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Towards a circular economy production system: trends and challenges for operations management

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Editorial

Towards a circular economy production system: trends and challenges for operations management

With the current pace of world population growth, in 2050 more than 9 billion people will consume food, water, resources and demand basic services such as transportation and health. By 2050, to cope with humanity's demand, it is estimated that production systems will devour about 140 billion tons per year of minerals, ores, fossil fuels and biomass – three times the current consumption. Global food production alone needs to increase by 50% by 2050. Natural resources, such as water, are in serious danger, agriculture alone already accounts for about 70% of global water consumption. To meet such huge food production increase, the two-thirds of the water withdrawn from the rivers of the earth, lakes and aquifers currently used for irrigation will need to be dramatically increased. In addition, in the post-production stage, goods are not efficiently managed. As an example, projections suggest that food loss and waste will reach 2.1 billion tons – representing $1.5 trillion – by 2030 (Hegnsholt et al. 2018). That means that about one-third of food intended for human consumption is wasted which cannot be justified in any way given that more than about 900 million people are hungry (UNICEF 2018). On the other hand, after consumption we are not doing well. The majority of electronic products end up in landfills and just a small percentage comes back as/in new electronic devices. In 2016, about 45 million tons of electronic waste (e-waste) was discarded worldwide, with only 10–40% of disposal done properly (Balde et al. 2017). Approximately nine million tons of plastic waste end up in the ocean each year and only about 20% worldwide is recycled (Parker 2018) and that constitutes a serious threat to our ecosystems, wildlife and human health. It is estimated that of all the plastic waste generated till 2015, only 9% have been recycled (Geyer, Jambeck, and Law 2017). In addition, it is projected that about 20% of the world's oil production will be used to make plastic and power the manufacturing of it (Parker 2018). It is urgent to decouple the rate of world economic growth and demand to the rate of consumption of our natural resources. With the growing global publicity and increasing consumer consciousness over the volumes of natural resources required for production of goods, the loss of natural resources by waste and its scarcity, companies and organisations worldwide are being pressed to adopt sustainable practices and make their operations more sustainable, i.e. finding the right balance between profitability and the impacts on the environment and society. In this context, the Circular Economy (CE) concept has gained increasing attention in many parts of the world as a tool to optimising resource usage and extending the lifespan of products, parts and components by simultaneously minimising water and energy consumption, reducing carbon emissions, plastics and organic waste, among others. CE's growing popularity is due in large part to the awareness of resource scarcity and economic activities' negative impacts on the environment. CE represents a drastic change from existing business models with an emphasis on reducing resource usage and waste, whilst maximising recyclability (Awasthi et al. 2019). According to Schroeder, Anggraeni, and Weber (2019), circular economy business models could reduce the overconsumption of resources and address waste generation; therefore, sustainable development may be achieved through CE principles. CE is a production system that requires the transformation of production processes and consumption patterns, system redesign (Sakai et al. 2017), and business model innovation (Geissdoerfer, Vladimirova, and Evans 2018). Therefore, CE is a strategy that promotes economic growth by optimising the consumption of natural resources (Sakai et al. 2017; Webster 2013).

Similarly, green supply chain management aims to reduce the negative environmental impact by streamlining procurements that are based on the principles of reduction, reuse and recycling. Although the practices such as sustainable and green SCM exist, they need to be improved to capture the holistic impact engendered by practices governed by the principles of circular economy. CE principles are pushing and expanding the boundary of SCM and focuses on the development of a holistic business and that 'seems to prioritise the economic systems with primary benefits for the environment, and only implicit gains for social aspects' (Geissdoerfer et al. 2017). It is worth to notice that this lack of integration of the social aspects into circularity has been also highlighted by Murray, Skene, and Haynes (2017). CE takes a proactive stance of creating self-sustaining systems that facilitate a repeat and recycle usage rather than a reactive stance of saving the environment from adverse consequences of business operations (Genovese et al. 2017). In fact, successful CE implementation requires facilitation of SCM (Koh et al. 2017). Key SCM processes such as sourcing, manufacturing, and distribution are also critical processes in CE (Gupta et al. 2019). In addition, some SCM concepts are very much in line with CE. For example, SCM researchers such as (Bell, Mollenkopf, and Stolze 2013) have also recognised the criticality of natural resource scarcity, which is a fundamental driver for CE. Also, a popular SCM concept – the closed-loop supply chain – can also be considered as a basis for broader CE practices. Closed-loop supply chain management refers to the design, control, and operation of a system to maximise value creation over the entire lifecycle of a product with the dynamic recovery of value from different types and volumes of returns over time (Guide and Van Wassenhove 2009). It is apparent that these concepts fit in well with CE and thus those concerned with CE implementation can draw upon existing SCM principles and practices to inform design and operation considerations.

In contrast to the 'take, make and dispose' widely used production model, the CE paradigm is gaining increasing attention from academia, practitioners and policy-makers. The CE paradigm focuses on closing the loop in the production-consumption scheme by implementing restorative systems towards achieving a better balance between the economy, the environment, and hence improving well-being of humanity. CE assumes an efficient circulation of flow of materials, components and products and the use of raw materials and natural resources such as energy and water through the whole production system. To this end, CE aims to regenerate resources, reduce wastes and losses, and enlarge the usability/utility of products, components and materials, as a means of reducing carbon emissions and the depletion of natural resources. This is not a zero sum game and in a fierce competitive world, companies around the world have started to embrace CE as an opportunity to gain competitive advantages and bring value to their stakeholders. From a theoretical perspective, a number of concepts, approaches and/or paradigms have been related to CE, such as cradle-to-cradle, sustainability, industrial ecology, blue economy, circular business models, closed loop value chain, green supply chain and closed loop supply chain to name a few.

Whilst the number of research papers on CE, and the companies keen to adopt it are increasing, there are still many challenges to be addressed from an operational point of view. With this Special Issue, we challenge researchers and practitioners to unpick the essential contributions that operations management approaches should make to support the adoption of the CE paradigm in companies and organisations around the World. We invited researchers to submit cutting-edge research to build and extend the existing body of literature and applications of classical operations management theories in connection with CE. Research that builds theory, validates and extends existing theory with rigorous research methods was especially invited. Submissions from all theoretical and empirical perspectives were encouraged.

Regarding the processes in circular economy model, to simplify our analysis of contributions, we adopted four major processes. Following the classical 'take, make and dispose' widely used linear production model, we introduce a simple '**t**ake-**m**ake-**u**se-**r**estore (tmur)' CE production model to classify the papers, where the tmur are the four stage process of this production model (Webster 2016). Observe that the use process generalises consumption, and the restore process includes waste management and the management of the reverse material flows which could include disposal.

The special issue

This special issue includes 13 papers. As the emphasis of this special issue is on the methodological contribution, the papers were grouped according to the theoretical-analytical approach used. In addition, we introduce a second classification dimension that suggests on which stage process (tmur) in Circular Economy the article is focused on. A list of papers order grouped in these two dimensions is shown in Table 1. It is necessary to emphasise that, some papers could contribute to more than one process in the Circular Economy, however, we have considered pertinent to select the predominant process.

Empirical studies

Make stage process

With regard to the product design process, traditional new product development (NPD) has been widely studied and has a significant impact on the performance of the firm (Praxnikar and Skerlj 2006). The stages of generating an innovative new product to the introduction of this new product to the market plays a key role in business growth by helping companies to face the fierce competition, maintain the existing market and explore new markets (Friedman 1996; Mu 2015). The introduction of sustainable considerations in designing new products make this process significantly different from the conventional NPD (Gmelin and Seuring 2014). Traditional NPD approaches focus on fulfilling the product functions and the returns from the financial costs of development, however the new sustainable and circular economy (CE) trends of NPD considers additional relevant factors such as the type and extent of resources used for developing the new product and the reduction of the negative impact of the product on the natural environment (Sharma and Iyer 2012).

The paper by Subramanian et al. (2019) 'Role of traditional Chinese philosophies and new product development under circular economy in private manufacturing enterprise performance' empirically examines the effect of the introduction of CE practices on the NPD process (CE-NPD) on both time-to-market (TTM) and profit performance in the context of Chinese private enterprises. The authors also study the role of traditional Chinese philosophies of Confucianism and Taoism in influencing the CE-NPD process–performance link. They found that Confucianism positively moderates the relationship between the CE-NPD process and TTM performance. However, it negatively moderates the CE-NPD-profit link. On the other hand, the moderating effect of Taoism is negative on both the CE-NPD-TTM and CE-NPD-profit links. An interesting finding of this study is that the coexistence of Confucian and Taoist values in NPD workers has the strongest positive impact on the relationship between the CE-NPD process and performance.

As the global concern of consumers, politicians and governments is progressively increased about environmental issues, companies have begun to implement strategies to recover consumer trust and increase public support, thereby enhancing these firms' competitiveness (da Silva et al. 2018; Sarkis and Zhu 2008; Zhu et al. 2018). The over-exploitation of natural resources and the pollution and destruction of ecosystems during earlier industrialisation have been largely documented. Thus, there is an urgent demand on manufacturing firms for adopting more sustainable production practices to reduce the use of natural resources and curb the emissions of waste and pollutants (Kearney and World Economic Forum 2018). Circular economy practices are generally considered to increase the efficiency of resources by minimising waste and resource extraction (Lieder and Rashid 2016), and in this respect green manufacturing can be considered one of those practices.

The paper by Mao and Wang (2019) 'Is green manufacturing expensive? Empirical evidence from China' analyses the costs of implementing green manufacturing (GM) and how external institutional pressures can impact the adoption of green manufacturing practices in manufacturing companies in emerging economies. Through an analysis of over 10 thousand observations of 1470 listed manufacturing firms in the Chinese share market from 2008 to 2015, this paper finds that GM

Table 1. List of papers published in this special issue.

Article Title	Authors	CE stage process	Research approach
Role of traditional Chinese philosophies and new product development under circular economy in private manufacturing enterprise performance	Nachiappan Subramanian, Angappa Gunasekaran, LinWu and Tinghua Shen	Make	Empirical
Is green manufacturing expensive? Empirical evidence from China	Yunshi Mao and Jing Wang	Make	Empirical
Circular supply chains in emerging economies – a comparative study of packaging recovery ecosystems in China and Brazil	Luciano Batista, Yu Gong, Susana Pereira, Fu Jia and Alexandre Bittar	Restore	Empirical
Consumers' values and behaviour in the Brazilian coffee-in-capsules market: promoting circular economy	Leila Abuabara, Alberto Paucar-Caceres and Toni Burrowes-Cromwell	Use-Restore	Empirical
Factors influencing the purchase intention of consumers towards remanufactured products: a systematic review and meta-analysis	Deepak Singhal, Sarat Kumar Jena and Sushanta Tripathy	Use-restore	Empirical
The regenerative supply chain: a framework for developing circular economy indicators	Mickey Howard, Peter Hopkinson and Joe Miemczyk	Multiple	Empirical
A circularity measurement toolkit for manufacturing SMEs	Jose Arturo Garza-Reyes, Ailin Salomé Valls, Simon Peter Nadeem, Anthony Anosike and Vikas Kumar	Multiple	Empirical
Antecedents of implementation success in closed-loop supply chain: an empirical investigation	Manjot Singh Bhatia and Rajiv Kumar Srivastava	Multiple	Empirical
The boomerang returns? Accounting for the impact of uncertainties on the dynamics of remanufacturing systems	Thanos E. Goltsos, Borja Ponte, Shixuan Wang, Ying Liu, Mohamed M. Naim and Aris A. Syntetos	Restore	Empirical
Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study	Gianmarco Bressanelli, Marco Perona and Nicola Saccani	Multiple	Empirical
Manufacturer's product choice in the presence of environment-conscious consumers: Brown product or green product	Qi Zhang, Qiuhong Zhao and Xuan Zhao	Use-restore	Math model
Novel model and kernel search heuristic for multi-period closed-loop food supply chain planning with returnable transport items	Yipei Zhang, Feng Chu, Ada Che, Yugang Yu and Xin Feng	Multiple	Math model
The impacts of the coal-electricity price linkage on the profit efficiency of China's thermal power plants	Na Duan, Jun-Peng Guo, Peng Zhou and Bai-Chen Xie	Restore	Math model

increases operating cost (OC). In addition, the positive relationship between GM and OC is strengthened with reduced pollution level in the local city. Furthermore, synergistic effects of the local pollution level and the local government's pollution information transparency are found. Firms' OC increases more as firms carry out GM when both the local pollution level and pollution information transparency of local government are high, or when the local pollution level and the local government's pollution information transparency are low.

Restore stage process

The paper by Batista et al. (2019) 'Circular supply chains in emerging economies – a comparative study of packaging recovery ecosystems in China and Brazil' proposes a circular supply chain framework to derive insights from specific packaging recovery supply chain ecosystems. The proposed circular supply chain model is built upon and expands the closed-loop supply chain perspective. The authors argue that the circular supply chain model represents an expansion of the closed-loop supply chain perspective in terms of scope and focus of the materials recovery systems considered. In terms of scope circular supply chains extend the boundaries of closed-loop supply chains by taking into account post-production stewardship to include forward feeding flows (open loops) into alternative supply chains. A case study approach was applied to validate the proposed framework and capture the particular features of packaging recovery chains developed by Tetra Pack in China and Brazil. The paper concludes that due to the complex multi-layered composition of different materials in its packaging, and food regulation requirements, the company's main supply chain of packaging products is still based on the traditional linear system. Also, to implement its packaging recovery flows, the recovery processes in the circular supply chains model of this company support cascading flows of used packaging into recycling operations that are able to derive a number of materials that are used as feedstock by manufacturers of different recycled products. The circular supply chains enabling packaging recovery flows in both countries are predominantly characterised by open-loops involving third-party companies engaged with cascading processes. In particular, the distinct environments in the Chinese and Brazilian markets render Tetra Pak opportunities to design circular supply chains in different ways showing adaptation and learning to local market characteristics.

Use-restore stage processes

In this Special issue, two papers are focused on the use and restore stage processes of the CE model. In particular, they address the consumer perspectives regarding the CE principles.

The paper by Abuabara et al. (2019), 'Consumers' values and behaviour in the Brazilian coffee-in-capsules market: promoting circular economy' proposes a conceptual framework to support business decision making by adopting a systemic intervention from the consumer viewpoint. The major concern treated in this paper is on the adoption of more design innovation, 'waste to resource' management and, reverse logistics pertaining to the Brazilian coffee in capsules market. Brazil is the world's largest producer and exporter of coffee and it comes as no surprise that Brazilians are also the world's second largest consumers of coffee. According to the national Coffee Industry Association (Associação Brasileira da Indústria do Café – ABIC), this translates as 98.2% of families as coffee drinkers. The sophisticated 'coffee-incapsules' market means a new approach to an individual gourmet experience. Brazilian coffee consumers are now joining this coffee monodose consumption trend. The coffee production chain is demanding additional packaging requirements including materials such as aluminium and plastic. On the reverse flow, capsules collected are composed of organic and recycled waste and needs to be separated in order to meet appropriate waste streams. In this regard, organic material is assigned for composting and aluminium for recycling. Since plastic is used by some manufacturers, they would have included plastic as an additional waste material beyond aluminium and the actual coffee. Despite much talk about an innovative and promising market, it seems that little has been done about the residue and consequences of this re-styled product (ABIC 2017). Rather, there appears to be a drive to increase profitable coffee capsule sales and marketing, at the expense of responsible production (Folha do Meio Ambiente 2016). It is this indiscretion on the part of enterprise which also raises timely questions about the ethical views of coffee consumers and, whether there is an opportunity for an industry shift towards more circular business. To structure the situation, over 40 interviews were conducted, using purposive sampling. Analytic hierarchy process, value focused thinking and Rich Picture technique informed our problem structuring approach. Findings illustrate that reverse logistics supply chain in coffee capsule manufacturing presents real challenges to achieving circular practice. Yet, the eco-values of Brazilian coffee enthusiasts may be partly considered a 'wealth of information flow' and a potential driving force for change.

The second paper by Singhal et al. (2019), 'Factors influencing the purchase intention of consumers towards remanufactured products: a systematic review and meta-analysis' address the end-of-use and end-of-life products and their current unsustainable disposal methods, and raise remanufacturing as a viable option to solve this sustainable problem. In connection with the successfully implementation of remanufacturing as part of a CE strategy, the paper poses the question on the key role that consumers play and study the purchase intention of the consumers towards remanufactured products. The paper uses meta-analysis to statistically synthesise and analyse the factors relevant to the customers purchase intention of the remanufactured products. The authors selected a total of ten studies published in the literature as suitable for the meta-analysis. Some of the findings show that purchase intention of consumers is positively and strongly influenced by attitude and subjective norm, whereas it is moderately influenced by perceived green benefits and perceived behaviour control. In addition, a negative relationship between perceived risk and purchase intention is supported by the analysis. Another interesting conclusion that this research suggests is that consumers who purchase remanufactured electrical and electronics products are less environmentally conscious than consumers who purchase remanufactured automotive products.

Multiple CE stage processes

The following two papers focus on the developing of performance measures to monitor, control, report and communicate progress towards the implementation of the circular economy (CE). Indicators are widely discussed in the literature, however, the concept is not fully developed or applied in a consistent way, with several authors proposing further work is needed in this area (Genovese et al. 2017; Ghisellini, Cialani, and Ulgiati 2016). As a consequence of the increasing concern about sustainability and the adoption of CE practices, traditional indicators need to be revised. As an example, waste reduction language is now inadequate for the systemic shift needed towards CE (Geng, Sarkis, and Ulgiati 2016), where there is a need for significant change in how firms measure their business activity. Indicators are used by organisations to support overall strategy and to show progress towards strategic objectives (Kaplan and Norton 1993). Many business level indicators are publicly available through annual financial reports to keep stakeholders appraised of business performance, but indicators also provide internal support for more operational objectives (Neely, Gregory, and Platts 1995). However, the recent development of strategies relating to sustainability has also led to the development of indicators that are non-economic in nature covering a company's intentions with regard to social and environmental issues, driven by accountability and transparency imperatives (Keeble, Topiol, and Berkeley 2003). Indicators that are reported publicly for accountability reasons often follow the Global Reporting Initiative approach and thus have become relatively standardised and in some cases, companies have adapted sustainable development goals in line with United Nations imperatives on sustainable development (Searcy 2009).

The paper by Howard et al. (2019) 'The regenerative supply chain: a framework for developing circular economy indicators' proposes a framework based on the Ellen MacArthur Foundation butterfly model for developing CE indicators which link core goals, principles and building blocks of a CE. Based on nine multinational organisations and four cases of leading companies engaged with CE activity, they address the types of indicators being used and make recommendations for indicators to reflect key goals and principles of CE. Their research on the development and expansion of circular practices leads to the question of what new opportunities and challenges CE raises for such companies in terms of competitive business advantage and resultant requirements for supply chain redesign and indicator development, over and above pre-existing closed-loop production. The new framework emphasises the importance of both closed- and open-loop circulation and cascade processes for technical and biological materials and provides the basis for developing indicators for measuring and monitoring whole organisation, supply chain, production and operations activities.

The paper by Garza-Reyes et al. (2019) 'A circularity measurement toolkit for manufacturing SMEs' also focuses on performance measurement in manufacturing SMEs in contrast to the paper by Howard et al. (2019). They also argue that, despite the widespread adoption of CE principles, little progress has been made regarding its measurement, especially in manufacturing SMEs. The paper proposes a Circularity Measurement Toolkit (CMT) which enables the assessment of the degree of circularity in manufacturing SMEs. A conceptual CMT framework provides the basis for the proposed tool. Based on an extensive literature review, different types of circular practices and levels of circularity were developed. A Delphi-study was applied to validate the structure's accuracy of the proposed CMT. Finally, a case study approach was conducted on a manufacturing SME to validate its applicability. By using the proposed CMT framework, SMEs organisations can evaluate its degree of circularity and can also identify corrective actions or future efforts for the adoption of CE practices.

The third paper in this line, by Bhatia and Srivastava (2019) 'Antecedents of implementation success in closed-loop supply chain: an empirical investigation' relates to performance measure of firms linking closed-loop supply chain (CLSC) and circular economy models. This paper, in contrast with the previous two, does not propose a set of indicators. The purpose is to identify critical success factors that most influence the performance outcomes of CLSC implementation. Critical Success Factors (CSFs) represent those few areas that should be given special attention to bring improvement in certain outcomes (Boynton and Zmud 1984). Due to the increasing environmental global awareness, closed-loop supply chain has gained increased attention as a framework concept to address environmental, product returns and scarcity of natural resources concerns. CLSC is defined as 'the design, control and operation of a system to maximize value creation over the entire life cycle of a product with the dynamic recovery of value from different types and volumes of returns over time' (Guide and Van Wassenhove 2009) and integrates social, environmental and economic concerns. Systems that manage the integration of forward and reverse flows in the supply chain are also known as circular production systems (Goltsos et al. 2018). Thus, the relationship between CLSP and CE is straightforward. This paper examines the impact of CLSC critical success factors (CSFs) on performance outcomes. Firstly, by conducting an exploratory factor analysis, the CSFs and performance outcomes are extracted. The resulting proposed model groups eight critical success factors including production planning, product design and collection, product recovery, environmental concerns, demand and inventory management, organisational leadership, sustainable production and raw material price. Then, using the data collected from 138 professionals working in remanufacturing, refurbishing and recycling operations in North American manufacturing organisations, the relationships between CLSC CSFs and performance outcomes are empirically tested. The authors found that 'environmental concerns', 'sustainable production' and 'product design and collection' have a significant positive effect on environmental performance of CLSC implementation. Results also validate the significant positive effect of 'demand and inventory management' and 'raw material prices' on economic performance. According to the authors' knowledge, this is the first study that examines the impact of CLSC CSFs on performance outcomes.

Literature review

In this special issue, we have two literature review papers addressing different aspects of Circular Economy. The paper by Goltsos et al. (2019), 'The boomerang returns? Accounting for the impact of uncertainties on the dynamics of remanufacturing systems' provides a literature review on the field of closed-loop supply chain dynamics, exploring the time-varying interactions of material and information flows in the different elements of remanufacturing supply chains. Remanufacturing, defined by (Daniel, Guide, and Jayaraman 2000), as 'the transformation of used products (referred to as cores), consisting of components and parts, into products that satisfy exactly the same quality and other standards as new products' has its origins dating back to the 1940s in both US and European automotive firms aiming at retaining the value of their products (Zhang and Chen 2015). Due to the increasing sustainability concerns over the last two decades, manufacturing has resulted in a shift from a linear to a circular production model (Lieder and Rashid 2016). From this perspective, remanufacturing networks are gaining momentum as the backbone of 'circular economy' models, given their strong association with financial, environmental and social sustainability (Abbey, Daniel, and Guide Jr 2018; Agrawal, Singh, and Murtaza 2015; Giutini and Gaudette 2003; United States International Trade Commission 2012). The paper considers the three 'pillars' of closed-loop systems to be the functions of forecasting, collection, and inventory and production control. Through this interdisciplinary lens the authors investigate how sale, consumption, and return processes ('boomerang' effect) impacts on the behaviour of the closed-loop system and how it can be controlled. In particular, this paper analyses how the uncertainties due to remanufacturing in supply, process, demand and control affect the dynamics of the closed-loop supply chain. Research approaches from different disciplines are described and insights for future research are drawn.

The literature review paper by Bressanelli et al. (2019) 'Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study' conducts a systematic literature review about the challenges connected to supply chain redesign for CE, combined with a case-based research. Supply chain management and configuration activities play a major role in decoupling economic growth from resource extraction and environmental losses. For instance, through a Life Cycle Assessment, it has been demonstrated that circular supply chains for insulation materials – in which waste is utilised as raw materials – reduce the emissions of Carbon Dioxide by 60% (Nasir et al. 2017). Despite the environmental, economic and social benefits, companies face several obstacles that make the transition to CE far from obvious (van Loon, Delagarde, and Van Wassenhove 2018). For instance, some such obstacles widely recognised in the literature are the uncertainties about quantity, quality and timing of product returns that arise in closed-loop supply chains, which are transferred to uncertainties in, for instance, capacity planning for renovation activities such as remanufacturing (Linder and Williander 2017). When adapting supply chain management to CE principles the literature lacks a systematisation of such obstacles and challenges and of the ways to overcome them. This paper covers this gap and identifies and systematises 24 challenges, grouped into 7 categories, that may hamper a supply chain redesign for the Circular Economy. Sixteen among these challenges are well known from research in related topics. On the contrary, the remaining eight are relatively new or take a different relevance within the Circular Economy context. It also identifies a set of levers (e.g. modular design, integrated forward/reverse supply chains, collaborative agreements, access replacing ownership, etc.) that can be used to overcome these challenges. The paper also includes an empirical study of four companies of different size and scope and at different supply chain levels, analysing the challenges they face in their CE initiatives and the levers adopted. The empirical study, in conjunction with the literature analysis, leads to the development of a framework linking the challenges to specific levers that companies may pursue to overcome them. The framework can be seen as a reference for managers undertaking the path towards Circular Economy.

Mathematical models

We compile three papers that use mathematical models to address some particular problems related to the implementation of CE strategies.

Use-restore stage processes

The paper by Zhang et al. (2019), 'Manufacturer's product choice in the presence of environment-conscious consumers: Brown product or green products' emphasise the necessity to switch to green alternative products due to the increasing environmental consciousness of customers. In this paper, a green product is a product that is less detrimental to the environment or human health than the traditional one at function parity; and the traditional product is defined as a brown product. A number published and surveys have reported that environment-conscious consumers' valuation for green products is higher than their valuation for brown products. In this paper, the targeted consumers are assumed to be environment-conscious, they value green product higher than brown product and would like to pay more for product with higher green level. In the dyadic supply chain problems addressed in this paper, a manufacturer currently only produces a brown product and distributes the product through a retailer. Green products are not currently produced by the manufacturer, so the manufacturer has limited green expertise. Based on this background, the paper explores the optimal product choice for the manufacturer using a Stackelberg game model where the manufacturer is the Stackelberg leader, and the retailer would act as the follower. It first derived the optimal results for each product choice. Then we analyse the optimal product choice for the manufacturer. Next, the paper studies how to induce the production of green product. Finally, the fraudulent behaviour on product's environmental attributes is addressed. Main findings are as follows. First, manufacturer's optimal product choice is to produce a green product if the investment-to-value ratio and the unit production cost for the green product are low, and to produce a brown product if the investment-to-value ratio and the unit production cost for green product are high. Second, the two-part tariff contract is applicable to stimulate the manufacturer to produce green products under certain conditions. While exterior intervention is necessary under other conditions. Third, when the manufacturer and the retailer diverge in product preference, the manufacturer has a strong incentive to behave fraudulently, and this type of manufacturer needs strict supervision.

Multiple stage processes

In the paper by Zhang et al. (2019) 'Novel model and kernel search heuristic for multi-period closed-loop food supply chain planning with returnable transport ítems' the physical network design of a closed loop supply chain (CLSC) for the food industry is addressed. We have already highlighted in this special issue the importance of the design and management of the closed loop supply chain in the successful implementation of CE strategies. This paper aims to investigate a multi-period CLSC network-design problem that coordinates the flows of perishable food products and returnable transport items (RTIs) considering food quality. The objective is to maximise the total profit of the holistic supply chain over a finite planning horizon. To this end, a novel mixed integer linear programming model is first formulated. As the problem is proven NP-hard, an improved kernel search-based heuristic is then developed. A real case study deriving from a food manufacturer in China shows the applicability of the proposed model and method. The results indicate that the manufacturer's profit can be improved by more than 10% with the method. Numerical experiments on randomly generated instances demonstrate that the proposed heuristic can yield high-quality solutions with much less computation time compared with the commercial solver CPLEX and an existing heuristic.

The paper by Duan et al. (2019) 'The impacts of the coal-electricity price linkage on the profit efficiency of China's thermal power plants' studies the on-grid electricity and coal price linkage involving the businesses of the plants and grids at the same time. From the perspective of circular economy, which is widely recognised to be effective in achieving low-carbon transition, the coal reserves/mines and thermal power plants are both vital components of the closing materials loops (Fang et al. 2017; Li et al. 2010; Rafique, Mun, and Zhao 2017). Apart from renewable energy sources and carbon capture, the future circular economy will also require high penetration of energy efficiency (Budzianowski 2017). Fundamentally, a power plant would be profitably operating if the electricity price sufficiently covers its production costs for which the fuel costs account for a large part (Carraretto 2006). Under the dual track mechanism of 'market coal and plan electricity', China's power price cannot be adjusted in a timely manner according to the changes in the coal price. The authorities put forward the policy of coal electricity linkage to overcome this dilemma in 2004 and updated the relevant details in 2016. Based on the directional distance function, this study measured the profit efficiency of over 1300 thermal power plants in China during 2002–2011 and investigated the impacts of the linkage policy using scenario analysis. The authors implemented the bootstrap method to analyse the sensitivity of the estimators of efficiency to sample variation and the impacts of plant-specific factors. The empirical results show that: First, compared to the predetermined directional vector approach, the generalised endogenous projection vectors made the estimated inefficiency scores perform better in objectivity, feasibility, and differentiation. Second, technical inefficiency was the primary cause of the profit inefficiency during the study period rather than allocative inefficiency. The large generation groups attained higher profit efficiencies than the power plants not affiliated to them. Finally, in straightening out the relationship between the coal and power prices, the linkage mechanism could only be a transitory step to the electricity market-oriented reform.

Conclusion

This special issue demonstrates that a multidisciplinary community of researchers in operational research, economics, engineering, administration and other areas are studying the adoption of circular economy practices and analysing their impacts on production systems. The results and findings compiled demonstrate that still there is much research needed to advance theory on the way to adjust and improve the integration of circular practices in the planning and management of production systems. In addition, empirical results provide a significant understanding about the opportunities and barriers that companies and organisations are facing to adopt circular economy practices and moving away from the traditional linear economy model. We realise that the preferred approach to implementing circular economy principles on production systems is supply chain management-based models, in particular, closed-loop supply chain management. However, the interrelationship of the source-make-use-restore process stages of the circular economy concept needs still to be clearly explored and integrated in the closed-loop supply chain management models. In fact, closed-loop supply chain mathematical models for supporting the implementation of circular economy practices seems to be an interesting path for future research.

The editors of this special issue recognise that this is a small piece of contribution shedding lights on how the implementation of circular economy practices can help to achieve some of the most pressing sustainable development goals. Without doubt, the investigation on how production systems are being impacted and how companies will be impacted by the adoption of circular practices is not a mature area yet, and further efforts are needed to expand the existing body of research on what we could call circular production systems, i.e. production systems that adopt circular economy practices.

Researchers, managers, policy-makers and decision-makers can benefit from this collection by having a better understanding of the circular economy concepts and the impacts that its adoption could have in companies and organisations. In particular, they will find the following:

- A collection of empirical studies and survey papers that indicate the level of adoption of CE principles and the barriers and challenges to its adoption;
- Case studies in the levels of adoption of CE, among producers and consumers, and approaches taken for its facilitation and implementation;
- Several papers that emphasise the need for unified terminologies of CE and its relationship with existing production systems and operations management concepts and approaches;
- Papers that propose a set of performance measures to monitor and analyse the adoption level of CE;
- This Special Issues also include methodological papers on how Operations Management principles and practices can be adapted to account for CE objectives.

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