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Circular Economy: Recent Technology Management Considerations

Supply chain innovation key to business-to-consumer closed-loop systems

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As citizens, organisations and governments across the globe increase their interest in environmentally and socially sustainable means of production and consumption, the idea of a circular economy (CE) has been at the forefront of recent discussions held at organisational, national and international levels. This article briefly presents the CE concept from a supply chain management perspective. Then, two contemporary, representative CE technology management problems are introduced. The article concludes with some takeaways that policy makers and managers can use to inform further CE development.

1. Introduction

The United Nations (UN) World Commission on Environment and Development defines sustainable development as a trajectory where future generations are secured the same level of welfare as present living generations (1). The economic implication of this approach is a requirement for constant and regenerative utility (2). The global middle class is estimated to double in size to nearly five billion by the year 2030 (3). As the number of middle-class consumers increases, natural resources required to support population expansion are rapidly decreasing (4). In addition, the waste generated by first world economies is estimated to be 3.5 million tonnes per day; the amount of waste generated will grow proportionately with the number of middle-class consumers throughout the world (5), approximately 2 billion tonnes of solid waste are produced each year by the world's cities, roughly half of which is organic waste (6). Thus, strategies that support sustainable industrial initiatives to emphasise the reclamation and retransformation of resources need to become more ubiquitous in order to support global population growth and subsequent increases in consumption.

The European Union (EU) recently set a strategy to transition towards a CE by adopting a 'closing the loop' approach to industrial production systems. One of the goals of this strategy is to maintain the value of products, materials and resources in the economy for the longest time possible, in consideration of waste minimisation (7).

CE is a regenerative approach to sustaining consumption requirements while preserving natural resources (8) and can be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (9). For any given organisation, adopting a CE approach entails incorporating strategies, policies and processes that consider environmental performance, waste reduction and efficient consumption across the entire supply chain network (10).

The proper leveraging of technology is already proving to be a necessary condition for developing and sustaining both large and small CE initiatives alike. However, not only is the idea of CE new and somewhat daunting, but the emerging technologies upon which these CE networks will be operated are not well understood even by those who manage today's linear supply chains. This article introduces CE from a supply chain management perspective and introduces two supporting technologies for the purpose of informing current and future stakeholders about CE technology management.

2. Circular Economy as a Closed-Loop Supply Chain

As the interest surrounding CE continues to grow, supporting supply chain practices are also gaining more attention. From a supply chain perspective, CE is based on many of the same concepts used to employ business-to-business closed-loop systems. These systems are typically in place to support the lifecycle of large or expensive assets such as aircraft and large machinery. Conversely, business-to-consumer models historically employ more linear concepts, where products are delivered to consumers, who then chose if, and if so, how to maintain and dispose of them. In essence, CE is the operationalisation of a business-to-consumer closed-loop supply chain system. As such, there is a lot that can be learned from business-to-business closed-loop supply chain best practices. Such practices include increasing resource reuse throughout the supply chain, increasing resource efficiency, dematerialising waste through resource conversion and slowing the amount of new resources introduced into the system *via* product life cycle extension (11).

Managers and policy makers are promoting CE as a means of sustainable resource consumption (12). However, the transition from a linear economy to a circular one requires fundamental changes in the way businesses are currently operated (13). While change in itself is often a difficult process to manage, making these changes might be worth the effort in that it can leverage opportunities to introduce new, more sustainable business models.

For example, HP Inc, USA, closed-loop printer ink programmes have reduced waste associated with consumer printing by 67% (14). In addition, Italian fashion brand company Calzedonia Group promotes a recycling campaign that incentivises in-store drop-off of all types of used garments *via* store credit. These garments are then recycled and, to date, the company has collected over 2 million kg of clothing that has been subsequently recycled (15). In another example, Nestlé, Switzerland, estimates that it produced about 1.5 million tonnes of plastic in 2018. Recognising the negative ramifications of this production, the company announced that it strives to make 100% of its packaging reusable or recyclable by 2025 and has recently begun an initiative to eliminate all plastic straws in its products (16). Those are some of many examples where CE can be implemented to produce a win-win for all stakeholders (i.e. consumers *via* lower prices; environment *via* lower resource usage; producer *via* lower production costs).

Perhaps other organisations can adopt similar programmes that have the opportunity to improve both environmental and economic performance. In today's technology driven supply chains, the importance of leveraging existing and emerging technologies that help to enable CE cannot be understated. In the next section, two supporting technologies are described as a means to demonstrate the role of technology in making CE a reality.

3. Circular Economy Technologies

Many of today's CE challenges are driving technological advancements as a means to close the loop and reuse resources. Although there are indeed many challenges to implementation such as motivating new consumption behaviours, redesigning supply chains and revamping regulation, governments and managers alike continue to build and leverage technology to support their CE initiatives. In fact, Korhonen *et al*. (17) suggest that, when CE processes are effectively combined with appropriate technological innovations, the result has significant positive impacts on several echelons and levels of contemporary value chains. This pairing is proposed to lead to transformation in favour of both the environment and economic growth (18). As such, CE participants require a robust strategy to plan and manage increasing complexity across their supply chain processes that support CE (19).

New technologies will play a prevalent role in CE development (20) and help to shape fundamental strategies for organisations seeking to participate in CE (21). These technological advancements will not only help improve industrial processes and operations, but also help to integrate the critical role of the consumer (22). Two major categories of technological innovation deal with the multidisciplinary problem of plastic manufacturing and recycling and the employment of big data analytics (BDA). The following subsections describe these technologies.

3.1 Plastics

Less than 15% of plastic waste is collected for recycling while the rest is put in landfills, incinerated, moved to less-developed nations or abandoned completely (23). Approximately half of all plastic ever produced has been manufactured since 2000 (24). Unfortunately, recapturing plastic waste has been problematic for many reasons. For instance, polypropylene (resin identification code 5) cups and lids promoted as recyclable by fast food restaurants are not recyclable in a growing number of places of the United States (25).

Current chemical recycling technologies can return used plastics into their original naphtha (petroleum) form, at which time they can be converted into new polymers (26). However, these processes are seen by many as cost restrictive in that new plastics are cheap and already clean and the cost to recycle is often more than the cost to discard and simply make new plastics. As such, recycling of plastics and many other raw materials is declining in favour of more cost-effective practices, despite the negative environmental impacts.

The EU is a first mover among large governmental institutions to support CE initiatives and has recently put into place strong policies with goals such as making all plastic packaging recyclable, compostable or reusable by 2030 (27). Consequently, governments and other institutions seek innovations related to the plastics industry. As one example, a report by the World Economic Forum reveals that bioplastics represent one of the most important breakthrough technologies expected to radically impact the global social and economic order (23). Similar CE technologies facilitate making plastics from urban food waste (28, 29) or lignin from plant waste (30), which increases material strength without using crops that could otherwise be used for food. From a CE perspective, these wastes can be seen as a resource, not simply a cost to manage.

3.2 Big Data Analytics

BDA is seen as an imperative for designing and implementing CE strategies (31, 32). Insights derived from BDA facilitate decision-making in sustainable production (33). In CE, these insights can be leveraged to integrate processes (both internal and external) and facilitate resource sharing. As shown in **Figure 1**, managers start with identifying shared goals with internal and external partners. Then, the employment of technologies that enable better information sharing and relationships among members of the network add value that goes beyond the transactional level and thus creates true knowledge-sharing networks. This synergistic approach facilitates the ability to sense and seize problems and opportunities across the CE ecosystem. In the end, collaboration, visibility and transparency across processes and between organisations allows supply chains to achieve several goals, such as: to improve customer service and fulfilment, to react faster to supply chain disruptions, to increase efficiency, to improve integration and to better monitor product life cycles (34).

Disruptive technologies (such as cloud computing, the internet of things, machine learning and artificial intelligence (AI)) might eventually become a part of the CE ecosystem and will need to be constantly monitored and assessed for their usefulness to develop new CE business models and address current challenges presented by CE operations. Good supply chain partners should jointly monitor information, people, processes and decisions made regarding a product throughout its entire life cycle (35) using these advanced, complimentary technologies.

Managers appreciate the operational complexity surrounding the large-scale implementation of consumer-focused closed-loop supply chains. This can lead to resistance to adoption of CE practices. However, this resistance can be allayed when existing or new BDA processes are used to generate greater understanding of operational-level elements and how they relate to higher-level CE strategy.

3.3 Other Technologies

Supply chain digitalisation efforts are driving the way organisations compete with their supply chains. These technologies include additive manufacturing, AI, augmented reality, blockchain, cloud computing, internet of things and many others (36). Although it is beyond the scope of this article to go into detail, we briefly describe some of these technologies and uses next.

One of the most prominent technologies today is AI. As a facet of AI, machine learning suggests "the machine's ability to keep improving its performance without humans having to explain exactly how to accomplish all the tasks it's given" (37).

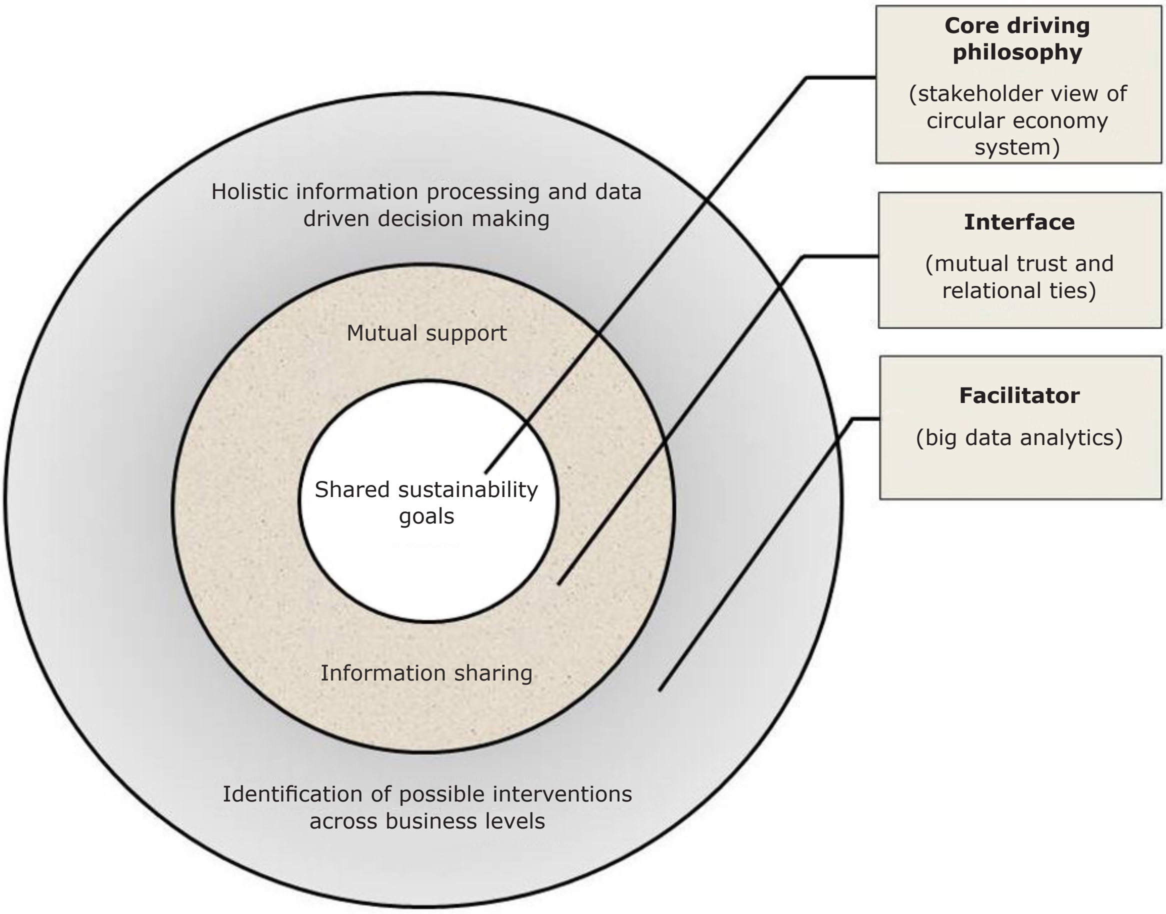

Fig. 1. A stakeholder view of using BDA for CE. Reprinted from (32) with permission from Elsevier, copyright (2019)

The near future will see humans working further to structure extant complex problems such that appropriate inquiries can be formulated to leverage the computational advantages presented by ever increasing machine capabilities. It is thus imperative to understand how to strike the right balance between human and machine interaction (38). To face increasing environmental challenges, companies and researchers are developing AI assisted robotic technologies that can work with humans to optimise processing of recycled materials in terms of sustainability, efficiency, profitability and safety (39).

The advent of blockchain technology has brought the discussion of trustless systems to the forefront of both academic and business discussions. Blockchain denotes a secure database system based on distributed ledger technology, where business rules dictate automated consensus algorithms that serve to validate and write transactions to an immutable ledger that is distributed across a given network of computers. Companies are currently using blockchain for track and trace and financial transaction applications and are realising benefits related to transparency, trading partner trust, provenance validation and transaction costs. These benefits can help to enable accountability and consistency in CE networks.

4. The Road Ahead

Here is a summary of key takeaways for managers and policy makers who are new to CE or charged with implementing its concepts:

- Transition to CE will be successful only if all parties involved in the supply chain (including the consumer) are involved and committed. This works if the new business model will create value for all stakeholders *via* advancing more sustainable closed-loop systems
- Supply chain collaboration is essential when it comes to transforming a business to CE
- The future of CE as a viable and profitable business model depends on technologies that

will enable organisations to move beyond participating in the current linear (cradle to grave) paradigm and advance to the circular (cradle to cradle)

- BDA and related technologies will be key drivers to help economies become more circular. Advancements toward this end will require multidisciplinary expertise in order to inform new processes and organisational constructs. Logistics and supply chain management skills are fundamental for the successful reorganisation of processes and policies aimed at closing the loops
- BDA and associated AI-related technologies can be employed to help organisations measure and control their impacts
- Solving the zero-trust problem is critical for supply chain management and global trade. Technologies like blockchain might be leveraged to solve this problem
- The role of consumers is a significant determinant of CE success. Consumers are no longer the final position in the supply chain, but serve as an important, decision-making actor within the supply chain
- Organisations that organise and manage their CE processes in order to allay societal and environmental consequences will be better positioned to compete on economic, environmental and social performance
- A critical component of advancing CE initiatives includes managing closed-loop supply chains at the business-to-consumer level. Several CE objectives can be achieved only when an efficient and effective closed-loop system is well designed and managed.

5. Conclusion

This article introduced CE and discussed two areas of technological innovation that are helping to initiate and support CE initiatives: plastics innovation and big data analytics. Of course, there are several other technologies that are being used to close the supply chain loop and make CE a reality, as also discussed. However, we submit that the technologies discussed herein are representative of extant CE technology management problems in that they both require and facilitate multidisciplinary collaboration, information sharing and the inclusion of relevant stakeholders (especially consumers who are becoming important nodes in the supply chain, rather than the end point of a linear production process).

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