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CIRCULAR ECONOMY AS A NEW INDUSTRIAL PARADIGM

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Abstract. As a result of the fourth industrial revolution technologies spread and the digitalization of the economy, new opportunities are opening up for the development of circulaprinciples of production. The use of digital economy technologies is associated with obtaining positive effects related to the use of raw materials and energy resources. The positive effects are due not only to the rationalization of resource consumption, but also to the implementation of operations to restore and regenerate the natural environment through the use of innovative digital technologies. All this contributes to the formation of a fundamentally new model of the economy, which acquires a restorative and closed character, based on the principle of "take-make-reuse" and being an alternative to the previously dominant linear model based on the principle of "take-make-waste". The article is devoted to defining the role of the circular economy in the transition to the fourth industrial revolution. Also, a comparative analysis of linear and circular models of the economy is presented.

Keywords: *eco-design, fourth industrial revolution, green economy, linear model, remanufacturing, recycle, sustainable development.*

Rezumat. Drept urmare a răspândirii tehnologiilor celei de-a patra revoluții industriale și a digitalizării economiei, se deschid noi oportunități pentru dezvoltarea principiilor circulare de producție. Utilizarea tehnologiilor economiei digitale este asociată cu obținerea de efecte pozitive legate de folosirea materiilor prime și a resurselor energetice. Efectele pozitive se datorează nu numai raționalizării consumului de resurse, ci și implementării operațiunilor de restaurare și regenerare a mediului natural prin utilizarea tehnologiilor digitale inovatoare. Toate acestea contribuie la formarea unui model fundamental nou al economiei, care capătă caracter restaurativ și închis bazat pe principiul „folosește-produce-reutilizează”, fiind o alternativă la modelul liniar anterior dominant bazat pe principiul „folosește-produce-aruncă”. Articolul este dedicat definirii rolului economiei circulare în tranziția la a patra revoluție industrială. De asemenea, este expusă analiza comparativă a modelelor liniare și circulare ale economiei.

Cuvinte-cheie: *proiectare ecologică, a patra revoluție industrială, economie verde, model liniar, remanufacturare, reciclare, dezvoltare durabilă.*

Introduction

In 2016 at the *World Economic Forum in Davos*, one of the main topics of discussion was the Fourth Industrial Revolution, which results in blurring boundaries between physical, digital and biological technologies [14]. These technologies include artificial intelligence, the Internet of Things, self-driving vehicles, 3D printing, nanotechnology, biotechnology, quantum computers. Previously, the ideas of the fourth industrial revolution were presented by the German program Industry 4.0, which was developed in 2011 and focused on smart manufacturing technologies based on the global industrial network of the Internet of Things [11]. However, the fourth industrial revolution is not only about smart, connected interactions of machines and systems. *One of the leading directions of the fourth industrial revolution is the formation of production and technological systems that are based on circular principles*. It is the synthesis of digital technologies and circular production principles, as well as their interaction in the physical, digital and biological spheres that make up one of the fundamental differences of the fourth industrial revolution from all previous revolutions. As a result of the fourth industrial revolution technologies spread and the digitalization of the economy, new opportunities are opening up for the development of circular principles of production. The use of digital economy technologies is associated with obtaining *positive effects related to the use of raw materials and energy resources*. The positive effects are due not only to the rationalization of resource consumption, but also to the implementation of operations to restore and regenerate the natural environment through the use of innovative digital technologies. All this contributes to the formation of a fundamentally new model of the economy, which acquires a restorative and closed character, based on the principle of “take, make, reuse” and being an alternative to the previously dominant linear model based on the principle of “take, make, waste”.

At the same time, only at the present stage, taking into account the goals of sustainable development, the principles of a green economy and inclusive growth, on the one hand, and the emergence of new opportunities due to the formation of the digital economy and its infrastructure - on the other hand, *an ecologically, economically and socially efficient model of a circular economy began to actively develop***.** Thus, the spread of digital technologies contributes to improving communication and collaboration, changing the manufacturing process with an emphasis on resource regeneration, and accelerating systemic shifts that have a crucial role for the formation of a circular economy, and the balanced achievement of economic, environmental and social goals in the field of sustainable development.

Circular economy versus linear economy

In the process of evolution and heterogeneity, the industrial economy strictly follows its main path **- *a linear model of resource consumption*** according to the *take-make-waste* principle. Within this production model, the consumer receives a finished product made from a certain amount of raw materials, subsequently, when fulfilling its purpose of having been used. As an alternative to the development of the economic system, the world community has recognized ***a circular economy model*** that excludes the usage of toxic chemicals (that in fact prevent reuse), and is aimed to completely eliminate waste through improved development (design) of materials, products, systems and business models. The main features of linear and closed economic models are presented in *Table 1*.

The circular economy is characterized as a complex economic system that is restorative or regenerative in design and structure, it is characterized by a closed nature, replacing the concept of "end of life" with the concept of "recovery and transition to the use of renewable energy sources" [10].

Table 1

Comparative characteristics of linear and closed models of the economy

Comparison parameter	Circular economy	Linear economy
Subject	The consumer acts as an *integral part of society and nature*	Consumer is pursuing only *to maximize benefits*
Main object	Achieving ecological balance with *a sustainable economic and social growth* in the well-being of the world's population, while maximizing the efficiency of the life cycle of various resources, goods and services	Getting the *maximum possible economic profit*, while environmental issues are not given a due attention. The well-being of the world's population is growing extremely unevenly, there is a powerful social stratification
Type of nature use	*Resource producing*	*Resource consuming*
Used resources	The *interaction of financial, informational, intellectual, labour and other resources* in the process of obtaining and using goods from secondary processing resources	*Primary resources extracted* in nature, as a rule, without taking into account the environmental harm and damage caused by anthropogenic activities
Production volume	A closed production cycle is aimed at *minimizing the amount of goods produced*, as a rule of higher quality and subject to repeated use	*A constant increase in the number of goods and services produced* (often of low quality), an increase in the rate of production in all sectors. There is a crisis of overproduction and redundancy of the commodity market
Relationship between society and nature	Active introduction of *greening into production processes*. Reducing anthropogenic pressure on ecosystems	Nature is actively transforming, *the anthropogenic load on ecosystems is increasing*, which gives rise to an ecological crisis of a planetary scale
Product life cycle	*Maximizing the duration of the life cycle of a product* (service), in which its processing and reuse is possible	*Short product life cycle*, coupled with its rapid obsolescence
Waste volume	*Gradual reduction to complete disappearance* through the application of new approaches available in the process of technological development. The emergence of new industries	*Permanent growth* of production and consumption waste, the rapidly accumulating volume of which leads to a global environmental problem.

Source: made by author.

The key difference when considering the initially adopted concept of sustainable development and the concept of a circular economy, which appeared later, as an independent direction, is the expansion of the scale of the concept sphere of the latter:

when the ecological and economic spheres interact, there is a much greater merger through the necessary interaction. The Ellen MacArthur name is closely related to the concept of circular economy. Its principles are to design out waste and pollution, keep products and materials in use, and regenerate natural systems. The advantages of such an approach are substantial [10].

The circular economy aims:

- firstly, at restoring the original value of products at the end of their use to ensure economic efficiency;
- secondly, to reduce the negative impact on the environment through operations to restore this initial value, which leads to the fulfilment of social, economic and environmental requirements of sustainable development.

Traditional linear models of organizing production and economic activities are characterized by insufficient efficiency in the use of raw materials and energy resources, the formation of significant volumes of waste with their subsequent burial at landfills and unauthorized dumps, then circular models of production and consumption are aimed at creating closed life cycles of products that are processed at the end of use, restored or reused. The circular economy was originally based on three key principles called "3R": reduce - reuse - recycle, eventually transformed into "9R" (see figure 1) [7]:

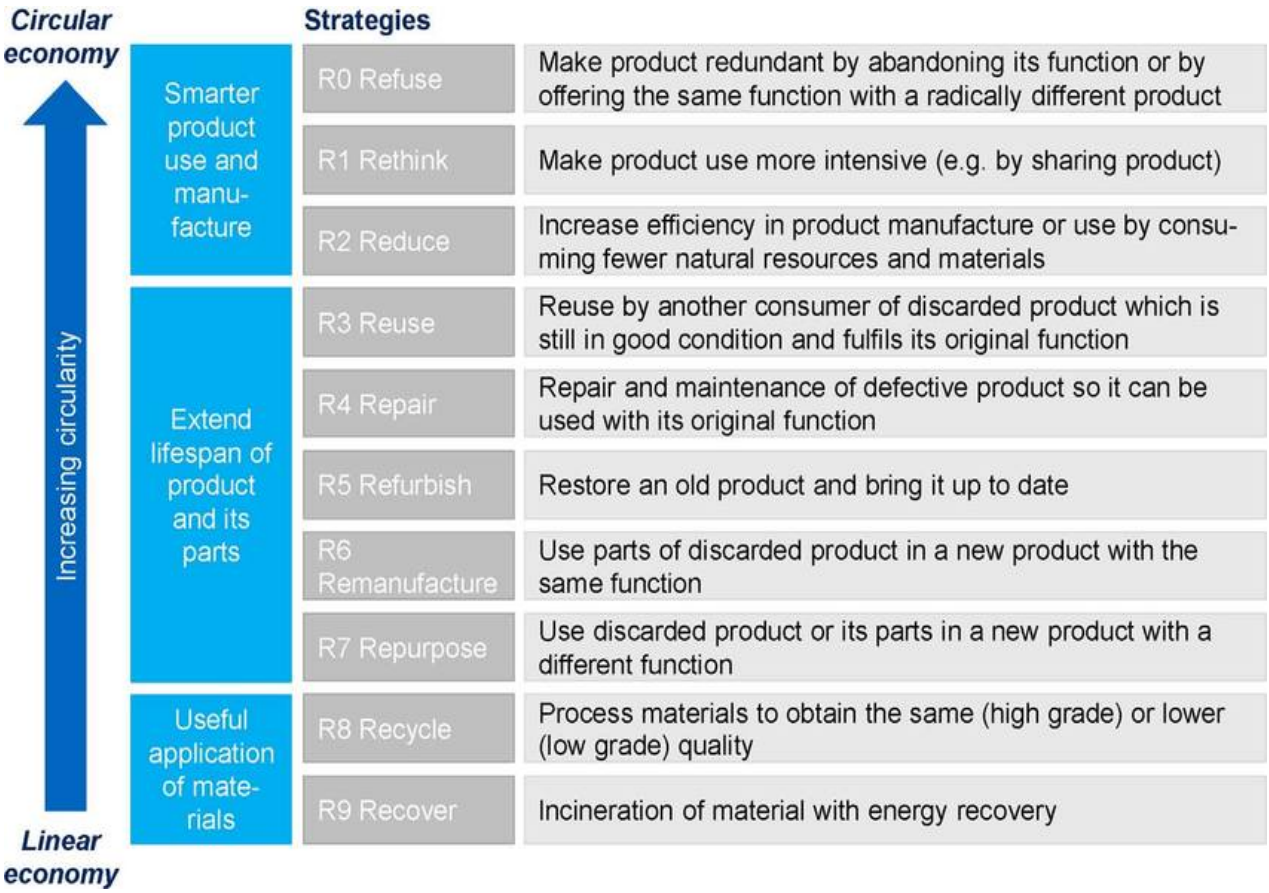

Figure 1. The 9R Framework for circular economy.
Source: [7].

- 3R – Reduce-Reuse-Recycle;
- 4R – Reduce-Reuse-Recycle-Renewable;
- 5R - Reduce-Reuse-Recycle-Recover–Reclamation;

- 9R - Refuse-Rethink-Reduce-Reuse-Repair–Refurbish–Remanufacture–Repurpose-Recycle-Recover.

The lack of a clear conceptualization of the basic principles, coupled with an ever-increasing number of additionally emerging directions in the study of the R-principles, can be explained by the following:

- a large number of authors from various scientific schools are engaged in the study of circular economics, which does not make it possible to define a clear area of knowledge;
- circular economy is not a strictly isolated field of study, its very origin took place at the junction of a number of sciences;
- the globalization processes taking place in the scientific environment make it possible to identify and present previously unknown research to the world scientific community, which is reflected in the dynamic perception of the circular economy;
- international organizations use in their terminology and official documents various R-principles, sometimes not agreed upon among themselves.

Within the linear production model raw materials are used in an inefficient way, because the focus is not on their conservation. On the contrary, in a circular economy, this is the emphasis. This means that other production models are also used within a circular economy, but with more accent on services rather than on products. An example of a model that simplifies the transition to the circular economy is a product-service combination (Product-As-A-Service System), which is seen as a model to integrate products and services [12]. A common example of using the product-service combination is the Xerox printer system, where companies receive a printer free of charge and pay per copy. Thus, as a manufacturer, Xerox has an interest in ensuring that the printer will be used for a long time, by being able to repair and update it. While within the linear system, the manufacturer will often search for benefits by selling the product if it breaks down quickly.

Circular economy principles during the transition to the 4th industrial revolution

The concept of a circular economy was formed on the one hand within the framework of the paradigm of sustainable development, the ideas of a green economy and inclusive growth, and on the other hand, its practical implementation became possible based on technologies resulted within the fourth industrial revolution and the digital economy. The circular economy is a prerequisite and at the same time a driver of a new industrial revolution. Conceptually, it has two main goals. On the other hand, the full value of the used products must be restored to ensure maximum economic efficiency. On the other hand, the restoration of this value leads to a decrease in the negative impact on the environment and thus most compliance with the socio-economic and environmental requirements of sustainable development. Taken together, this leads to a sustainable formation of value (see figure 2). A circular economy can be developed on the basis of different approaches in industry and agriculture, taking into account the creation of closed supply chains. So, within the framework of the circular economy model, a phased closed cycle occurs, which begins with the development of mineral deposits, the procurement and processing of raw materials and energy resources, followed by the production of components, intermediate and finished products, their transportation, marketing and final consumption and use, and at the end of the life cycle, waste products are collected and subsequent recovery operations are performed.

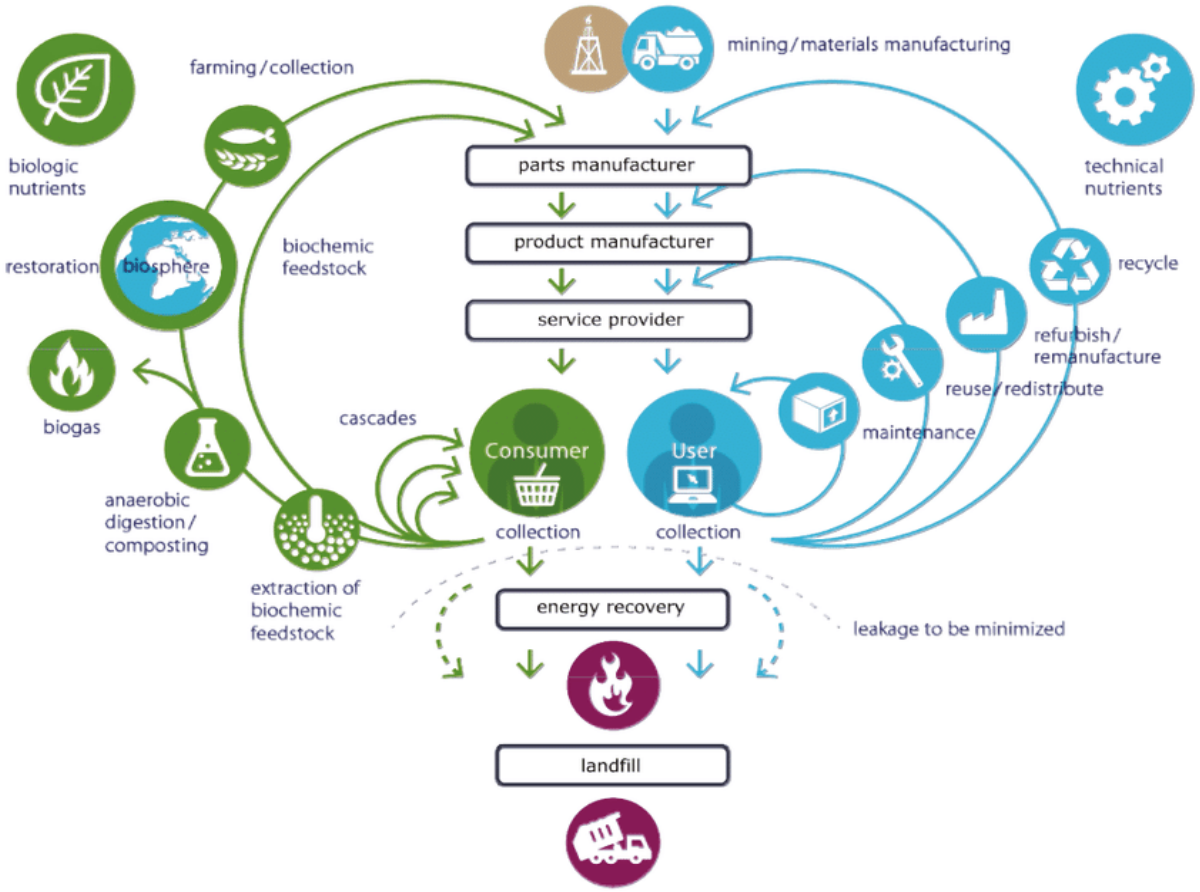

Figure 2. A theoretical model of a circular economy.
Source: [10].

In industry, closed supply chains are formed on the basis of the following basic approaches:

1) maintain an efficient way to maintain or restore products to the desired performance level in order to protect them from further damage and extend the life cycle, includes diagnostics and repair [3];
2) reuse of goods - the product is reused for original or new purposes and in its original form, or with some changes and improvements [4];
3) product remanufacturing and / or component remanufacturing - the process of disassembling and restoring a product at the component level; parts to be restored are removed from the former use of the product, are cleaned, repaired, and incorporated into a new product, while the finished product is positioned "as new" [5];
4) recycling of waste and used products (recycling): any recovery operations, with the help of which waste and used products are processed into materials, resources, substances for original or other purposes; the main types of processing are as follows:
   - upcycling - converting materials and waste into new materials of higher quality;
   - functional recycling - the recovery of materials for the original purpose or other purposes, with the exception of energy production;
   - downcycling - transformation of materials and waste into new materials of lower quality [1].

In agriculture, the formation of a circular economy is based on the following approaches:

1) Cascading of materials: The process of recycling waste and products into new products close to the original purposes and with a higher value than the receipt of raw materials (for example, the processing of food waste into animal feed) [9].

2) Extraction of biochemical: the generation of electricity and process fuels, energy and chemicals from biomass. In factories, these processes are combined into a single cycle to produce more than one product or type of energy.

3) Anaerobic digestion: a process in which microorganisms break down organic materials such as food waste, sewage sludge, etc., in the absence of oxygen, to generate biogas.

4) Composting: a form of natural waste recycling to produce fertilizer and energy.

5) Soil restoration and restoration: the process of ecological restoration of a site of natural landscapes and habitats, safe for people, wild animals and plants.

6) Agriculture and gathering in a circular economy (Farming / collection), processes of hunting, fishing, farming, etc. are lean in nature.

The widespread use of recyclable products and, thus, the reduction of waste is possible due to its eco-design (environmental design), which refers to the process of product development with special consideration of its impact on the environment throughout its life cycle [2]. With ecological design, products and their elements are developed with an emphasis on zero waste not only during the manufacturing process, product use, but also at the end of the life cycle.

Eco-design of products is based on three principles: *firstly*, establishing product design requirements for efficient dismantling and disassembly; *secondly*, the use of materials and components for reuse, recovery or recycling; *thirdly*, the absence of hazardous substances in the product that can impede the possibility of reuse or recycling.

Compliance with the principles of environmental design puts forward a number of requirements for the manufacturer and his product:

- *Production requirements:* taking measures to combat product obsolescence, extending the warranty period, certification and labelling of products and their individual components, information on the chemical composition for the purpose of effective reuse and recycling.
- *Technical requirements:* use of homogeneous materials and simplified design for quick and efficient product disassembly, disassembly, repair or recovery.
- *Material requirements:* exclusion of harmful substances from the chemical composition of products, provision of materials in production, taking into account further recovery and processing.

Closed supply chains are the backbone of the circular economy. And closed supply chains mean supply chains that maximize added value over the entire product life cycle with dynamic recovery within relatively long-time intervals of value of various types and volumes [6]. Ideally, the formation of closed supply chains implies zero waste, and the development of closed supply chains in all industries makes it possible to form a circular economy as a whole. In doing so, the circular economy goes beyond just recycling at the end product life cycle, and provides an impetus for technological, organizational and social innovation along the entire value chain with the goal of sustainable design products and waste prevention. Thus, a circular economy involves the use of fundamentally new models of production and consumption for achieving the well-being of society with low material, energy and environmental costs. Along with the issues of eco-designing and closed supply

chains, a significant attention is being drawn to the *remanufacturing of products* and individual components. Remanufacturing is one of the most important elements of the circular economy and the basis for the transition from the traditional linear model of the economy to a closed one in a number industrial sectors [8]. Remanufacturing is the highest form of recycling of waste products and waste, since compared to traditional manufacturing, manufacturing costs of finished products with the help of remanufacturing for refurbishing companies is lower, the cost of remanufactured products for the consumer is less, the benefits are also significant for the environment are also significant, since restoration of products, its individual units and parts, reduces consumption of raw materials and energy. When forming circular production and a closed supply chain, the manufacturer must build a strategy for the relationship with the buyer regarding return of products at the end of their use for further recovery, repair, recycling and other forms of disposal. Depending on the industry, type products, as well as the applied business model of the circular economy, it is rational to develop one or another strategy of relationships. So, when using agricultural machinery, it is advisable to apply the strategy "based on ownership" corresponding to the product-as-a-service business model, in which ownership the product remains with the seller, and the buyer uses the product with a package of services, for example maintenance and repair. Combination of the cyber physical systems, data mining, Internet of Things, Big Data and new business models could offer major opportunities for circular economy principles. Increasing use of technology by industries through usage of artificial intelligence or blockchain technology brings new opportunities to improve traceability and transparency throughout the product lifetime [15].

Smart, connected products allow manufacturers to control, monitor, analyse and optimize the products' performance. Knowledge of the product location in real time enables increased product accessibility and improves the possibilities for end-of-life collection, refurbishment, remanufacturing and recycling. Information on the product condition allows predictive and condition-based maintenance, advanced diagnostics and prognostics of the components and products, which in fact extends the lifetime of products and allows a continuous remanufacturing. While the information on the availability of the product allows to better share use cases through digital platforms and market places, which offer opportunities for recycling. Circular economy systems with interrelated cycles include large quantity of data. Digitalisation provides new ways to use this data. Decisions will be made on the lifecycle stages of the products, how waste materials will be reused and who are the actors involved in the value network of the product. The digitalisation also promotes a more efficient collaboration and networking formation, as well as collaboration with the existent and new stakeholders, including customers. In this order of ideas, ecosystems come as an efficient solution for an efficient organization of within the chain value. Generally, the ecosystem approach, allows to include a complex system of actors, technologies, as well as institutions that are related through closed interdependencies and co-evolutionary patterns.

Conclusions

The linear production patterns we inherited from previous revolutions today reveal many serious flaws, one of which is growing environmental problems; and the new industrial revolution is designed to correct the accumulated negative factors. One of the tools for solving the problem of pollution and ensuring a stable ecological future is a circular economy, which implies a continuous circulation of technical and biological materials in production and the preservation of valuable natural resources. The circular

economy is a fundamentally different way of doing business, forcing companies to rethink everything from how they design and manufacture products to how they treat customers. Ultimately, this model is the best way to both increase the competitiveness of individual enterprises, and the development of society as a whole. As a result of the spread of technologies of the fourth industrial revolution and the circular economy, the standard changes and new consumption patterns are formed. So, the purchase of ownership of products is replaced by the sharing or use of the product with the purchase of a package of services, and thanks to exchange platforms the possibilities for the reuse of used products are expanding. The proliferation of the Internet of Things opens up opportunities for circular innovation. The declining cost of sensor technology and the proliferation of networks make it possible to connect every component that goes into the manufacturing process. The data collected through such connections makes it possible to find out the place of origin of a product, the method of production and the amount of energy used to produce it. This data is at the heart of the circular economy. The information obtained on their basis gives businesses, cities and entire countries the opportunity to more efficiently restore, create and relocate these resources.

References

1. Braungart M., McDonough W. Cradle to cradle: Remaking the way we make things. Farrar, Straus and Giroux, 2010.
2. Lacoste R., Robiolle M., and Vital X. *Ecodesign of Electronic Devices*, Paris: DUNOD, 2011.
3. Ajukumar V., Gandhi O. Evaluation of green maintenance initiatives in design and development of mechanical systems using an integrated approach. In: Journal of Cleaner Industrial, 2013. Volume 51, pp. 34–46.
4. Amelia L. Initiating automotive component reuse in Malaysia. In: Journal of Cleaner Industrial, 2009, Volume 17, Issue 17, pp. 1572–1579.
5. Gray C., Charter M. Remanufacturing and product design. In: International Journal of Product Development (IJPD), 2008, Vol. 6, No. 3/4, pp. 25-37.
6. Guide J., Wassenhove L. The Evolution of Closed-Loop Supply Chain Research. In: Operations research, 2009, Vol. 57, pp. 10-18.
7. Kirchherr J. & R., DENISE & Hekkert M.P. Conceptualizing the Circular Economy: An Analysis of 114 Definitions. In: SSRN Electronic Journal, 20017, 127. 10.2139/ssrn.3037579, pp. 221-232.
8. Matsumoto M., Yang S., Martinsen K. Trends and research challenges in remanufacturing. In: International Journal of Precision Engineering and ManufacturingGreen Technology. 2016. Volume 3, Issue 1, pp. 129–142.
9. EC. *Cascading use of biomass: opportunities and obstacles in EU policies*. [online]. 2010. [accesat 10.11.2020]. Disponibil: http://www.birdlife.org/sites/default/files/attachments/cascading_use_memo_final.pdf .
10. Ellen Macarthur. *Artificial intelligence and the circular economy. AI as a tool to accelerate the transition*. [online]. 2019. [accesat 05.10.2020]. Disponibil: https://www.ellenmacarthurfoundation.org/assets/downloads/Artificial-intelligence-and-the-circular-economy.pdf .
11. European Commission. *Germany: Industrie 4.0*. [online]. 2017. [accesat 22.10.2020]. Disponibil: https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Industrie%204.0.pdf
12. Michelinia G., Renato N., et al. *From linear to circular economy: PSS conducting the transition*. [online]. 2017. [accesat 28.10.2020]. Disponibil: https://reader.elsevier.com/reader/sd/pii/S2212827117301567?token=BE30DCED0D8D1E989F87FB6273B3E59321197335629624A6BFBA58E06FD20059C29547F23AE92AEDE3A650CC17AB7706
13. Potting J., et al. *Circular Economy: Measuring Innovation in the Product Chain*. [online]. 2017. [accesat 16.09.2020]. Disponibil: http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf.
14. Schwab K. *The Fourth Industrial Revolution: What it means and How to respond*. [online]. 2015. [accesat 07.09.2020]. Disponibil: https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution.
15. Stankovic M., Gupta R., Figueroa J. *Industry 4.0 - Opportunities behind the challenge. UNIDO Background paper*. [online]. 2017. [accesat 16.10.2020]. Disponibil: https://www.unido.org/sites/default/files/files/2020-06/UNIDO%20Background%20Paper%20on%20Industry%204.0_FINAL_TII.pdf