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THE INNOVATION THE DRIVER FOR CIRCULAR ECONOMY

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Abstract. The modern economy faces critical challenges, including resource depletion, environmental degradation, and biodiversity loss, driven by population growth and rising consumption. These issues necessitate a transition from a linear to a circular economic model. A circular economy emphasizes resource efficiency, waste reduction, and product lifecycle extension through practices such as recycling, refurbishing, and eco-design. It integrates sustainability-oriented innovation to minimize resource consumption, optimize production processes, and foster new business models like the sharing economy and reverse logistics.

Technological advancements, such as IoT, AI, and blockchain, enable circular strategies by enhancing traceability, reducing emissions, and creating efficiencies. Innovations like biodegradable materials, modular product design, and waste-to-resource transformation contribute to circularity, as do policy measures like Extended Producer Responsibility (EPR) and public-private partnerships. However, challenges remain, including high transition costs, regulatory differences, and limited scaling opportunities, often leaving innovation in this domain to agile start-ups.

Education and policy reforms are crucial to fostering a culture of sustainability and stimulating innovation in circular practices. Investments in research, infrastructure, and incentives are essential to overcome barriers and promote systemic change. Ultimately, innovation serves as a vital catalyst for the circular economy, enabling businesses to align environmental, social, and economic goals, thereby paving the way for a sustainable future.

Keywords: *Circular economy, sustainability, eco-innovation, waste management, resource efficiency, digital technologies*

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The modern economy is characterized by multiple challenges such as global warming, diminishing natural resources and aggravating ecological problems. Indeed, the effects of human activity manifest themselves through the pollution of the environment, respectively the reduction of biodiversity and the decrease of the quality of human life. Thus, the extensive development of the economy is no longer possible, which is due both to the increase in the number of the population and to the increase in the level of consumption per capita. Current research finds that many developing countries are characterized by both population growth and individual consumption [1]. Therefore, a transition from linear to circular economic model is necessary. At the current moment, we are at the moment when the question is not whether or not the circular economy will be, but whether it will be circular or not at all. In the literature there are several definitions of the circular economy, according to the Ellen MacArthur Foundation: a circular economy is an economic model that is restorative and regenerative by design, aiming to keep products, components, and materials at their highest utility value in both technical and biological cycles [2].

A similar approach, only broader, which includes besides the production and consumption model has the following definition The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended [3]. The definition of the European Commission refers to the transition from the linear to the circular system "The circular economy is an economic system that aims to eliminate waste and the continual use of resources, through a transition from a linear 'take-make-dispose' model to a circular 'make-use-return' model"

[4]. However, it must be highlighted that with all the efforts, additional costs, in the long term the transition to a circular economy can bring the following benefits: improved environmental conditions, improved supply of raw materials, increased competitiveness, stimulated innovation, stimulated growth and created new jobs [5].

The need to create and develop the circular economy is becoming more and more clear and obvious at the global level, but, at the same time, we note the complexity and high costs related to this process. In order to implement the necessary changes, both legislative and technological measures are needed. Regarding the technological aspects, we must highlight the fact that innovation is the necessary solution to remodel the current production and consumption systems by creating new circular ones. The new technologies, innovations are necessary for various industries, including digitization, which is a fundamental, comprehensive component that can facilitate transformation. The innovation that contributes to circularity is characterized by the fact that it finds solutions to extend the life cycle of the product and its components and requires the consumption of less resources to produce a product unit.

The transition to the circular economy has a close connection with innovation. Innovation within a circular ecosystem can be realized through cooperative efforts, ongoing experimentation, and the adoption of platform-based approaches, all designed to optimize material resources and reduce waste [6].

According to the Organization for Economic Cooperation and Development innovation refers to the implementation of a new or significantly improved product (good or service), or process, a new marketing model, or a new organizational structure, business practices, workplace organization, or external relations. In a circular economy context, innovation is crucial for developing sustainable technologies, products, and services [7]. Another approach emphasizes the environment and considers innovations in the circular economy drive organizations to rethink the way they create value through sustainable models, focusing on designing for longevity, reuse, and resource efficiency, which are keys to reducing environmental impact [8]. Other studies consider the minimization of resource consumption: sustainability-oriented innovation includes the development of new products and services that contribute to environmental and social goals. In the context of circular economy, this also emphasizes finding new ways to create value while minimizing resource consumption and waste [9].

Indeed, the circular economy requires a systemic, comprehensive approach that is not specific to the linear economy. According to some estimates, around 80% of the negative impact on the environment of a product is already determined at the stage of technological design and development of the product, so at the stage of design it is necessary to include the principles of the circular economy, like using biodegradable raw materials or creating biodegradable materials. Another solution would be to reduce waste as a result of production and (or) use it for other technological processes. Therefore, from idea generation, concept development, product planning, technological design, launch, after-sales services, the life cycle of the product to its recycling, it is necessary to integrate environmental requirements, to ensure the principle of extended responsibility and to approach through the principles of the circular economy. For example, the choice of the type of materials needed for production will not only depend on their technical characteristics and cost - specific to the linear economy, but their impact on the environment will be taken into account both during the product using period, as well as the methods of extracting the raw material necessary for their production and recycling the products at the final stage. Thus, for certain goods such as clothes, it is possible to extend the life of the product or materials, but also to separate natural and synthetic fibers or other accessories at the end of the life cycle. If the technologies do not allow this, these materials must not be admitted for production. The changes to include the principles of circularity are complex, they require considerable effort and the adoption of legislation that would stimulate this transition.

Innovation and the Circular Economy are interdependent areas that can influence each other, so various solutions can be examined.

To embrace the circular economy, businesses need to rethink their value propositions and reshape their operational models, integrating both environmental and social considerations into their strategies [10].

Achieving the goals of a circular economy demands sustainable solutions, which rely on increased awareness, collaborative efforts, and transformative changes to traditional business models [11].

We have to mention that it is necessary to approve some policies and regulations regarding stimulation of innovations towards the transition to the circular economy. For example, the term Extended Producer Responsibility (EPR) should be included, so that the producer bears responsibility for the product both during its life cycle, but also afterwards, at the stage of recovery, recycling and final disposal. Different new entities must be formed and strengthened, such as Public-Private Partnerships, the formation of alliances between state institutions, NGOs and companies for collaboration with the aim of creating the infrastructure and implementing the best practices of the sustainable economy. Research, development of new business models based on the principles of the circular economy can be carried out through such organizations as Innovation Hubs and Incubators. At the same time, subsidies and grants are needed for the implementation of innovations and the development of new businesses integrated on the principles of the circular economy. Another approach can be consumer incentives to participate in return and recycling programs and to form a behavior oriented towards the sustainability.

The circular economy, combined with sustainability-focused innovation, enables businesses to move toward a cleaner energy future by enhancing customer value while addressing environmental and social priorities [12].

Innovation and the circular economy are complementary concepts, as they can work together to provide cost-effective products while simultaneously lowering CO₂ emissions [13].

Education is an important factor with long-term impact on both consumers and producers regarding the need, the benefits of implementing the principles of the circular economy. It is necessary to educate new values, according to which mankind must exist in a natural ecosystem based on the principles of sustainability, of the circular economy, which must be fundamental for humanity.

Eco-design is the integration of environmental aspects into the product development process, by balancing ecological and economic requirements [14]. Eco-design is characterized by the development of products that can be easily assembled and disassembled, thus the repair or recycling is done on certain modules, a fact that would allow increasing the life cycle of the product and facilitating the repair process. Another way is to use biodegradable materials such as plastic etc., which can decompose after the expiration of the term of use of the product without harming the environment. The use of the 3-D printer has the advantage of localizing the production, which determines the reduction of transport costs, but also of substance emissions.

Therefore, eco-design can include several innovations as follows:

- Innovations related to material resources - refers to aspects such as reducing the weight and volume of the product, respectively the consumption of materials, increasing the share of the use of recycled materials instead of virgin raw materials, increasing the share of refurbished products, the use of those materials that require less consumption of resources needed for their production.
- Technological innovations – it is manifested by the reduction of energy consumption, the reduction other resources consumption, the reduction of waste formed as a result of the production process, the elimination of the use of hazardous substances for production, the intensive use of restored and recycled materials.
- Product innovations (including installation, maintenance and repairs) – can be implemented by reducing energy consumption, reducing water consumption and other resources when using the developed product, facilitating maintenance, facilitating disassembly and reducing energy and other resource consumption, also the emission of harmful substances for this process.

- Innovations for the end-of-life stage of the product - can be achieved by reducing residual waste after recycling and reducing costs and material consumption for recycling. Therefore, if we refer to eco-design, innovations determined by the activity of some interdepartmental teams are needed, by remodeling business processes both internal to the company but also of suppliers or other stakeholders, thus the circular transformation frequently requires correlated measures throughout the value chain.

Innovations in logistics are characterized by the minimization of the size of the product and its weight, thus we will ensure less costs and consumption of resources for the transport of the products, optimization of the density for packaging, optimization of logistics thus will ensure the reduction of the use of fuels and the reduction of emissions, the perfection of the packaging, thus ensuring the reduction of the consumption of resources for the production of the packaging, the increase of the weight of recycled materials in the packaging, the non-admission of harmful substances in the packaging, etc.

Waste-to-Resource Transformation is characterized by the conversion of waste into new products, sooner than their recycling. Another option can be the formation of an ecosystem in which the waste of one producer constitutes the raw material of another, thus a closed cycle will be formed.

Innovative business models could be, for example, by changing the business model from sales to services, where the consumer leases or rents the goods. This allows more intensive and efficient use of the products. Also, the sharing economy is based on the joint use of some products and services, which makes their consumption more efficient. Another perspective business model is Reverse Logistics, which is characterized by the formation of a network that would allow the collection, renovation and distribution of used products and their return to the consumer circuit, relevant in this sense can be clothes, vintage retro cars, etc.

Circular Supply Chains could be developed through the use of blockchain technology, a fact that allows to ensure traceability, implicitly to implement the principle of extended responsibility, stimulating the valorization of the regional or local use of resources, a fact that would reduce costs and the negative impact on the environment due to transportation.

Energy Efficiency and Renewable Resources is determined by the use of renewable resources (solar energy, wind energy, etc.) to reduce the emissions characteristic of fuel burning. Energy Recovery can be achieved by using technologies for capturing or reusing the energy emitted by certain technological processes.

The 4th industrial revolution is determined by the economic convergence of several technologies such as: broadband internet connection, digital wireless communication channels, man-machine and machine-man technological support and the miniaturization of devices such as microprocessors, sensors, etc., the development of technical and technological capabilities to produce to individual requirements.

The Fourth Industrial Revolution (4IR) marks a profound shift in how we live, work, and engage with technology. Defined by the convergence of innovations like Artificial Intelligence (AI), the Internet of Things (IoT), and autonomous systems, this revolution is transforming industries, societies, and everyday life.

These innovations are complementary to the principles of sustainability and can facilitate the transition to the circular economy. Certain fields such as: transport, energy, agri-food sector, telecommunications, financial services, industrial production, medicine can become sustainable with the support of digital tools. Digital technologies can optimize production processes, reduce material and energy consumption, reduce emissions and waste, create competitive advantages and facilitate the launch of new services and products on the market. In particular, the transition to the circular economy can be ensured by digital technologies such as IoT, Smart Systems or Big Data Analytics. Internet of Things (IoT) technology is able to monitor and manage resource usage in real-time, enabling more efficient use and reducing waste. Big Data Analytics use data analytics to optimize production processes, predict maintenance needs, and improve the overall efficiency of resource use. Artificial intelligence is a new innovative tool with multiple sustainable applications in such fields as

medical, financial, transport services, it can also improve production processes, determine the formulation of ecological solutions, etc.

The Fourth Industrial Revolution, fueled by advancements in AI, IoT, and autonomous vehicles, is reshaping industries, society, and the nature of work. This transformation demands a careful balance between technological innovation and the development of new job opportunities and employment models [15].

At the present moment we can observe that innovation in the circular economy is most frequently presented in the areas of food production, textiles and the recovery of materials from urban waste streams. Another area with enormous potential can serve us is the electronics industry which can benefit a lot from innovations in extracting valuable materials.

Innovation in the circular economy is an interdisciplinary process, very complex and with multiple risks, which include legislative, socio-economic, but also mental changes, therefore investments in the circular economy are not very wide-spread, being met major impediments especially at the stage of scaling. This is due to the differences in regulations, financial and other incentives characteristic for different states. Thus, new business models based on the principles of the sustainable economy are developed sooner by start-ups or spin-offs, due to the fact that they are more agile and capable of building new models. Therefore, entrepreneurs looking for solutions for the circular economy must examine the problem holistically, be agile enough to validate the solutions in a creative way and by continuously improving them as a result of receiving feedback.

Innovation serves as a crucial catalyst for the circular economy, paving the way for sustainable business models, eco-friendly solutions, and cooperative ecosystems. Through the adoption of advanced technologies and strengthened collaboration, businesses can shift toward a circular economy, minimizing environmental impact and advancing sustainability.

Conclusions

In conclusion, the transition from a linear to a circular economy is not only an environmental imperative but also an economic necessity in the face of increasing resource scarcity and growing ecological challenges. The linear "take-make-dispose" model has proven unsustainable, and a shift toward a circular economy - one that prioritizes the reduction of waste, the continual use of resources, and the promotion of sustainable production and consumption practices - is essential for achieving long-term sustainability. This paradigm shift requires a systemic approach, involving both technological innovation and comprehensive policy frameworks to support its implementation.

The role of innovation in the circular economy cannot be overstated. Technological advancements such as Internet of Things (IoT), Artificial Intelligence (AI), and blockchain are pivotal in enabling the optimization of resource use, enhancing the traceability of materials, and improving production efficiency. These innovations help businesses not only reduce their environmental impact but also create new business models that are more aligned with sustainability. Furthermore, the integration of eco-design, renewable energy solutions, and waste-to-resource transformation can significantly reduce the ecological footprint of industries, from manufacturing to consumer goods.

However, the transition to a circular economy presents significant challenges. These include high initial costs, regulatory barriers, and the need for new business models that may not yet be fully scalable. Governments, industries, and research institutions must work together to create the necessary infrastructure and incentives to drive this change. Public-private partnerships, subsidies, and regulatory measures such as Extended Producer Responsibility (EPR) will play critical roles in enabling the transition.

Ultimately, the success of the circular economy depends on a collective effort across sectors, supported by both technological innovations and the widespread adoption of sustainable practices. Education, public awareness, and collaboration are key to shifting societal mindsets toward a future where resource efficiency, waste reduction, and environmental stewardship are not merely goals, but fundamental principles of economic activity. By embracing these principles, businesses and individuals alike can contribute to a more resilient, sustainable, and prosperous global economy.

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