a strategic factor in the transition towards a CE-oriented business model. Indeed, the difficulty is due to the complexity of the manufacturing sector, which also needs to acquire the guidelines deriving from the sustainable development goals and consistently the CE principles.

Womack and Jones (1996) introduced a method—the LP, which proved to be particularly efficient and effective in the interpretation and management of processes and operations. LP contains, in short, five basic elements, namely, value, value flow, flow, pull, and perfection. In this sense, the authors also take into account the principles of production management, for example, elimination of waste, satisfying customer needs, focusing on activities that generate value and value flows, striving for perfection, guaranteeing reliability at all phases of production (Womack & Jones, 1990), and guaranteeing continuous improvement (Kaizen) in all processes (Salem et al., 2006).

Recalling that CE aims at the following: (a) reducing waste, prices volatility, and the number of steps in the processes; (b) improving flow, transparency, flexibility, and control in processes; (c) satisfying customer needs through benchmarking and continuous improvement (Koskela, 1992), there is a clear awareness that LP principles have great potential to contribute to environmental well-being, and it is necessary to explore in detail the fundamental principle of lean management, which focuses on identifying and minimizing waste (Taddeo et al., 2019).

Lean management was introduced by Toyota's lean philosophy, which has evolved over time by adopting different application methods (Babalola et al., 2019; Koskela et al., 2002; Shingo, 1989).

On the other hand, lean supply chains have their origin in the just-in-time (JIT) philosophy that was first adopted by many American and European companies in the late 1980s and, then, performed at Toyota's Takaoka facility.

One of these approaches is an attempt to apply lean tools directly in the production environment (i.e., 5S, value stream mapping [VSM], and just-in-time) (Tan et al., 2013).

Specifically, 5S, which stands for "order, straighten, standardize, polish, and sustain," is a lean tool that is usually adopted as a first step towards lean manufacturing by most companies (Chiarini, 2014; Salem et al., 2014). Furthermore, 5S focuses primarily on labeling and organizing material storage and inventory management; it is able to quickly identify spills, dangerous leaks and reduce air pollution (Bae & Kim, 2008; Francis & Thomas, 2020).

Dieste et al. (2019) developed a framework for integrating lean and environmental sustainability. Chugani et al. (2017) specified tools such as lean and six sigma, claiming that sustainability can be easily achieved in corporate business saving energy and resources.

VSM lean tool is used to understand waste and value in the production process. At the same time, it is possible to implement environmental assessment tools in order to understand the environmental impact.

In addition, the six-sigma approach has been adopted using cause and effect diagrams and Pareto diagrams, thus helping to take steps to mitigate and control costly activities in processes. Hence, it is assumed that it is necessary to incorporate lean, environmental tools, and six-sigma to evaluate and improve processes and to achieve better efficiency with less environmental impact.

Erdil et al. (2018) developed a framework to integrate sustainability into lean and six-sigma projects. In detail, it introduces sustainability aspects into the six sigma, lean, and DMAIC (Define, Measure, Analyze, Improve and Control) cycle to promote design improvements in projects in all dimensions of sustainability.

Traditionally, the lean approach does not directly identify opportunities for resources such as energy efficiency but is instead strategic for activities focused on eliminating waste and improving process flow time. This is the reason why a large number of SMEs are providing themselves with lean-digitized strategies (Ghobakhloo & Fathi, 2019).

Arroyo and Gonzalez (2016) suggest that the definition of waste within the lean boundary should be rethought to also incorporate social and environmental impacts. Therefore, it is worth exploring the potential of lean practices in the context of combating both resource and energy waste in all processes. A rethinking of the LP paradigm could be the start of a CE adoption strategy. In this sense, LP can therefore support a Sustainable Supply Chain in Muda (Defect) Management, by being able to clearly and schematically represent bidirectional flows and highlight waste and wasteful activities. Evidence from the production environment shows that resources and energy are considered to be a significant and expensive input for the flow of value and therefore unnecessary energy and material consumption must be considered as waste (Sciortino et al., 2009).

From this perspective, "energy waste" that incorporates underutilization, loss, dissipation as well as uneconomical energy use and transformation processes could be identified by the lean philosophy as the ninth waste, considering its potential for saving money and reducing polluting emissions (Baysan et al., 2019).

Therefore, the lean philosophy already allows to support ecodesign already at the design stage, thus promoting a circular production model that improves, through RL, the recyclability of a product that is increasingly sustainable, less energy-consuming, and based on secondary raw materials. Nonetheless, the lean-sustainable production concept is still a new business strategy, without tangible feedback on its practical implementation (Abualfaraa et al., 2020; Zhang et al., 2020).

In Figure 3, there is a built-up matrix in which LP strategies and I. 4.0 attributes are combined. Also here, it is shown a strong correlation between them. As a large number of authors argued (Rosin et al., 2019), I. 4.0 technologies are able to strengthen the efficiency of lean approaches, despite the lack of their empirical validation, for example, through real increase in profits for the organization.

This means that adopting lean strategy under the umbrella of CE principles, achieving the aims underlying new technologies, which can be summarized in improving efficiency, productivity, flexibility, transparency, and reducing complexity, is strongly enhanced.

Lean production features	Improving efficiency	Increasing productivity	Improving flexibility	Improving transparency	Reducong complexity
	I. 4.0 features				
Elimination of wastes	⊕	⊕	⊕	⊕	⊕
Satisfaction of customers' needs	⊕	⊕	⊕	⊕	⊕
Generation of value	⊕	⊕	+	+	⊕
Pursuing perfection	⊕	⊕	⊕	⊕	⊕
Guaranteeing reliability	+	+	+	+	+
Providing continuous improvement	⊕	⊕	⊕	⊕	⊕
Reducing lead times	⊕	⊕	⊕	⊕	⊕

⊕ Strong positive correlation
\+ Mild positive correlation
⊖ Strong negative correlation
− Mild negative correlation

FIGURE 3 Matrix combining lean production (LP) strategies and features of the environment I. 4.0. Source: authors' elaboration [Colour figure can be viewed at wileyonlinelibrary.com]

CE features	Reducing lead times	Providing continuous improvement	Guaranteeing reliability	Pursuing perfection	Generation of value	Satisfaction of customers' needs	Elimination of wastes
	Lean production features						
Optimizing	⊕	⊕	⊕	⊕	⊕	⊕	⊕
Regenerating	⊕	⊕	+	⊕	⊕	+	⊕
Sharing	⊕	⊕	⊕	⊕	⊕	+	⊕
Dematerializing	⊕	⊕	+	+	⊕	+	⊕
Innovating	+	⊕	+	⊕	⊕	+	−
Closing the loop	⊕	⊕	+	⊕	⊕	+	⊕
Increasing economic efficiency (reducing price volatility)	⊕	⊕	+	⊕	⊕	⊕	⊕

⊕ Strong positive correlation
\+ Mild positive correlation
⊖ Strong negative correlation
− Mild negative correlation

FIGURE 4 Matrix combining circular economy (CE) principles and lean production (LP) strategies. Source: authors' elaboration. In the Figure, the only mild negative correlation concerns innovating and elimination of wastes. The reason why the aforementioned correlation is mild negative is that innovation determines a complete elimination of wastes provided that it is considered not only sic *et simpliciter* as adopting emerging technologies and lean strategies but also as eco-innovation and eco-design of both technologies involved in the process flow, products, and packages [Colour figure can be viewed at wileyonlinelibrary.com]

Furthermore, in Figure 4, there is also a constructed matrix that summarizes the CE principles and LP strategies. This matrix emphasizes the existence of a strong, positive correlation between them. By interpreting these results, it can be said that both CE principles and LP strategies can be integrated into the same I. 4.0 environment to improve the competitiveness of organizations. In the figure, the only mild negative correlation concerns innovating and elimination of wastes. The reason lays in the fact that innovation should be considered not only sic *et simpliciter* as adopting emerging technologies and lean strategies but also as eco-innovation and eco-design of both technologies involved in the process flow, products, and packages (Sumrin et al., 2021). Innovation determines the elimination of wastes only if it is considered as eco-innovation and eco-design. Thus, this would imply recovering not only production wastes but also technological scraps. Therefore, achieving the elimination of wastes should involve the adoption of all forms of innovations (technologies, products, and services) that are able to reuse production waste as eco-designed smart new products (Gavrilescu et al., 2018).

3 | RESULTS

The exploration of LP shows that it represents an advanced production strategy that guarantees improved productivity (Ohno, 1988; Resta et al., 2017). Recently, stakeholders involved in the value chain have been expecting greater integration of performance and competitiveness with environmental and social issues (Gupta, 2016; Martínez León & Calvo-Amodio, 2017). LP in particular is increasingly used in highly complex socio-technical systems characterized by high levels of uncertainty, diversity, and dynamic interactions, making them in fact already oriented towards the complexity of sustainability issues (Azadegan et al., 2013; Cilliers, 1999).

Internal effects are greater operational efficiency achieved through a reduction of costs and waste, whereas the external effects are related to brand and reputation enhancement that maintain loyalty to new market portions (Geldermann et al., 2007).

Sustainable production can be considered as a complex strategy that achieves the success only through the involvement of the entire supply chain. In this sense, in order to promote sustainability, there is a need for a strong ability to identify and pursue common and mutual benefits for producers, suppliers, and customers in an integrated and holistic perspective.

Furthermore, it is crucial the interaction between policymakers and companies. In fact, it can support or hinder transition towards the implementation of circular business models.

The activity of regulation of policymakers and international institutions can significantly influence and lead toward a CE transition. In addition, they can have the power to get rid of the existing barriers to innovation and implementation of CE, through ad hoc actions for the market, society and for the adoption of the emerging technologies. Through this kind of collaboration, it could be feasible to reduction of waste, reuse of products, and the achievement of zero-waste goals.

Therefore, the role played by policymakers or international institutions has a high degree of importance. In fact, they can tip the balance leading the production model to a radical change. It would shift from a linear one, where natural resources are used for mass products to be disposed after use, to a “CE” model, where economic growth is boosted by RL.

Based on this statement, this is configured as a managerial problem. Adopting a lean approach as theoretical, methodological support can be useful for assessing the various contents and the areas covered by the supply chain management (SCM). Therefore, it would be noteworthy to highlight where principles of CE find a positive and pragmatic connection.

Indeed, thanks to SCM systems, which can be considered as the evolution of integrated company logistics, a strategic model based on the vertical integration of material management activities can be drawn as follows:

- the forecasting phase;
- the intermediate stages of the critical order process;
- the purchase activity;
- planning and programming;
- procurement and follow-up of production;
- storage of materials;
- the shipment, transport and delivery of the finished product to the market;
- the accounting of warehouse materials.

The SCM embeds eight business areas and relative processes:

1. Customer Relationship Management (CRM) including the identification of market objectives and targets and the development of engagement programs in collaboration with customers. The purpose of this process is to identify and acquire new customers in order to establish long-term loyalty relationships.
2. Customer Service Management including the exchange of information with customers about the product and the progress of orders. To this end, many companies use information systems that, for example, allow the customer to modify their orders or check their status.
3. Demand Management providing reliable forecasts and reduces the variability of production installments, considering that the flow of materials and products is strongly correlated with the final demand.
4. Order fulfillment ensuring that deliveries to customers are accurate in terms of time, quality, and quantity.
5. Manufacturing Flow Management comprising the production of products requested by the customer. To this end, the company must be able to develop reliable predictions on the trend of market demand.
6. Procurement focusing on managing interactions with suppliers in order to create shared production process and new product development.
7. Product development/marketing (New Product Development and Marketing) integrating key customers and suppliers with the aim of developing new products and to reduce the time to market.
8. RL (Return Management) concerning the recycling and reuse of products at the end of their useful life cycle.

The analysis of the areas that characterize the SCM shows that only one refers to RL (point 8), which represents a strategic action suitable for integrating the principles of the CE into the supply chain, where LP can play a successful role. In this regard, the European working group (REVLOG, 2020) defines RL as the “process of planning, implementation, and control of flows of raw materials, semi-finished and finished products from production, distribution, and the end customer to the recovery point or to the collection and distribution point”.

Through RL, it is possible to recover important quantities of materials using circular flows. In the reverse cycle, in particular, the residue is reintroduced into the same or another production cycle as a second raw material (Howard et al., 2018).

According to Pushpamali et al. (2021), RL is perceived as an environmentally friendly practice in construction operations. In this study, in fact, it is highlighted that its implementation leads to a significant reduction of cost for materials in comparison with a purchase of new ones. The need for a quantitative analysis also addressed for future research. Therefore, it would be interesting carrying out empirical analysis based on case studies or statistical methods.

In order to access the opportunities deriving from the reverse cycles (closed circuits), it is necessary to strengthen the legislation, also through intersectoral agreements, promoting the key role of logistics also through symbiotic and inclusive production systems (Farooque et al., 2019).

Thierry et al. (1995) divided recovery into repair, renewal, regeneration, cannibalization, and recycling. In another study, Fleischmann et al. (2000) classified the recovery process into collection, inspection/separation, reworking, disposal, and redistribution, whereas Camilleri (2019) defined the recovery process as a combination of reuse, service, remanufacture, recycling, and disposal. From this definition, it emerges that RL differs from the classic definition of logistics, because it considers the product only at the end of its life or cycle.

Comprehensively, the Council of Logistics Management (CLM) defines RL as "*a term often used to refer to the role of logistics in recycling, waste disposal and management of hazardous materials; a broader perspective includes a report on logistical activities carried out in the reduction of sources, recycling, replacement, reuse of materials and disposal*". In summary, RL is considered more than a configuration of the logistics system to collect products from end users for recycling or renewal at recycling plants (Braungart et al., 2007).

According to Brandenburg and Rebs (2015), sustainable production encompasses the concepts of CE, RL, and sustainable supply chain in an integrated manner (see Figure 5) (Papachristos, 2014). As main result, the key success factor is the interdependence between technical and economic aspects and environmental responsibility (Sáez-Martínez et al., 2016).

4 | DISCUSSION

Based upon the previous paragraphs, sustainable production requires a throughout environmental assessment, applied to whole supply chain. In this sense, sustainable production can maximize resource efficiency in the entire industrial production system by minimizing negative environmental impact in each process (Macchi et al., 2020).

According to Ioppolo et al. (2014), LM contributes to the qualitative and quantitative measurement and analysis of consumption, and associated environmental loads of resources and energy, with particular attention to the recovery and secondary raw materials, derived also from RL processes.

Sustainable production improves the competitive positioning of small and large enterprises, anticipating consumer choices and regulatory decisions, and making the supply of resources and the prices more stable in each supply chain safer. Furthermore, sustainable global production fosters the combination of demand and supply of circular innovation.

The integration of LP with the CE allows the planning of a new—"sustainability oriented" business strategy, in line with the financial goal of the company.

Therefore, the previous analysis leads to a better understanding of relationships among I. 4.0, LP, and CE. Holistically considered, all of them can help companies to achieve a competitive edge in the market.

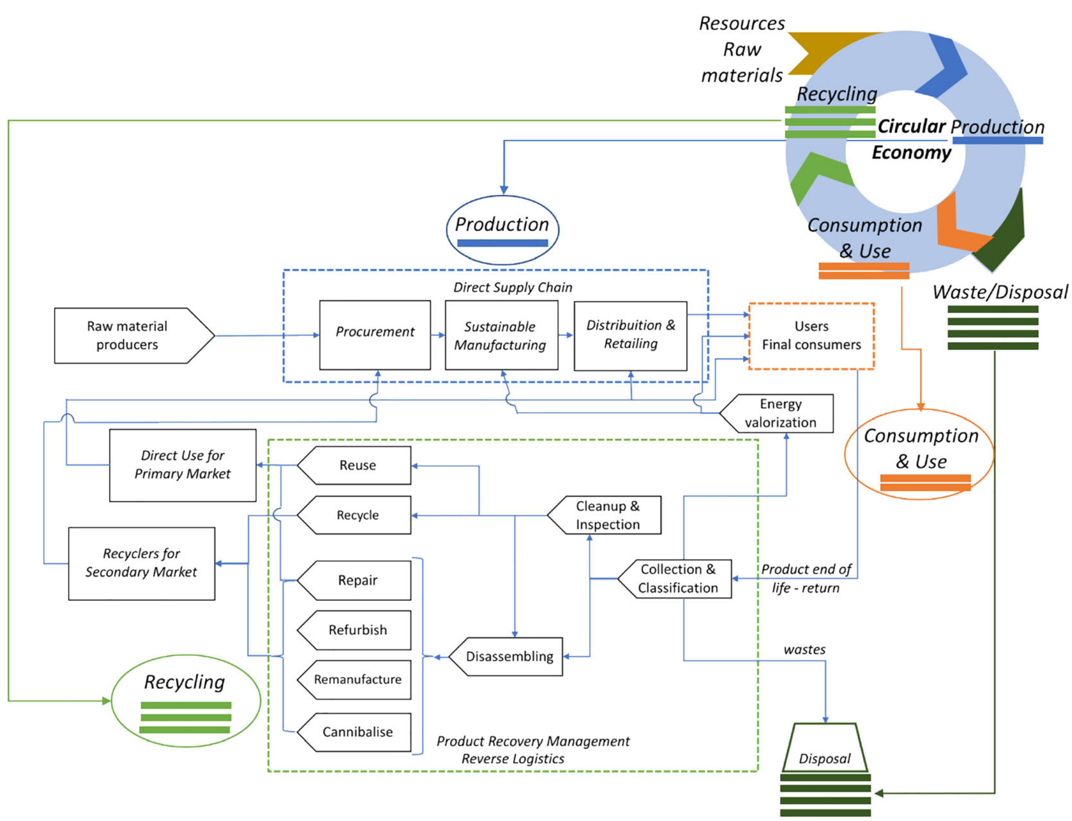

FIGURE 5 Production and Reverse Logistics within Circular Economy cycle. Source: authors' elaboration [Colour figure can be viewed at wileyonlinelibrary.com]

On the other hand, all the stakeholders involved, from policymakers to international institutions play a crucial role in the transition toward a CE-based and digitalized development, enhanced by the use of RL.

In detail, it is feasible through the following activities:

- dematerializing and de-energizing both production and finished products, enhancing services throughout its life;
- promoting the use of low environmental impact materials by reducing emissions and dispersion of toxic substances during and, especially, at the end of life;
- introducing the qualitative and quantitative measurement and analysis of consumption and associated environmental loads of resources and energy, with particular attention to the part coming from recovery as secondary raw materials derived from RL processes;
- investing in eco-design by promoting the use of recyclable materials and enhancing both "RL" actions and the use of renewable energy and sustainable resources, capable of extending the useful life of a product;
- strengthening a model of "functional economy" aimed at replacing products with services, increasing the efficiency of production and finished products.

This is highlighted in Figure 6. By integrating the three pillars, LP strategy, CE principles, and I. 4.0 environment, through RL, it is possible to improve process flows in supply chains and give rise to "digital, sustainable products, and processes".

Such "digital sustainable products and processes" could meet the essential human needs by satisfying their requests. In fact, digital process flows would be more simplified and smarter. This would lead to a reduction of lead times and a delivery of products customized on consumer needs. Furthermore, this would imply more sustainable supply chains aiming at minimizing wastes and depletion of natural resources. In this sense, they would meet the goals of "functional economy" based on the optimization of the use (or function) of goods and services and thus the management of existing resources and energy (Stahel, 1997). Furthermore, the role of CE in these process flows would be that of a functional economy, where end-users pay for the use of products and not for their ownership (Urbinati et al., 2017). In this sense, products with extensive lifecycles, which can be easily dismantled and recovered at the end of their life as well as technology, become the vehicles to provide a function and optimize their use.

In addition, the integration of CE principles within the lean philosophy improves its overall environmental contribution. Following Lewandowski's (2016) approach, which groups sustainable production into four strategic operating areas: business models and processes, asset and product lifecycle management, resource and energy management, and enabling technologies, future research should focus on expanding the existing horizons of lean management to contribute effectively to the application of CE principles in order to achieve sustainable development goals in all four areas. The digitization of the supply chain through the integration of new technologies in logistics is certainly an essential contribution to the implementation of extended and sustainable management from "cradle to cradle" (Uemura Reche et al., 2020). In this regard, digitalization supports RL, integrating the process with technologies and organizational elements that allow the system to be more efficient and flexible.

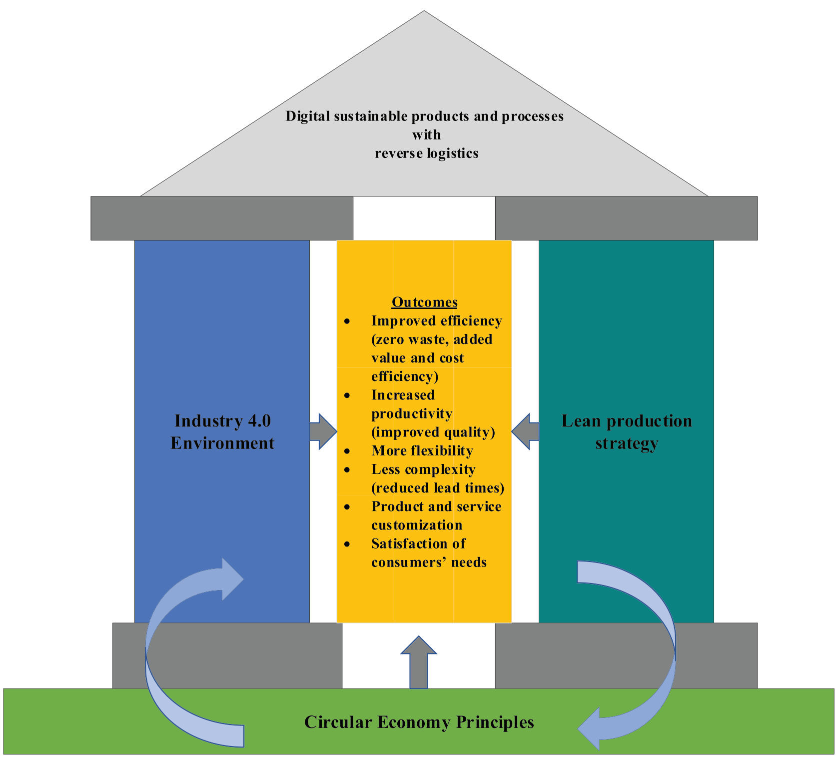

FIGURE 6 Conceptual framework integrating LP, CE and I.4.0. Source: authors' elaboration [Colour figure can be viewed at wileyonlinelibrary.com]

Nevertheless, this paradigm shift in manufacturing companies is still far from being implemented, as most of the processes and products are not designed to integrate the principle of "flexibility and speed at customer request" into the CE.

Beside this, other weaknesses of the current analysis concern the fact that it is only a theoretical study that aims at integrating I.4.0, LP, and CE. Thus, it would need further empirical investigations. Furthermore, a strong weakness of the topic tackled in the present study could regard the difficulty in engaging all the stakeholders such as Governments, international institutions, and companies to advance the transition toward sustainable and digitalized process flows.

5 | FUTURE OUTLOOKS

The innovative approach of I. 4.0 can face the challenge precisely in terms of RL. In fact, through the intelligent sharing of spaces (i.e., warehouses, loading/unloading areas, docks, and terminals), vehicles, and loads, this change can have a disruptive effect on economic system, able to optimize the flows due to investments in the digitalization of the supply chain. In this sense, RL can contribute in terms of access to sharing platforms in order to encourage resilient development.

Specifically, LP can manage the I. 4.0 model through an effective and integrated use of information technology (Superior Integration—Computer Integrated Manufacturing), artificial intelligence (AI), and robotics (Kagermann et al., 2013). Hence, the implementation of an LP model applied to I. 4.0 can make a winning contribution to increase product quality, productivity, and make processes fluid and efficient.

LP based on I. 4.0 provides real-time tracking and monitoring of all the functions of the systems allowing identification, tracking, communication, and control along the value stream. Management and communication information systems allow the development of an integrated end-to-end environment that connects digitally designed intelligent machines, storage systems, and intelligent production structures throughout the organization (Sanders et al., 2016). In this advanced technological environment, through the extensive and pervasive use of AI, it is possible to accurately forecast customer requests and manage the entire supply chain from incoming logistics to production, outgoing logistics, marketing, sales, and assistance (Flint et al., 2005; Kagermann et al., 2013; Klumpp, 2017).

Therefore, I. 4.0 can integrate the principles of the CE, creating a successful business that is structured on the systemic use of technologies, such as digital (information technology), engineering (materials technology), and hybrids (a mix of those two).

Investments in digital infrastructures are necessary to enable the dissemination of digital services and technologies not only across Europe, but everywhere. Furthermore, the development of broadband plays a crucial role in the implementation of innovative and competitive digital systems, rebalancing public initiative interventions directly on the less connected areas (white and gray) to avoid the risk of increasing the digital divide.

Digital technologies allow the systematic exchange of information in real time between users, machines, and management systems, with the aim of nurturing a widespread digital environment that supports a large, integrated, and interactive supply chain. Hence, the advantage in terms of CE is the dematerialization of all physical activities and the reconfiguration of the value chain (Jankowski et al., 2018; Urbinati et al., 2017).

Measuring the performance of CE at micro level (in manufacturing) is affected by the lack of a single and common framework of indicators, the lack of data inventory, and the lack of culture. In this sense, the cultural dimension concerns not only the business area but also the market the behaviors and choices of customers.

The maturity achieved through new technologies and the greater availability and openness of companies allow us to conclude that sustainable production in the digital ecosystem can become a real driving force for companies committed to the transition towards a CE.

Sustainable LP-based I. 4.0 operates through sensors and meters smart tool, connected to the company lean management system, integrated with the database for environmental impact analysis (as Life Cycle Assessment tools) and supported by economic and social assessments/feedbacks. Therefore, I. 4.0 tools can implement sustainability; integrating CE principles; and exploiting data collection and inventory information to carry out evaluations of environmental, economic, and social impacts (García-Muiña et al., 2020).

In this sense, both scientific and industrial sectors must focus on finding optimal strategies that will adopt new digital technologies enabling the promotion of sustainable development principles as a competitive business strategy. This productive environment finds application in I. 4.0 and digital environment, where the supply chain can be flexible, smart, integrative, and responsive thanks to technology. Consequently, despite difficulties in collecting data, a quantitative analysis of the beneficial effects in terms of both environmental and social benefits from the integration of the three main pillars, I. 4.0, LP, and CE, would be desirable.

Smart technologies and the digital environment improve the potential of the entire manufacturing supply chain but require greater awareness of the enhanced paradigms of human-machine interaction. In this regard, international and national programs are investing in long-term policies that support a transition towards sustainable production. Future research must better promote cooperation between all stakeholders involved in the production chain, giving strategic importance to those involved in recycling and recovery activities. In conclusion, the paper proposes an original point of view with a preliminary "fil rouge" drawing and integrating the possible relationship between lean manufacturing, CE, and I. 4.0 in order to stimulate productive discussion.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Abualfaraa, W., Salonitis, K., Al-Ashaab, A., & Ala'raj, M. (2020). Lean-Green Manufacturing Practices and Their Link with Sustainability: A Critical Review. *Sustainability*, *12*(3), 981. https://doi.org/10.3390/su12030981

Andersen, M. S. (2007). An introductory note on the environmental economics of the circular economy. *Sustainability Science*, *2*, 133–140. https://doi.org/10.1007/s11625-006-0013-6

Angelis-Dimakis, A., Alexandratou, A., & Balzarini, A. (2016). Value chain upgrading in a textile dyeing industry. *Journal of Cleaner Production*, *138*, 237–247. https://doi.org/10.1016/j.jclepro.2016.02.137

Aquilani, B., Silvestri, C., Ioppolo, G., & Ruggieri, A. (2018). The challenging transition to bio-economies: Towards a new framework integrating corporate sustainability and value co-creation. *Journal of Cleaner Production*, *172*, 4001–4009. https://doi.org/10.1016/j.jclepro.2017.03.153

Arroyo, P. & Gonzalez, V. (2016). Rethinking Waste Definition to Account for Environmental and Social Impacts. In: *24th Annual Conference of the International Group for Lean Construction*. Boston, Massachusetts, USA. Available online at https://iglc.net/papers/Details/1334

Awan, U., Sroufe, R., & Shahbaz, M. (2021). Industry 4.0 and the circular economy: A literature review and recommendations for future research. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.2731

Azadegan, A., Patel, P. C., Zangoueinezhad, A., & Linderman, K. (2013). The effect of environmental complexity and environmental dynamism on lean practices. *Journal of Operations Management*, *31*, 193–212. https://doi.org/10.1016/j.jom.2013.03.002

Babalola, O., Ibem, E. O., & Ezema, I. C. (2019). Implementation of lean practices in the construction industry: A systematic review. *Building and Environment*, *148*, 34–43. https://doi.org/10.1016/j.buildenv.2018.10.051

Bae, J. W., & Kim, Y. W. (2008). Sustainable value on construction projects and lean construction. *Journal of Green Building*, *3(1)*, 156–167. https://doi.org/10.3992/jgb.3.1.156

Batista, L., Bourlakis, M., Liu, Y., Smart, P., & Sohal, A. (2018). Supply chain operations for a circular economy. *Production Planning and Control*, *29*(6), 419–424. https://doi.org/10.1080/09537287.2018.1449267

Baysan, S., Kabadurmus, O., Cevikcan, E., Satoglu, S. I., & Durmusoglu, M. B. (2019). A simulation-based methodology for the analysis of the effect of lean tools on energy efficiency: An application in power distribution industry. *Journal of Cleaner Production*, *211*, 895–908. https://doi.org/10.1016/j.jclepro.2018.11.217

Brandenburg, M., & Rebs, T. (2015). Sustainable supply chain management: A modeling perspective. *Annals of Operations Research*, *229*, 213–252. https://doi.org/10.1007/s10479-015-1853-1

Braungart, M., McDonough, W., & Bollinger, A. (2007). Cradle-to-cradle design: Creating healthy emissions—A strategy for eco-effective product and system design. *Journal of Cleaner Production*, *15*(13–14), 1337–1348. https://doi.org/10.1016/j.jclepro.2006.08.003

Camilleri, M. A. (2019). The circular economy's closed loop and product service systems for sustainable development: A review and appraisal. *Sustainable Development*, *27*(3), 530–536. https://doi.org/10.1002/sd.1909

Centobelli, P., Cerchione, R., Chiaroni, D., Del Vecchio, P., & Urbinati, A. (2020). Designing business models in circular economy: A systematic literature review and research agenda. *Business Strategy and the Environment*, *29*(4), 1734–1749. https://doi.org/10.1002/bse.2466

Chiarini, A. (2014). Sustainable manufacturing-greening processes using specific Lean Production tools: an empirical observation from European motorcycle component manufacturers. *Journal of Cleaner Production*, *85*, 226–233. https://doi.org/10.1016/j.jclepro.2014.07.080

Chugani, N., Kumar, V., Garza-Reyes, J. A., Rocha-Lona, L., & Upadhyay, A. (2017). Investigating the green impact of lean, Six Sigma and Lean Six Sigma. *International Journal of Lean Six Sigma*, *8*(1), 7–32. https://doi.org/10.1108/IJLSS-11-2015-0043

Cilliers, P., & Spurrett, D. (1999). Complexity and post-modernism: understanding complex systems. *South African Journal of Philosophy*, *18*(2), 258–274. https://doi.org/10.1080/02580136.1999.10878187

Circular Economy Network, ENEA. (2020). Rapporto sull'Economia Circolare in Italia. https://circulareconomynetwork.it/wp-content/uploads/2020/04/Rapporto-sulleconomia circolare-in-Italia-2020_r04.pdf

Dieste, M., Panizzolo, R., Garza-Reyes, J. A., & Anosike, A. (2019). The relationship between lean and environmental performance: Practices and measures. *Journal of Cleaner Production*, *224*, 120–131. https://doi.org/10.1016/j.jclepro.2019.03.243

Elkington, J. (1994). Towards the sustainable corporation: Win-win-win business strategies for sustainable development. *California Management Review*, *36*, 90–100. https://doi.org/10.2307/41165746

Elkington, J. (1998a). ACCOUNTING FOR THE TRIPLE BOTTOM LINE. *Measuring Business Excellence*, *2*(3), 18–22. https://doi.org/10.1108/eb025539

Elkington, J. (1998b). Partnerships fromcannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, *8*(1), 37–51. https://doi.org/10.1002/tqem.3310080106

Ellen MacArthur Foundation. (2013a). Circular economy overview. Available at https://www.ellenmacarthurfoundation.org/circular-economy/overview/concept

Ellen MacArthur Foundation. (2013b). Towards the circular economy. Available online at https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Ellen MacArthur Foundation. (2013c). Towards the circular economy. Opportunities for the consumer goods sector. Available online: http://www.ellenmacarthurfoundation.org/assets/downloads/publications/TCE_Report-2013.pdf

Erdil, N. O., Aktas, C. B., & Arani, O. M. (2018). Embedding sustainability in lean six sigma efforts. *Journal of Cleaner Production*, *198*, 520–529. https://doi.org/10.1016/j.jclepro.2018.07.048

European Commission. (2010). Europe 2020. https://ec.europa.eu/info/energy-climate-change-environment/overall-targets/2020-targets_en

European Parliament and Council of the EU. (2019). 9th Framework Program-FP9. https://ec.europa.eu/programmes/horizon2020/en/tags/fp9

Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Literature Review. Journal of Cleaner Production*, *228*, 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303

Fleischmann, M., Krikke, H. R., Dekker, R., & Flapper, S. D. P. (2000). A characterisation of logistics networks for product recovery. *Omega*, *28*, 653–666. https://doi.org/10.1016/S0305-0483(00)00022-0

Flint, D. J., Larsson, E., Gammelgaard, B., & Mentzer, J. T. (2005). Logistics innovation: A customer value-oriented social process. *Journal of Business Logistics*, *26*(1), 113–147. https://doi.org/10.1002/j.2158-1592.2005.tb00196.x

Flynn, A., Hacking, N., & Xie, L. (2019). Governance of the circular economy: A comparative examination of the use of standards by China and the United Kingdom. *Environmental Innovation and Societal Transitions*, *33*, 282–300. https://doi.org/10.1016/j.eist.2019.08.002

Francis, A., & Thomas, A. (2020). Exploring the relationship between lean construction and environmental sustainability: A review of existing literature to decipher broader dimensions. *Journal of Cleaner Production*, *252*, 119913. https://doi.org/10.1016/j.jclepro.2019.119913

García-Muiña, F., Medina-Salgado, S., Ferrari, A., & Cucchi, M. (2020). Sustainability Transition in Industry 4.0 and Smart Manufacturing with the Triple-Layered Business Model Canvas. *Sustainability*, *12*(6), 2364. https://doi.org/10.3390/su12062364

Garcia-Muiña, F. E., González-Sánchez, R., Ferrari, A. M., Volpi, L., Pini, M., Siligardi, C., & Settembre-Blundo, D. (2019). Identifying the Equilibrium Point between Sustainability Goals and Circular Economy Practices in an Industry 4.0 Manufacturing Context Using Eco-Design. *Social Science*, *8*(8), 241. https://doi.org/10.3390/socsci8080241

Gavrilescu, M., Campean, T., & Gavrilescu, D. A. (2018). Extending production waste life cycle and energy saving by eco-innovation and eco-design: The case of packaging manufacturing. In I. Visa & A. Duta (Eds.), *Nearly zero energy communities*. CSE 2017 Springer Proceedings in Energy. Springer.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*, 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy—A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geldermann, J., Treitz, M., & Rentz, O. (2007). Towards sustainable production networks. *International Journal of Production Research*, *45*, 4207–4224. https://doi.org/10.1080/00207540701440014

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development. *International Journal of Sustainable Development and World Ecology*, *15*(3), 231–239. https://doi.org/10.3843/susdev.15.3:6

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, *252*, 119869. https://doi.org/10.1016/j.jclepro.2019.119869

Ghobakhloo, M., & Fathi, M. (2019). Corporate survival in Industry 4.0 era: The enabling role of lean- digitized manufacturing. *Journal of Manufacturing Technology Management*, *31*(1), 1–30. https://doi.org/10.1108/JMTM-11-2018-0417

Govindan, K., Azevedo, S., Carvalho, H., & Cruz-Machado, V. (2015). Lean, green and resilient practices influence on supply chain performance: Interpretive structural modeling approach. *International journal of Environmental Science and Technology*, *12*(1), 15–34. https://doi.org/10.1007/s13762-013-0409-7

Guide, V. D. R. Jr., & Van Wassenhove, L. N. (2009). OR FORUM—The Evolution of Closed-Loop Supply Chain Research. *Operations Research*, *57*(1), 10–18. https://doi.org/10.1287/opre.1080.0628

Gupta, S., Sharma, M., & Sunder, M. (2016). Lean services: A systematic review. *International Journal of Productivity and Performance Management*, *65*(8), 1025–1056. https://doi.org/10.1108/IJPPM-02-2015-0032

Gupta, S. M. (2016). Lean manufacturing, green manufacturing and sustainability. *Journal of Japan Industrial Management Association*, *67*, 102–105.

Helleno, A. L., de Moraes, A. J. I., & Simon, A. T. (2017). Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes: Application case studies in Brazilian industry. *Journal of Cleaner Production*, *153*, 405–416. https://doi.org/10.1016/j.jclepro.2016.12.072

Henao, R., Sarache, W., & Gomez, I. (2019). Lean manufacturing and sustainable performance: Trends and future challenges. *Journal of Cleaner Production*, *208*, 99–116. https://doi.org/10.1016/j.jclepro.2018.10.116

Hertwich, E. G. (2008). Consumption and the Rebound Effect: An Industrial Ecology Perspective. *Journal of Industrial Ecology*, *9*(1-2), 85–98. https://doi.org/10.1162/1088198054084635

Howard, M., Hopkinson, P., & Miemczyk, J. (2018). The regenerative supply chain: A framework for developing circular economy indicators. *International Journal of Production Research*, *57*(23), 7300–7318. https://doi.org/10.1080/00207543.2018.1524166

Ioppolo, G., Cucurachi, S., Salomone, R., Saija, G., & Ciraolo, L. (2014). Industrial Ecology and Environmental Lean Management: Lights and Shadows. *Sustainability*, *6*(9), 6362–6376. https://doi.org/10.3390/su6096362

Jankowski, J., Zioło, M., Karczmarczyk, A., & Wątróbski, J. (2018). Towards Sustainability in Viral Marketing with User Engaging Supporting Campaigns. *Sustainability*, *10*(2), 15. https://doi.org/10.3390/su10010015

Jia, F., Yin, S., Chen, L., & Chen, X. (2020). The circular economy in the textile and apparel industry: A systematic literature review. *Journal of Cleaner Production*, *259*, 120728. https://doi.org/10.1016/j.jclepro.2020.120728

Kagermann, H., Wahlster, W., & Johannes, H. (2013). Recommendations for implementing the strategic initiative Industrie 4.0. Acatech – National Academy of Science and Engineering. Available online at https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2017). Circular economy—From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, *135*, 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Klumpp, M. (2017). Automation and artificial intelligence in business logistics systems: human reactions and collaboration requirements. *International Journal of Logistics Research and Applications*, *21*(3), 224–242. https://doi.org/10.1080/13675567.2017.1384451

Koskela, L., 1992. Application of the new production philosophy to construction. Stanford University, CA. Technical Report No. 72, CIFE. Available online at https://stacks.stanford.edu/file/druid:kh328xt3298/TR072.pdf

Koskela, L., Howell, G., Ballard, G., & Tommelein, I. (2002). The foundations of lean construction. In R. Best & G. de Valence (Eds.), *Design and construction: Building in value* (pp. 211–226). Oxford, UK: Butterworth-Heinemann. http://usir.salford.ac.uk/id/eprint/598/

Kristensen, H. S., & Mosgaard, M. A. (2020). A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, *243*, 118531. https://doi.org/10.1016/j.jclepro.2019.118531

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research*, *120*, 241–261. https://doi.org/10.1016/j.jbusres.2020.07.044

Lewandowski, M. (2016). Designing the Business Models for Circular Economy—Towards the Conceptual Framework. *Sustainability*, *8*(1), 43. https://doi.org/10.3390/su8010043

Lüdeke-Freund, F., Gold, S., & Bocken, N. M. (2019). A Review and Typology of Circular Economy Business Model Patterns. *Journal of Industrial Ecology*, *23*(1), 36–61. https://doi.org/10.1111/jiec.12763

Macchi, M., Savino, M., & Roda, I. (2020). Analysing the support of sustainability within the manufacturing strategy through multiple perspectives of different business functions. *Journal of Cleaner Production*, *258*, 120771. https://doi.org/10.1016/j.jclepro.2020.120771

Martínez León, H. C., & Calvo-Amodio, J. (2017). Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective. *Journal of Cleaner Production*, *142*, 4384–4402. https://doi.org/10.1016/j.jclepro.2016.11.132

McDonough, W., & Braungart, M. (2002). *Cradle to cradle*. New York: North Point Press. https://mcdonough.com/writings/cradle-cradle-remaking-way-make-things/

McDowall, W., Geng, Y., Huang, B., Bartekovà, E., Bleischwitz, R., Turkeli, S., Ren'e Kemp, R., & Doménech, T. (2017). Circular Economy Policies in China and Europe. *Journal of Industrial Ecology*, *21*(3), 651–661. https://doi.org/10.1111/jiec.12597

Moktadir, M. A., Ahmadi, H. B., Sultana, R., Zohra, F.-T., Liou, J. J. H., & Rezaei, J. (2020). Circular economy practices in the leather industry: A practical step towards sustainable development. *Journal of Cleaner Production*, *251*, 119737. https://doi.org/10.1016/j.jclepro.2019.119737

Moktadir, M. A., Rahman, T., Rahman, M. H., Ali, S. M., & Paul, S. K. (2018). Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh. *Journal of Cleaner Production*, *174*, 1366–1380. https://doi.org/10.1016/j.jclepro.2017.11.063

Mourtzis, D., Papakostas, N., & Makris, S. (2019). Complexity in Industry 4.0 Systems and Networks. *Complexity*, *2019*, 1–2. https://doi.org/10.1155/2019/7817046

Ohno, T. (1988). *Toyota production system: Beyond large-scale production* (1st ed.). Productivity Press. https://books.google.it/books/about/Toyota_Production_System.html?id=7_-67SshOy8C&redir_esc=y

Papachristos, G. (2014). Transition inertia due to competition in supply chains with remanufacturing and recycling: A systems dynamics model. *Environmental Innovation and Societal Transitions*, *12*, 47–65. https://doi.org/10.1016/j.eist.2014.01.005

Pushpamali, N., Agdas, D., Rose, T. M., & Yigitcanlar, T. (2021). Stakeholder perception of reverse logistics practices on supply chain performance. *Business Strategy and the Environment*, *30*, 60–70. https://doi.org/10.1002/bse.2609

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, *135*, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Resta, B., Dotti, S., Gaiardelli, P., & Boffelli, A. (2017). How Lean Manufacturing Affects the Creation of Sustainable Value: An Integrated Model. *International Journal of Automation Technology*, *11*(4), 542–551. https://doi.org/10.20965/ijat.2017.p0542

REVLOG, 2020. https://www.rev-log.com

Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2019). Impacts of Industry 4.0 technologies on lean principles. *International Journal of Production Research*, *58*(6), 1644–1661. https://doi.org/10.1080/00207543.2019.1672902

Sáez-Martínez, F. J., Lefebvre, G., Hernández, J. J., & Clark, J. H. (2016). Drivers of sustainable cleaner production and sustainable energy options. *Journal of Cleaner Production*, *138*, 1–7. https://doi.org/10.1016/j.jclepro.2016.08.094

Salem, O., Pirzadeh, S., Ghorai, S., & Abdel-Rahim, A. (2014). Reducing environmental, economic, and social impacts of work-zones by implementing lean construction techniques. In *22nd Annual Conference of the International Group for Lean Construction* (pp. 145–155). Norway: Oslo. https://iglc.net/Papers/Details/1057

Salem, O., Solomon, J., Genaidy, A., & Minkarah, I. (2006). Lean construction: From theory to implementation. *Journal of Management in Engineering*, *22*(4), 168–175. https://doi.org/10.1061/(ASCE)0742-597X(2006)22:4(168)

Sanders, A., Elangeswaran, C., & Wulfsberg, J. P. (2016). Industry 4.0 implies lean manufacturing: Research activities in Industry 4.0 function as enablers for lean manufacturing. *Journal of Industrial Engineering and Management*, *9*(3), 811–833. https://doi.org/10.3926/jiem.1940

Sassanelli, C., Rosa, P., Rocca, R., & Terzi, S. (2019). Circular economy performance assessment methods: A systematic literature review. *Journal of Cleaner Production*, *229*, 440–453. https://doi.org/10.1016/j.jclepro.2019.05.019

Savaskan, R. C., Bhattacharya, S., & van Wassenhove, L. N. (2004). Closed-Loop Supply Chain Models with Product Remanufacturing. *Management Science*, *50*(2), 239–252. https://doi.org/10.1287/mnsc.1030.0186

Schrader, U., & Thøgersen, J. (2011). Putting Sustainable Consumption in practice. *Journal of Consumer Policy*, *34*(1), 3–8. https://doi.org/10.1007/s10603-011-9154-9

Sciortino, M., Watson, S., Presnar, R., 2009, The importance of energy efficiency in lean manufacturing: Declaring energy the ninth waste. In: Proceedings of the 2009 ACEEE Summer Study on Energy Efficiency in Industry, 113-122. Available at https://www.aceee.org/files/proceedings/2009/data/papers/3_6.pdf

Shankar, K. M., Kannana, D., & Kumar, U. (2017). Analyzing sustainable manufacturing practices—A case study in Indian context. *Journal of Cleaner Production*, *164*, 1332–1343. https://doi.org/10.1016/j.jclepro.2017.05.097

Sheldon, R. A. (2014). Green and sustainable manufacture of chemicals from biomass: State of the art. *Green Chemistry*, *16*(3), 950–963. https://doi.org/10.1039/c3gc41935e

Shingo, S. (1989). *A study of the Toyota production system: From an industrial engineering viewpoint*. Productivity Press. https://books.google.it/books/about/A_Study_of_the_Toyota_Production_System.html?id=RKWU7WEIJ7oC&redir_esc=y

Simboli, A., Raggi, A., & Rosica, P. (2015). Life cycle assessment of process eco-innovations in an SME automotive supply network. *Sustainability*, *7*(10), 13761–13776. https://doi.org/10.3390/su71013761

Slaper, T., & Hall, T. (2011). The triple bottom line: What is it and how does it work? *Indiana Business Review*, *2*, 4–8. https://www.ibrc.indiana.edu/ibr/2011/spring/article2.html

Smith, L., & Ball, P. (2012). Steps towards sustainable production through modelling material, energy and waste flows. *International Journal of Production Economy*, *140*(1), 227–238. https://doi.org/10.1016/j.ijpe.2012.01.036

Stahel, W. (1997). *The functional economy: Cultural and organizational change*. The Industrial Green Game: Implications for Environmental Design and Management.

Sumrin, S., Gupta, S., Asaad, Y., Wang, Y., Bhattacharya, S., & Foroudi, P. (2021). Eco-innovation for environment and waste prevention. *Journal of Business Research*, *122*, 627–639. https://doi.org/10.1016/j.jbusres.2020.08.001

Svensson, G. (2007). Aspects of sustainable supply chain management (SSCM): conceptual framework and empirical example. *Supply Chain Management International Journal*, *12*(4), 262–266. https://doi.org/10.1108/13598540710759781

Taddeo, R., Simboli, A., Di Vincenzo, F., & Ioppolo, G. (2019). A bibliometric and network analysis of lean and clean (er) production research (1990/2017). *Science of the Total Environment*, *653*, 765–775. https://doi.org/10.1016/j.scitotenv.2018.10.412

Tan, K. H., Denton, P., Rae, R., & Chung, L. (2013). Managing lean capabilities through flexible workforce development: A process and framework. *Production Planning and Control*, *24*(12), 1066–1076. https://doi.org/10.1080/09537287.2011.646013

Tan, Y., Shen, L., & Yao, H. (2011). Sustainable construction practice and contractors' competitiveness: A preliminary study. *Habitat International*, *35*(2), 225–230. https://doi.org/10.1016/j.habitatint.2010.09.008

Thierry, M., Salomon, M., Van Nunen, J., & Van Wassenhove, L. (1995). Strategic Issues in Product Recovery Management. *California Management Review*, *37*(2), 114–135. https://doi.org/10.2307/41165792

Uemura Reche, A. Y., Canciglieri, O. Jr., Estorilio, C. C. A., & Rudek, M. (2020). Integrated product development process and green supply chain management: Contributions, limitations and applications. *Journal of Cleaner Production*, *249*, 119429. https://doi.org/10.1016/j.jclepro.2019.119429

United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

Urbinati, A., Chiaroni, D., & Chiesa, V. (2017). Towards a new taxonomy of circular economy business models. *Journal of Cleaner Production*, *168*, 487–498. https://doi.org/10.1016/j.jclepro.2017.09.047

Vinante, C., Sacco, P., Orzes, G., & Borgianni, Y. (2021). Circular economy metrics: Literature review and company-level classification framework. *Journal of Cleaner Production*, *288*, 125090. https://doi.org/10.1016/j.jclepro.2020.125090

Womack, J. P., & Jones, D. T. (1996). *Lean thinking, banish waste and create wealth in your corporation* (1st ed.). Productivity Press. https://www.worldcat.org/title/lean-thinking-banish-waste-and-create-wealth-in-your-corporation/oclc/51031471

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The machine that changed the world* (p. 323). New York: Rawson Associates. https://www.lean.org/Bookstore/ProductDetails.cfm?SelectedProductID=160

Yadav, G., Luthra, S., Jakhar, S. K., Mangla, S. K., & Rai, D. P. (2020). A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: An automotive case. *Journal of Cleaner Production*, *254*, 120112. https://doi.org/10.1016/j.jclepro.2020.120112

Zhang, B., Niu, Z., & Liu, C. (2020). Lean tools, knowledge management, and lean sustainability: The moderating effects of study conventions. *Sustainability*, *12*, 956. https://doi.org/10.3390/su12030956

Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent manufacturing in the context of industry 4.0: A review. *Engineering*, *3*, 616–630. https://doi.org/10.1016/J.ENG.2017.05.015

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