Circular economy as challenge to the fourth industrial revolution

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The paper intends to describe the role of the circular economy as an important innovation within the framework of the fourth industrial revolution. The circular economy is prerequisite and a driver of the industrial revolution. Its conception follows two main objectives. On one hand, the full value of used products should be recovered for reaching a maximum of economic efficiency. On the other hand, by recovering this value the pressure on the environment will be lowered and contributions will be made to meet better the requirements of the social, economic and environmental sustainable development. These two objectives lead together to a «sustainable value creation – SVC». More concretely, the authors discuss the so called «6R» model of closed supply chains as a practical implementation of the innovative conception of recovering the product value. They describe the steps that need to be done to reach the level of SVC and display examples of a successful implementation of closed supply chains. Finally, the authors analyze the problems and obstacles of and the needed measures for implementing the conceptions of the circular economy and closed supply chains in the Russian Federation.

Keywords: circular economy, closed loop supply chain, the fourth industrial revolution, environmental innovation, recovery.

Environmental innovation in the fourth industrial revolution

When studying the key directions of the fourth industrial revolution and its challenges to Russia [1, 2], scholars usually emphasize on essential trends such as the formation of the digital economy [3], the application of robotics in production [4] and consumption, the Internet of things [5], the design of materials with fundamentally new properties, as, for instance atomic-molecular design methods [6], etc. The environmental innovation itself, which is to respond to such important issues, as the global climate change and the limited access to natural resources is so far not so much in the focus. In the literature, the latter is mainly highlighted from the perspective of the transition to alternative energy, especially in the automotive and other transport modes, as well as innovative technology to improve energy efficiency in the context of the formation of a low-carbon economy. Meanwhile, the decisions of the Paris of the UN Climate Conference (December 2015) have set the task to keep the temperature rise in the surface layer of Earth's atmosphere, «... significantly below 2 degrees Celsius» and, it is clear, that the goal to ensure the reduction of greenhouse gas emissions in the second half of the XXI century virtually to zero is not achievable without the support of innovative approaches. The Paris agreement formulate that directly in its Art. 10. These few remarks show that the environmental issues set up the ground of the recent industrial revolution technologies and work as drivers for the latter. And, as we are going to convince the readers, circular economy and closed supply chains will implement the approach of environmental innovation at best.

From the complex set of environmental innovations [7] the focus of the paper will be given to the formation of circular economy and its practical implementation: the closed supply chains. Traditional supply chains, which use the so called linear business model, cover a network of economic subjects and objects to provide customers with goods and services and produce large quantities of waste and other emissions by the principle «take, make, waste». Closed supply chains implement a new organizational and technological model which intends to return as many as possible products and byproducts after use back into the chain. In other terms, in closed supply chains the attempt is made to recover as much as possible from the previous value of used products. Such supply chains will help to develop effective solutions to several most pressing resource and environmental problems. They drive the organization of modern production and consumption to the «nature-like» paradigm [8]. As K. Schwab stated, the 4th Industrial Revolution « is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres» [1].

Studies show that the linear model of economic activity inherited from the industrial era is mainly responsible for the increasing pressure of modern economy and consumption on the environment, the exacerbation of the global environmental problems and the growing waste streams [9]. Per 80% of products after use are transferred into waste. The following implications of this linear scheme for Russia serve special attention:

- Official records state, that production and consumption generate annually about 31,5 billion tons of waste in 2015, which increases yearly by 5 billion tons. The amount of hazardous waste per capita, for instance, is 4 times larger than that level in the EU.
- More than 90% of municipal solid waste MSW generated is disposed by landfilling, and garbage-processing plants process just over 7% (2015) of the total amount of MSW. The organized landfills and illegal dumps occupy a total area of 47,7 thousand hectares, which is equivalent to one fourth of Russian space reserves.
- A significant impact on the environment is given by the unacceptably high level of material consumption of economy and its raw specialization: the extraction, production, processing and transportation of natural raw materials generate 87% of greenhouse gas emissions, 59,6% of harmful emissions into the atmosphere, 74% of discharges of polluted water and 92% of the total volume of industrial waste.
- The economic losses and damages caused by environmental pollution and deterioration of natural resources are estimated by 6% of GDP and, the health cost of people, caused by the environmental situation, by another 15% of GDP [10].

To some extent, the described shortcomings of the Russian situation are typical for all economies and they call for the transition to the fundamentally new model of circular economy, which is based on the principle of «take, make, reuse», while in the linear model raw materials and energy resources are assumed «as existing in abundance» by producers and consumers. At the end of the product production and consumption life the reusable used products and their individual components are moved usually as waste to landfills or illegal dumps. Such type of business generates environmental pollution and loss of economic turnover of limited natural resources. Instead of that, the circular economy intends to recover resources and their inherent value and to set up, as far as it is possible, closed production — consumption cycles. By moving to the implementation of the principles of the circular economy an increased control over natural resources can be gained. Furthermore, a sustainable balance of renewable resources can be reached, which helps to preserve and to maintain the interest of future generations in having access to the natural capital at an inexhaustible level. The circular economy enables to optimize the consumption process by developing and distributing products, components and materials which meet the highest acceptable level of reuse. Finally, the detection and prevention of negative external effects of economic activities may improve the effectiveness of economic and ecological systems [11, 12].

Innovative principles and elements of circular economy

By the time, the scientific perception of the circular economy as organizational and technological innovation in the framework of the 4th Industrial Revolution is changing. While the original conception of the circular economy was mainly based on ideas to optimize the production processes by applying the principles of 3Rs: «reduce, reuse, recycle», today its scope is seen much broader. It was recently extended to the 6R principles, which are described in [13] by an example from improving the product sustainability for metallic automotive components.

The main activity fields to be considered cover the area of **d**esign/redesign, **r**educe, **m**anufacturing and **u**se **(DRMU)**, the «**P**ost **U**se» area **(PU)** and the **l**and**f**ill **(LF)** (fig. 1).

Design and redesign are oriented at reducing and slowing down the resource input at the **p**re**m**anufacturing phase **(PM)** by the application of environmental design methods to set up products which, also due to better input quality, will have a longer service life and which can be repaired, rebuilt and, re-used. This leads to the reduction of resource consumption. The slowing down and reducing the resource throughput at the manufacturing phase **(M)** can be implemented by improving the technologies and by using remanufactured end of life products, their components and the contained material which reduce significantly material and component requirement and cost. This leads

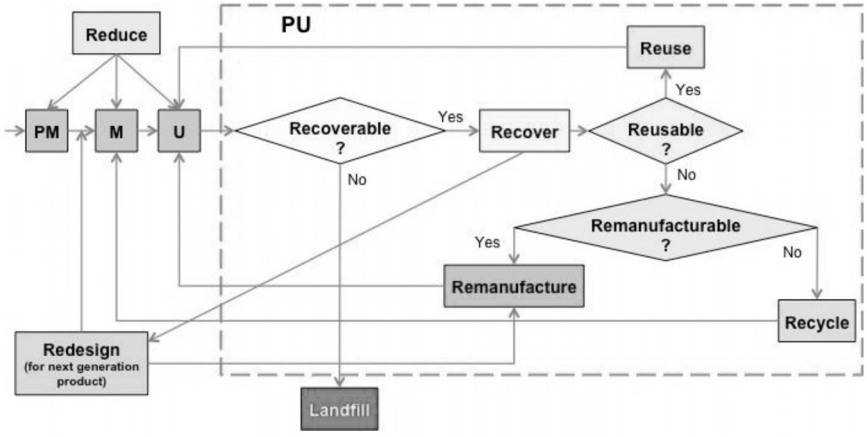

Fig. 1. Sequencing of 6R application within the life-cycle with decision points and multiple closed-loops (the fig. from [14] modified by the authors)

to less operation and resource intensity per unit of output. Reduction and slowing down the waste output at the use phase (**U**) is again accomplished by the application of environmental design and remanufacturing technologies which, also due to improved production quality, allow setting up resources loops (closed supply chains). This leads to the reduction of waste output since the used resources are again returned to the production phase.

These activities require clearing, if used items are recoverable or not. If not at all then landfilling is a last but improbably option. The other option to recover the used product may demand for some redesign, or it permits reuse for another time and takes the item back to the use phase. If such direct reuse is not possible remanufacturing can restore the product by replacing some of the components and additional operations for the use phase. If not, the recycling of components will produce raw materials to be used in the manufacturing phase. Finally, redesign may open better opportunities to remanufacture products. Among the many practical examples, see, for instance, the case of the company Cisco (see [21]).

The complete picture of the methodology 6R: «reduce, recover, redesign, reuse, remanufacture, recycle» is shown in (fig. 1).

The presented approach creates a closed 6R supply chain in the framework of the circular economy. It simultaneously reduces the energy and raw material consumption and the generation of waste and of emissions per product output unit [15].

The gradual application of the principles of circular economy is accompanied by multilateral effects. Environmental effects, according to fund Ellen MacArthur, is to reduce CO_2 emissions in the range of 8 to 70%, reduction in raw materials consumption by up to 98% and on a loss of energy savings of 83% as well as reducing the land area occupied by landfills and illegal dumps. The economic effects are associated with a drop of the finished product cost — up to 40%, with the emergence of new sources of profit, increase of innovativeness of companies and improving their image, increase of customer loyalty and strengthen relationships with partners along the entire value chain. The possible increase in GDP is estimated at the range of 0,8-7%. Social effects, on which the attention focuses in the study of the effects of the forth industrial revolution, are expressed by possible job growth of 0,2-3,0%, by an improvement of public health as a result of improving of the environment and by the consumption of environmentally friendly products.

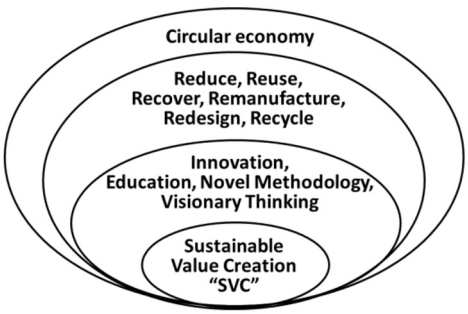

Fig. 2. Circular economy leading to sustainable value creation through its integral technological elements and the associated characteristics [16]

The development of the circular economy based on the methodology 6R requires some mechanism to change the linear economy model gradually (fig. 2). It includes innovation processes, the improvement the education quality, the development of new teaching methods and the formation of proactive thinking. In turn, the innovation processes are based on advances in technology, as well as on the modernization of previously applied business models.

However, the required transformation and the transition to the circular economy will be accompanied by negative external effects for a various of branches and companies. Resource extracting countries and companies will suffer from the reduced requirement of their products by the markets, and the number of related jobs can drop dramatically. Achieving the objectives of the circular economy challenges radical technological modernization of the manufacturing industry and the creation of sustainable closed production and processing chains, which can form the basis of a new technological revolution. One of the main challenges to the circular economy consists in the development, implementation and dissemination of innovative business models that support the development of the circular economy and affect almost all aspects of existing production processes. On one hand, the products delivered by the circular economy require certain acceptance by the industry and the consumers. On the other hand, the changing consumption patterns by the consumers call for such changes in the economy. These aspects, however, are beyond the scope of this paper.

A relatively new field of studies is innovative entrepreneurship in the framework of the circular economy. Several authors published first results about business activities with respect to sustainable development objectives [17, 18]. So far, Russian authors did not draw much attention to the potentials of the circular economy. Russian specifics attract more attention by foreign specialists [19]. However, the transformation to a circular economy model is essential not only for the formation of eco-efficient waste treatment schemes, but also for alleviating global climate problems [20], as well as for the correct positioning of the country in the technological revolution of the XXI century. The leading world businesses are aware of the necessity to move to the circular economy model and to closed supply chains for maintaining their competitive advantages.

The development of circular economy needs not only certain understanding of its advances, but also the creation of related technological, institutional and legal bases. The backlog of Russia with respect to all these factors sets up barriers for the transformation of the linear model to the circular economy. First, the formation of circular economy in Russia is impeded by technological barriers. The rather low level of the dissemination of innovative technologies of processing raw materials and of environmental product design does not create that needed innovation climate. Second, economic barriers such as the low investment attractiveness of the activities related to the phased implementation of the principles of circular economy, does not contribute neither to internal sources of financing, nor to foreign direct investment. Third, regulatory barriers as, for example, the Federal Law № 458-FL «On Production and Consumption Waste...» (from 12.29.2014), does not

contain rules governing the procedures for the formation of separate collection systems, which seriously complicates the recycling of waste and leads to high cost and, it does not provide any government support and incentive measures aimed at creating closed supply chains.

Principles of the circular economy, their implementation in the EU and challenges for Russia

The practical implementation of the following principles contributes to the development of the circular economy in various industries (table 1). The experience of many world-class manufacturers proves that even the application of only one of these principles presented below provide the opportunity for achieving significant results.

As for any strategic project, the development of a strategy for the implementation of the circular economy requires support by concerned and responsible stakeholders, the government, the business and the scientific community with their active cooperation.

The state plays a key role with respect to the formation and implementation of the circular economy, as it sets up the needed institutional and legal environment and the required infrastructure. For example, in a pilot project for the development of the circular economy in Denmark representatives of six ministries (the Ministry of Business and Growth, Ministry of Environment, Ministry of Finance, Ministry of Foreign Affairs, the Ministry of Climate, Energy, and Construction and the Ministry of Food, Agriculture and Fisheries) were involved. In the Russian Federation, the current government's measures are aimed at creating a modern scheme of waste management by changes in legislation (Federal Law «On Production and Consumption Waste...», Federal Law № 458-FL of 29.12.2014) and at the development of an industrial development strategy for the processing, recycling and disposal of industrial and municipal waste for the period up to 2030. Furthermore, several measures were determined by the State Council to speed up Russia′s economy moving towards to the model of sustainable development. However, these actions mean just first steps towards the formation of circular economy. Its development requires, first, determining precise goals and actions by the state in cooperation with the business and the society and developing a long-term strategy. Second, the current standards for production and recycling of waste to all product groups need improvement and regular reviews. Third, preferential taxation of companies implementing the circular business models may provide incentives for the business to become active. Fourth, budget savings from environmental and recycling fees may help funding and subsidizing of circular business projects, the building of a waste collection and sorting infrastructure and the implementation of closed supply chains by companies. Fifth, the extension of the producer responsibility principle to all companies, the tightening of the liability for violating the environmental legislation, better control of the environmental data collection and increase of the transparency of reporting will improve the conditions for the implementation of the circular economy.

The most promising segments and opportunities for the development of circular economy are determined at the company level. Companies alone, however, have no chance to succeed by shifting to this new conception. Therefore, Russian companies need integration into the

Table 1

Principles of the circular economy (the table from [11] completed by the authors)

Principles	Description	Examples of companies	Opportunities for the Russian companies
Regene-rate	Switching to renewable sources of energy and materials; Preservation and restoration of ecosystems; Return of restored biological resources in the biosphere	First Solar, Gamesa, GE Energy, Hanwha Q-Cells, Sharp, Siemens, SunOpta	Switching to renewable energy sources and the development of small hydro power plants, solar and wind power, biogas plants and biomass
Share	Sharing of assets; Reuse of products; Extending the product life cycle through the maintenance, design for the purpose of durable use and etc.	Patagonia, BlaBlacar, Nearly New Car, BMW, Drivy, Daimler, Lyft, BMA Ergonomics	Exchange platforms for food, clothing and footwear, typographic products
Optimize	Improving the efficiency and the performance of the product; Reducing waste in manufacturing and supply chains	Coca-Cola, Danone, Ford, Toyota, Maersk	Development of ecological design of the product , the use of biodegradable and recyclable materials
Loop	Recovery products and components; The recycling of materials; Anaerobic digestion and getting bio-chemicals from organic waste	Caterpillar, Michelin, Rolls Royce, Philips, Renault, Bosch, Volvo	Formation of remanufacturing in the automotive and aerospace industry, in the production of large household appliances in the MIC. The use of composting and anaerobic digestion in agriculture to produce fertilizer and energy, as well as the processing of MSW and products unfit for recovery and reuse
Virtualize	Direct and indirect dematerialization	Google, Apple, and most OEMs plan to release driverless cars on the market in the next decade. Apple, Amazon, De Kledingbibliotheek	Development of showrooms and online sales, replacing the actual media by intangible media
Exchange	The use of new technologies; Selection of new products and services; Substitution in the products of non-renewable materials and resources to renewable	Winsun –3D-printing	Development and implementation of innovative technologies in the field of product recovery, the development of biodegradable materials

global networks of ecologically responsible businesses. Then first, they will be able to attract foreign direct investment. Second, they will to contribute to technology transfer into the recovery industries, to the development of coopetition (i. e. cooperation between competitors) and to the exchange of circular business best practices. Third, such activities will also contribute to the growth of consumer awareness for sustainable and inclusive products and processes from the closed supply chains.

So far, the Russian science community did not draw adequate attention to the problems and potentials of the circular economy. Russia needs more research projects on the design of biodegradable materials that are not harmful to the environment and on innovative recovery technologies. State-business-science community alliances in Russia are needed for speeding up the movement to a sustainable society with a circular economy.

Conclusion

The simultaneous achievement of the objectives of sustainable economic growth and of international competitiveness, social well-being and reduction of the pressure on the environment presuppose the implementation of a large-scale transformation. Important drivers of this transformation are provided by the forth industrial revolution and by its the circular economy model. Deepening cooperation between government, business, science and society is needed to move Russia forward on the trajectory to sustainable, inclusive and socially accepted growth and to take decent position in the modern world economy. The development of the circular economy will contribute significantly to get successfully on that path.

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Циркулярная экономика как вызов четвертой промышленной революции

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Целью статьи является раскрытие роли циркулярной экономики в качестве инновации четвертой промышленной революции. Циркулярная экономика является предпосылкой и вместе с тем драйвером новой промышленной революции. Концептуально она преследует две основные цели. С одной стороны, полная ценность использованных продуктов должна быть восстановлена для обеспечения максимальной экономической эффективности. С другой стороны, восстановление этой ценности обусловливает снижение негативного воздействия на окружающую среду и тем самым соблюдение социально-экономических и экологических требований устойчивого развития. В совокупности это приводит к устойчивому формированию ценности. В данном контексте авторами обсуждается модель замкнутых цепей поставок «6R», обеспечивающая имплементацию инновационной концепции восстановления ценности продукта. На конкретных примерах раскрываются шаги, которые должны быть сделаны для успешного применения этой модели. В заключение анализируются проблемы и препятствия, стоящие на пути реализации принципов циркулярной экономики и перехода к замкнутым цепям поставок в Российской Федерации.

Ключевые слова: циркулярная экономика, замкнутые цепи поставок, четвертая промышленная революция, экологические инновации, восстановление.