THE ROLE OF LEAN PRODUCTION AND THE LIFE CYCLE ASSESSMENT IN A CIRCULAR ECONOMY

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Abstract

This article summarizes bibliographic and comparative analysis which is an extensive review of the scientific literature in this area to reveal the basic ideas of a closed-loop economy, global implementation experience at the micro and macro levels, and the development prospects of this area. The authors also examined the basic principles of the functioning of the circular economy, its advantages and disadvantages. Reveal the vital role of lean production and the life cycle assessment (LCA) in a circular economy. Besides, this effect can be further enhanced by applying lean principles to the loop, providing additive value to every step of the cycle. The stages of the analysis by the LCA method are disclosed. The article shows the interconnectedness of the circular economy and lean principles. Using modern monitoring methods like IoT and pushing automation even further with recent advancements in computer science makes implementing this type of economic model, not a what-if scenario, but a feasible reality.

Key words: circular economy, lean production, LCA

JEL Code: O14, Q01

Introduction

One of the main challenges of the modern economy is to move from the current linear model of production and consumption to a new, more efficient one. Scientists see the solution of this problem in the transition to a closed-loop economy or a circular economy. The circular economy is an attempt to conceptually integrate economic activity and environmental well-being, based on reducing the environmental intensity of economic growth, reducing greenhouse gases, more rational production, extending the life cycle of goods, reducing waste, preserving natural resources, creating new jobs, etc. The essence of the circular economy in achieving harmony between the economy, the environment and society. This predetermined the relevance of the study.

According to experts of the Ellen MacArthur Foundation, the circular economy (CE) can annually provide an increase in the global economy's income of over $ 1 trillion by 2025, and through industrial innovations offer an increase in productivity of 3%, and as a result, an increase in world GDP of 7%. McKinsey estimates the transition to a closed-loop economy will bring the economy of the European Union 1.8 trillion dollars by 2030, will lead to a 53% reduction in primary resource consumption and 83% reduction in carbon dioxide emissions by 2050.

On the one hand, the article focuses on barriers to the development of a circular economy; on the other hand, opportunities are presented for developing strategies for transition from the current linear economic model to a circular one. Opportunities for the transition to a circular economy are revealed through values of life cycle assessment (LCA) and lean production. This paper is based on the aspiration to actively promote a culture of continuous improvement with the flexibility to adapt as needed. Therefore, processes, design and strategies must be developed throughout the organization and can be developed through inter-organizational learning and collaboration. The goal is to use and rely on knowledge from any available sources.

1 Methodology

The methodological basis for this study is the use of such methods of scientific knowledge as induction, deduction, analysis and synthesis. At the same time, comparative and bibliographic analysis became the main ones, which made it possible to determine the principles and mechanisms of the circular economy and the value of the life cycle assessment and lean production in the CE. The information base for the study was analytical reviews, reports and analytical materials from relevant international departments and agencies, as well as the work of Russian and foreign scientists.

The conducted bibliographic and comparative analysis is a review of the scientific literature in this area, to reveal the basic ideas of a closed-loop economy, the role of LCA and lean manufacturing. The authors also examined the basic principles of the functioning of the circular economy, its advantages and disadvantages.

2 Principles and mechanisms of the circular economy

The circular economy is represented by such processes that require minimal extraction of natural resources, do not have a depressing effect on the environment due to the reuse of materials. The sustainability of a circular economy is determined by a functional social structure that contributes to human well-being. The circular economy is based on the use of renewable, non-toxic and biodegradable materials. The useful life of materials is extended by reuse in the production of new products, modern technological development, focused on the longevity of resources and minimization of waste, as well as sharing economy. (Foster, 2020). At the same time, the circular economy model prescribes that waste is not only minimized but also cycled back into production processes. Accordingly, studies of CE policies focus primarily on waste treatment, including production process-based approaches to eliminating waste. However, some studies examine the circular economy in many aspects: the contribution of government purchasing decisions to CE advancement, referenced primarily in the context of sustainable public procurement. There are examples of meta-level reviews or comparisons of CE policies; most studies are case- or industry-specific and focus on quality standards, public procurement, market mechanisms, education, promotion, and upskilling, infrastructure financial incentives and labelling related to the quality of reused and remanufactured products (Hartley et al., 2020).

The basic principles of a circular economy complement bioeconomics and should facilitate the recycling and reuse of materials, which should be aimed at creating integrated sustainable approaches that develop a holistic utilization of resources. It is also expected that the transition to a promising area of bioeconomics will provide the prospect of renewed competitiveness, positive economic development and job creation through organizational, social and technological innovations. The circular economy is by definition, “restorative and regenerative,” demonstrating the quality principles of using resources and components, increasing their functionality and value, thereby reducing waste generation and closing loops. Technological, socio-political and economic restructuring is fundamental to the inclusion of new technologies and approaches that will contribute to a circulating economy and economic closure (Maina et al., 2020). Thus, we can distinguish the main nine principles of the circular economy (Table 1).

For a more systematic study of barriers in practice, a classification of barriers to CE transformation for companies has been proposed. Barriers are easy to find, barriers are also presented - in our analysis, they are divided into categories presented in Table 2, which also presents the barriers most often found in the literature. There are a large number of barriers, and they must be multidimensional and multi-domain.

Tab. 1: The main principles of the circular economy

a) Use and create a product more intelligently	R0 Refuse	Making a product redundant by abandoning its function or supplying it with a radically different product.
	R1 Rethink	Intensify product use (for example by sharing products, or multifunctional products).
	R2 Reduce	Producing a product more efficient by using less (raw) materials in the product or its use.
b) Lifetime extension of product and parts	R3 Reuse	Reuse of discarded, still right product to the same function by another user.
	R4 Repair	Repair and maintenance of defective product for use in its old function.
	R5 Refurbish	Refurbish or modernize an old product.
	R6 Remanufacture	Use parts of the discarded product in a new product with the same function.
	R7 Repurpose	Use the discarded product or parts of it in a new product with a different function.
c) The useful application of materials	R8 Recycle	Process materials to the same (high-quality) or lower (low-quality) quality.
	R9 Recover	Incineration of materials for energy recovery purposes.
d) Substitution	Substitution	Substitution of non-renewable materials.

Source: Schoenaker et al. 2020.

To overcome barriers, integration can be integration between (Ritzén & Sandström, 2017):

- perspectives on sustainability and business development;
- perspectives on products, services and systems;
- different functional domains (functions/departments);
- different hierarchical levels;
- actors along the value chain from raw material suppliers to end-users.

Tab 2. Barriers for moving towards CE.

Financial	Measuring the financial benefits of the circular economy Financial profitability
Structural	Missing exchange of information Unclear responsibility distribution Operational Infrastructure/ Supply chain management
Attitudinal	Perception of sustainability Risk aversion
Technological	Product design

	Integration into production processes

Source: Ritzén & Sandström, 2017.

Based on these various contributions, we define a circular economy as a regenerative system in which resource costs and losses, emissions and energy leaks are minimized by slowing down, closing and narrowing material and energy loops. This can be achieved through long-term design, maintenance, repair, reuse, recovery, restoration and recycling. Thus, an essential concept of a circular business model arises (Schoenaker et al., 2020). Circular business models are a generic term for a wide variety of business models that seek to use fewer materials and resources to produce products and / or services; extending the life of existing products and / or services through repair and restoration; completing the product life cycle through processing, capitalizing on the residual value of products and materials. One of the mechanisms for implementing such business models is life cycle assessment and lean production (Geissdoerfer et al., 2020).

3 The value of the life cycle assessment and lean production in CE

The transition to a circular economy will contribute to the achievement of the Sustainable Development Goals (SDGs) by 2030, in particular, Goal 12 - ensuring sustainable consumption and production patterns. The foundations of a successful circulation of resources are laid long before the start of production phase Life Cycle Assessment is a method developed to evaluate the environmental impact of a product or process. The life cycle assessment allows evaluating the potential positive and negative effects of a product, some of which are usually invisible. Considering the source materials, processes and sub-products that are necessary or inevitable in the manufacture of the product, this can evaluate the impact of the choice of materials and processes. By measuring the subsequent impact of the product, it is possible to determine the environmental impact of the use, reuse and final disposal of the product (Ratner & Lychev, 2019). The value of the Life cycle assessment (LCA) method is to enable us to measure the holistic environmental impact or performance of a product at each stage in its life cycle. It provides a measure which can be used to compare the environmental sustainability of similar products and services which have the same function. LCA considers the potential impacts from all stages of the material's life cycle, including manufacture, product use and end-of-life stages. There are some international standards for assessing the life cycle (ISO14040 and 14044), but they do not prescribe the amount, quality of data, the method of assessment or category of impact (Walker & Rothman, 2020).

The LCA method consists of the following four main steps:

1) Goal and scope definition. At this point, the researcher must determine the research objective, define the functional unit and set the system's boundaries. The "cradle-to-grave" or "cradle-to-gate" approach is used most often when defining system boundaries.

2) Life Cycle Inventory (LCI). At this step, a complete map of the studied life cycle as a sequence of production and transportation processes is built. The inputs and outputs of each production / transport process are determined. Inputs can be such as raw materials, water and energy consumption, intermediate processes. The outputs can be such as main product, wastes and emissions to the air, water and soil.

3) Life Cycle Impact Assessment (LCIA). At this step, the identified potential environmental impacts of the production system are translated into such environmental impact categories as global warming, acidification, eco-toxicity, ozone depletion, abiotic depletion, eutrophication etc.

4) Interpretation. In this step, the researcher summarizes the LCI and LCIA results, identifies critical points of the life cycle with the most significant adverse effects and make recommendations for possible improvements.

Thus, LCA allows to complement the circular economy in three practical steps:

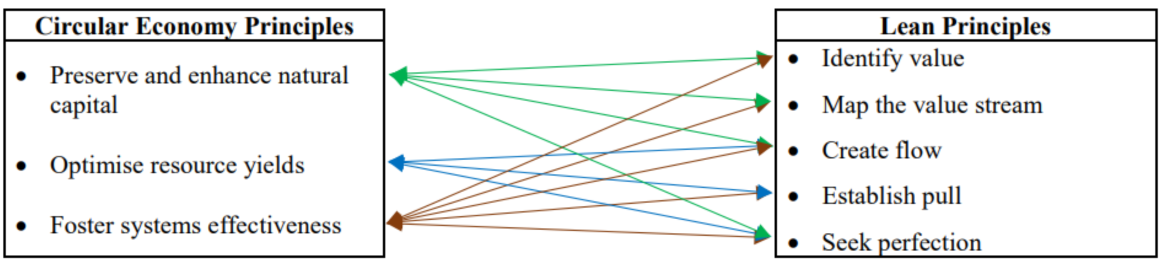
• Test the assumptions of the circular economy business models

• Recognize limitations of the circular model and explore new, alternative approaches

• Set objectives and continuously improve the circularity for practical implementation at the business level.

Even though Lean is a relatively old concept, its relevance is still high, especially in conjunction with principles of the circular economy. While the latter shows purpose and direction, the former provides the means to implement this vision. Lean and CE have different approaches to the two main elements: "waste management" and "value creation". The lean approach is not as holistic as the CE, and it lacks a closed system, a hallmark of CE (Figure 1).

Figure 1: The interconnectedness of the circular economy and lean principles

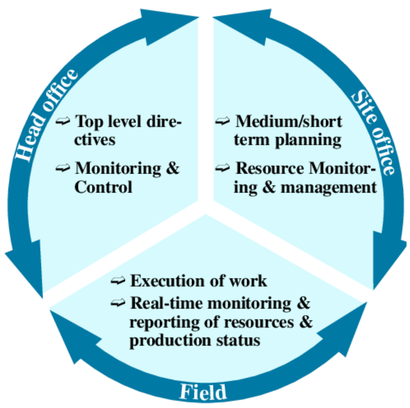


Source: Nadeem et al., 2019

Applying Lean principles to every step of CE can be beneficial to improve efficiency and reduce further waste, thus reducing the number of loops required to achieve a complete cycle. Furthermore, due to the maturity of Lean, it has a lot of actionable recommendations, how-to's and best practices in different industries, which can help to adapt and implement CE in real-world scenarios.

However, in every implementation of theory, there is a problem with control and validation whether processes are following the guidelines of the theory above, especially with modern requirements to any industry – to be dynamic and flexible, making things even more complicated through process variability. Nowadays, it is almost impossible to predefine and dictate the manufacturing flow as something strict and rigid while staying productive and competitive. Variability in both requirement and consequence can adapt a crucial necessity in adopting CE and scaling it beyond local workshops. To support this variability, involved parties have to adopt advanced forms of automation both in process planning and monitoring. One of the most promising additions to the roster of traditional tools, such as ERP, APS etc. is the Internet of Things (IoT). Real-time integration between a variety of different systems and technologies, providing the ability to monitor, assess and correct or improve all kinds of activities. Being integrated CE, Lean and the IoT tools provides both process and communication loop, supporting each other (Figure 2).

Figure 2: Example of a communication loop



Source: Dave et al., 2016

Researchers worldwide exploring different applications of these concepts to different areas of the manufacturing process. Notable theories that emerged recently are Lean-oriented optimum state control (L-OSCT) and dynamic value stream mapping (DVSM). Both teams are trying to tackle the lack of systematic theory on the control framework underlying Lean production. Using an IoT driven synchronization method, L-OSCT achieves the synchronization of the system optimum-state control for a large-scale production system with multi-workshop/plant in dynamic production environments (Zhang et al., 2018), while the idea of DVSM comes from the fact that Lean extends to cover all manufacturing aspects through a diversity of powerful tools that are mutually supportive and synergize well together to effectively reduce waste and maximize value (Ramadan et al., 2020).

Descending further into micro-management Kursad Turker et al. study proposes a decision support system (DSS) designed to increase the performance of dispatching rules in dynamic scheduling using real-time data, hence an increase in the overall performance of the job-shop. The proposed approach improves the performance of a system in terms of many tardy jobs, average waiting time in queue, the average utilization of the workstations, work in process, average tardiness and earliness. As expected, machine utilization increased and thus waiting times in the system, and the amount of work-in-process decreased using the DSS (Turker et al., 2019).

The main downside of Lean process optimization is that its focus is limited to a specific supply chain. However, from CE systems efficiency and thinking, the supply chain is expanding in a much broader perspective, where the identification of value and flow is not limited to one product or supply chain life cycle, but continues to evolve. CE's focus on the conservation and enhancement of natural capital can be achieved using the Lean principle: mapping the flow of value creation is a resource and creating a flow within a closed system, as well as the pursuit of excellence through continuous improvement. Similarly, resource yield optimization can be achieved by establishing traction by producing only what is required and creating a feedback flow while striving for excellence through continuous improvement.

Conclusion

The results of the study indicate that the closed-loop economy arose as a necessity for the qualitative growth of the economy. The transition to a circular economy is due to the participation of all interested parties in society and their ability to create effective models of cooperation. The role of the circular economy in reducing the use of resources, waste production and environmental pollution, as well as in contributing to significant economic and social progress, is revealed. Moreover, the interdisciplinary structure that underlies the closed-loop economy offers excellent prospects for the gradual improvement of existing production and consumption patterns, which are no longer adequate due to their environmental load and social inequality, which is an indicator of inefficient use of resources. The authors also examined the basic principles of the functioning of the circular economy, its advantages and disadvantages. Reveal the vital role of lean production and the life cycle assessment (LCA) in a circular economy. Besides, this effect can be further enhanced by applying lean principles to the loop, providing additive value to every step of the cycle. All of these studies show potential benefits of applying IoT to Lean Manufacturing which, in turn, applied to Circular Economy could bring the necessary methods and tools leading to the successful implementation of this vision.

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