Assessment of an Enterprise Circular Economy Development

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Abstract: Currently, much attention is paid to a circular economy development at the level of economic sectors. In this regard, the implementation of the circular economy business model within an enterprise becomes a key factor for a country competitiveness increase and a guarantee of a sustainable economic growth.
There has been drawn a hypothesis that energy efficiency and energy savings of an enterprise have a significant influence on the circular economy development. In the paper authors propose a representative set of economic and energy indicators, which allows to assess a circular economy formation of an industrial enterprise. Authors suggest an approach according to which the resulting vector of a circular economy of an enterprise may be assessed by the growth rates of the indicators mentioned above.
Based on this, it may be possible to make an integral assessment of an enterprise circular economy development through the ratio of the optimal growth rate of the closed cycle indicators characterizing a circular economy (n_{opt}) to the total number of growth rates indicators required for the identifying of a circular economy of an enterprise (n_{total}). In the paper authors also present theoretical model of closed large enterprise cycle.
Authors also propose different types of investment projects aimed to implement a circular economy model on an enterprise. For this reason, additional criteria for investment project, based on the above-mentioned indicators of a circular economy, were suggested.
The proposed approach makes it possible to conduct an assessment of innovative business model formation of an industrial enterprise in order to determine its sustainable development towards a circular economy.

Key-Words: circular economy, small cycles, business models, growth rates, criteria, investment projects

1 Introduction

Modern methods of design, production and industrial marketing allow to recycle and reuse materials, that enables minimizing of waste volumes, that is the basis for the transition to a circular economy realization. The circular economy model (Butterworth J. et al, 2013) emerged in the 2000s as a logical continuation of the sustainable development concept (Brundtland, Gro Harlem, et al), ecological economics (Costanza, 1992), works of Walter Stahel (Stahel, 1982; 2008), the concepts of Zero Waste (Murray, 2002) and Cradle-to-Cradle (Braungart, McDonough, 2002), the scientific basis of Industrial Ecology (Graedel, Allenby, 2010). The circular economy is the exact opposite of the traditional linear economy.

The circular economy model is a 3R model (Reduce, Reuse and Recycle), which means reducing the environmental impact and consumption of non-renewable resources, re-using resources, recycling waste.

The criteria for a circular economy are as follows:

- use of waste as raw material for the production of new goods;
- the design of the components in the way that they can be processed with minimal energy and without loss of quality;
- use of renewable energy sources;
- it is more efficient to reuse goods, carry out their maintenance and restoration, rather than recycle them and return them to the level of the component manufacturer;
- the need for a complex assessment, taking into account economic, environmental, social factors.

According to the forecast of the World Economic Forum, the introduction of a circular economy methods on a world-wide scale will give an opportunity to save a trillion dollars annually only by more rational use of natural resources by 2025 (Navi, Prabhu, 2015).

2 Theory

Nowadays business climate, customer requirements and the competitive environment itself are changing quite quickly. In this regard, the practice of project portfolio management of enterprises allows to find out the most priority ideas of products deserving the first-priority financing. Furthermore, the crossing functional integration for the correct statement of innovation processes is really significant today as well. This allows to bring into accordance technical and business projects, which, in turn, enable manufacturers to switch to a new cost-effective model of manufacturing managing which makes it possible for individual orders to be performed quickly and flexibly on an industrial scale at minimum cost with the resource savings.

The reasons for such a top result are the production assets of a new generation, which use advantages of a number of revolutionary technological innovations:

- new materials reducing the cost value and volumes of industrial waste without detriment to the quality and functionality of products;
- the latest production technologies including robotic and computer-aided design engineering and 3D printing;
- new conceptual approaches, such as social production, continuous flow manufacturing and decentralized production.

New digital tools, including 3D printers and robotics, allow to introduce resource-efficient approaches such as social business activity, continuous and decentralized manufacturing.

The social entrepreneurship (Abu-Saifan, 2012) includes customers involvement into technological process, while the concept of decentralized production allows to destroy the centralized production pyramid and turn it into a distribution horizontal network of thousands of mini-factories, which can be located close to retail consumers, and this, in turn, enables such plants to produce industrial products in small quantities which have a demand for such volumes. Such production is based on the design principle "as the demand arises," which intends the rapid development and launching just products of suitable quality in demand, and then gradually bring them up and improve. According to the analysis of customers feedback, this should be done promptly and timely, but this methodology of flexible development and effective product launch is possible only when the R & D strategy does not involve investing of all the funds in one large-scale project since financial risk management is based on investing in a number of small and promising small projects in order to concentrate all resources and capabilities on the most successful projects based on experience of failures in the early steps in meeting the demand, which will allow to use the R & D budget effectively and envisage rational financing of risks (Radjou, Navi, and Jaideep Prabhu, 2015). Under these conditions, researchers and developers should look for opportunities to establish partnerships with suppliers and sales partners in order to quickly process their proposals within the framework of strict limitations on the timing of new products launching to the market within the allocated budget for the project.

Nowadays a new "business model" at a number of foreign companies is successfully implementing a circular economy based on three principles of lean innovations: quality, accessibility and environmental friendliness. In this regard, each product must be developed providing the requirements of safety, efficiency, environmental cleanliness, aesthetics and affordability.

In fact, the environmental friendliness lies behind the product development strategy of companies, which organically fits into the C2C concept as a variant of a circular economy, that requires to carry out in practice waste-free production principles with a maximum use of natural raw materials and recycling of worn out materials for the later use starting from the design stage. These days, it is impossible realize lean innovations and get the opportunity for autonomous manufacturing of products and providing services with a cyclical increase in profits without the C2C concept implementing.

These processes can form the following business models that meet the canons of a circular economy.

The first classification of circular economy business models is given by Accenture (2014):

- circular supplies: provide renewable energy, bio based- or fully recyclable input material to replace single-lifecycle inputs;
- resource recovery: recover useful resources/energy out of disposed products or by-products;
- product life extension: extend working lifecycle of products and components by repairing, upgrading and reselling;
- sharing platforms: enable increased utilization rate of products by making possible shared use/access/ownership;
- product as a service: offer product access and retain ownership to internalise benefits of circular resource productivity.

And another one classification of circular economy business models, presented by Forum for the Future (2016):

- closed-loop recycling: using raw materials from existing products to make new products in order to move from a linear (make-use-dispose) towards a more circular system/business;
- downcycling: turning materials from one or more used products into a new product with lower quality;
- upcycling: turning materials from one or more used products into a new product, implying an improvement in quality;
- industrial symbiosis: the sharing of services, utility, and by-product resources among industries in order to improve resource efficiency;
- collection service: providing a service to collect old or used products;
- product as service: offers that put the focuses on offering a solution rather than a product only, this leads to a marketable set of joint products and services that are capable of fulfilling a user's needs together;
- lock-in: an offer that forces consumers to carry on using a specific product or service on a regular base;
- local loop: as production processes are re-shored back into the countries where the business has its main markets, the local manufacturing loop becomes closer and benefits clustering of industries;
- modularity: a design that divides a product into smaller parts that can then be independently created, used and replaced;
- personalization: company creates data management opportunities that enable product personalization.

The analysis of the existing business models of the circular economy allowed authors to identify the following main processes they all are based on:

- maintenance of goods;
- reuse of goods;
- sharing;
- refurbishment, remanufacturing;
- recycling (which can be upcycling - the transformation of materials and waste into new materials of higher quality; functional recycling - recovery of materials for the original purpose or other purposes, except for energy; and down recycling - the transformation of materials and waste into new materials of lower quality).

There are a number of papers, in which authors try to assess the level of circular economy development in the companies from different economic sectors using special indicators, which allow to determine how consistently the process of the formation of the circular economy is carrying out.

In the paper by Molina-Sánchez et al. (2018) authors applied the concept of the circular economy to the wastewater treatment from a paper mill, with the objective of recovering the resources contained in this type of effluent. In the paper by Molina-Moreno et al. (2017) authors suggest the indicator of circular economy to evaluate the degree of approximation of the pig manure treatment process to the circular economy model. In the paper by Nuñez-Cacho et al. (2018), the development of the circular economy scale for the building industry was described, treated as an instrument that allows to direct measurement of the importance of circular economy for companies. As for industrial enterprises, there are papers, analysing energy conservation and circular economy in China's industry (Li et al., 2010; Ma et al., 2014), and more generally indicators of circular economy are analysed in the paper by Banaitė (2016).

However, there is a lack of methods, that would allow to assess the circular economy development taking into account all its components at the enterprise level, especially energy and environmental performance.

In this context, the assessment of the circular economy development at the level of industrial enterprise becomes important since it forms a circular economy of the economic sectors.

3 Materials and Methods

Figures and Tables should be numbered as follows: In this regard, we define, to the first approximation, a representative and possible set of economic and energy indicators, which allow to assess a circular economy formation of an industrial enterprise (table 1).

The resulting vector of a circular economy will be assessed by the growth rates of the above indicators (Table 1), and by the correlation between them.

Let us look more closely at some ratios of growth rates and define the possible projects for the formation of rational ratios for assessing a circular economy. The first ratio of growth rate ($E' > V_{fuel}$) characterizes quality improvement of fuel and energy balance of an enterprise, since electric power, as the most qualified energy resource, characterizes a high level of manufacturability of an enterprise which is an important feature of a circular economy.

The second ratio of the growth rate between the production program (D') and the output of secondary energy resources (SER) (V'_{ser}) should be in favor of the latter ($V'_{ser} > D'$) and this will indicate a high level of energy savings and certainly represent a very important feature of a circular economy (Fedorov et al., 2010).

The third ratio of growth rate between the volume of materials for production (M'_{mat}) and the production program (D') should be in favor of the latter ($D' > M'_{mat}$), but at the same time the growth rates of volume of materials for production should be higher than that of physical waste from the production ($M'_{mat} > M'_{waste}$) and the greater this separation, the more intensive the process of the circular economy formation will be.

The fourth ratio of the growth rate of worn-out products recycling (T'_{rec}) should be higher than that of manufactured products (D'), that is ($T'_{rec} > D'$), this will also characterize the degree of intensity of a circular economy and, therefore, reduce the involvement of extra resources and the environmental burden.

The fifth ratio of growth rate of remanufactured products T_{rem} should be higher than that of manufactured products (D'), that is ($T'_{rem} > D'$), that further will provide a decrease in resources for manufacturing of new products and reduce the environmental burden as well.

The sixth ratio of the growth rate of production sales revenue (PR'_{rev}) should be higher than that of the production program (D'), that is ($PR'_{rev} > D'$). This will characterize the competitiveness of an enterprise in the market and strengthen the sustainable development of an enterprise towards the circular economy formation, as long as the investments, that the enterprise has at its disposal, will be directed to the renewal and modernization of production ensuring the decrease of the environmental burden, which in turn should provide the high growth rate of investments in treatment facilities (IN'_{treat}) and should be higher than the growth rate of polluting emissions from the production (V'_{emis}) and emissions of CO_2 in the production process (CO_2').

Since the circular economy includes small cycles, such as, reuse, recovery, modernization, the use of secondary energy resources, increasing the environmental friendliness of products by reducing harmful emissions, etc., it brings great benefits not only financial, and economical, but environmental as well. Therefore, when evaluating a circular economy, it is necessary first to assess small cycles through relative indicators, which will characterize the rate of turnover of these cycles, so the efficiency (speed) of the products reusing cycle is proposed to assess through the ratio of the reused products, after recovery or technical servicing to manufactured products. The efficiency (speed) of the cycle of recycling worn-out products for manufacturing is necessary to assess through the ratio of recycled products to manufactured ones. The efficiency (speed) of the recovery products cycle is necessary to assess through the ratio of recovered products to manufactured products. The efficiency (speed) of the modernized products cycle is necessary to assess through the ratio of modernized products to manufactured ones.

The efficiency (speed) of the waste-free production cycle is necessary to assess through the ratio of the volume of physical waste from the production to manufactured products and the more products produced from waste, the higher the efficiency of technological processes of a circular economy of an enterprise. Thus, the efficiency of small cycles will be an entire interconnected system of indicators, which will comprehensively allow to evaluate the formation of a large closed-loop economy of an enterprise.

However, the integral assessment for the process of formation of a circular economy of an enterprise should be presented through the ratio of the optimal growth rate of the closed cycle indicators characterizing a circular economy (n_{opt}) to the total number of growth rates indicators required for the identifying of a circular economy of an enterprise (n_{total}):

$$Q = \frac{n_{opt}}{n_{total}} \times 100\%$$

Such an assessment characterizes the level of development of a circular economy of an enterprise and if the assessment is more than 50%, then we can assume that the enterprise has reached a trajectory of a sustainable development formation. In this regard, it is necessary to conduct a systematic analysis of small cycles, which in turn requires determining the duration of these cycles that varies inversely with the speed of small cycles multiplied by 365 days that allows to correctly identify the priorities of reducing the amount of time involved in turnover of small cycles of a circular economy of an enterprise.

The definition of priorities will be based on a comparison of the duration of the turnover of small cycles with the payback period of attracted investments for reducing specific small cycles, but at the same time an important limitation will be the investments that the company has at its disposal. Under these circumstances, the state in the sphere of legislation on preferential crediting in order to increase the efficiency of a circular economy of an enterprise has an important role to play.

In this regard, it is necessary when selecting investment projects for the priorities realization of the efficiency (speed) of small cycles to properly assess the conditions of their implementation.

In the paper authors consider the example of the efficiency (speed) of the cycle of recycling worn-out products for manufacturing through the growth rate of indicators that form this figure.

1. The volumes of worn-out products for manufacturing increase, the manufacturing of products increases as well, but at a slower pace:

$$\frac{(\mathrm{T}_{rec}\ \uparrow)'}{(\mathrm{D}\ \uparrow)'}.$$

2. The volumes of worn-out products for manufacturing increase, the manufacturing of products remains at the same level:

$$\frac{(\mathrm{T}_{rec}\ \uparrow)'}{(\mathrm{D} = const)'}.$$

3. The volumes of worn-out products for manufacturing increase, the manufacturing of products decreases:

$$\frac{(\mathrm{T}_{rec}\ \uparrow)'}{(\mathrm{D}\downarrow)'}.$$

4. The volumes of worn-out products for manufacturing decrease, the manufacturing of products decreases, but at a faster rate:

$$\frac{(\mathrm{T}_{rec}\ \downarrow)'}{(\mathrm{D}\downarrow)'}.$$

5. The volumes of worn-out products for manufacturing increase by the same amount, the manufacturing of products decreases:

$$\frac{(\mathrm{T}_{rec} = const)'}{(\mathrm{D}\downarrow)'}.$$

Since the realization of investment projects is the basis for the formation of the implementation strategy for a circular economy of an enterprise and an enterprise is limited in its financial capabilities, it is necessary to use the NPV additivity property here to obtain the maximum effectiveness of projects in small cycles of a circular economy of an enterprise:

$$NPV_1 + NPV_2 + NPV_3 + ... + NPV_n = \sum_{i=1}^{n} NPV_i \to \max$$

where NPV_n is the investment project of the *n-th* small cycle.

For the selection and realization of the investment projects of small cycles, additional criteria are needed, the value of which is obvious for improving the efficiency of a circular economy of an enterprise (Table 2).

Based on the above researches and the provisions, there can be formulated the following hypothesis: energy efficiency and energy savings of an enterprise have a significant correlation with a circular economy of an enterprise, expressed by the growth of manufacturing products, worn-out products recycling, reuse of goods from recovery and modernized products, use of renewable energy sources, production sales revenue, energy savings, investments in treatment facilities to decrease the CO_2 and other polluting emissions in energy consumption, physical and other waste in manufacturing products. This hypothesis can be well illustrated by the authors' drawing of a theoretical model of a closed large enterprise cycle (Fig. 1). The proposed hypothesis is the basis for the formation and development of a circular economy of an enterprise, which is quite convincing in a number of scientific works (Anufriev, 2009; Breddik, 1977; Kozhuhovskij, Novoselova, 2011; Letyagina, 2011).

4 Conclusion

Authors suggested representative set of economic and energy indicators, which allow to assess a circular economy formation of an industrial enterprise.

Based on this, it may be possible to make an integral assessment of an enterprise circular economy development through the ratio of the optimal growth rate of the closed cycle indicators characterizing a circular economy (n_{opt}) to the total number of growth rates indicators required for the identifying of a circular economy of an enterprise (n_{total}) and to present theoretical model of closed large enterprise cycle.

Also the attention was paid to different types of investment projects aimed to implement a circular economy on an enterprise. For this reason, additional criteria for investment project, based on the above mentioned indicators of a circular economy, were suggested.

There has been drawn a hypothesis that energy efficiency and energy savings of an enterprise have a significant relation to the circular economy of an enterprise.

A serious methodological weakness in the formation and assessment of the energy policy of an enterprise is the lack of accounting and including external factors in the chain of links of an enterprise economy cycle, that further does not allow to assess fully the consequences of inter-sectoral interactions of enterprises in the realization of energy efficiency investment projects. And methodological tools, proposed by authors in the paper may help to overcome these limitations, since they allow for a direct measurement of the importance of circular economy for companies.

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Appendix

Table 1. Indicators and formal measures for assessment of a circular economy formation of an industrial enterprise

Circular economy indicator	Assessment of the dynamic characterizing the cycle taking into account the growth or reduction of indicators	
	Negative feature	Positive feature
1	2	3
Demand for fuel and energy resources V_{fer}	The growth rate of V'_{fer} is higher than that of the production program D'	The growth rate of V'_{fer} is lagging behind that of the production program D'
Demand for electrical energy E	The growth rate of E' is higher than that of the production program D'	The growth rate of E' is lagging behind that of the production program D'
Demand for fuel resources V_{fuel}	The growth rate of V'_{fuel} is higher than that of the production program D'	The growth rate of V'_{fuel} is lagging behind that of the production program D'
Demand for thermal energy Q	The growth rate of Q' is lagging behind that of the production program D'	The growth rate of Q' is higher than that of the production program D'
Volume of secondary energy resources V_{ser}	The growth rate of V'_{ser} is lagging behind that of the production program D'	The growth rate of V'_{ser} is higher than that of the production program D'
Volume of materials for production M_{mat}	The growth rate of M'_{mat} is higher than that of the production program D'	The growth rate of M'_{mat} is lagging behind that of the production program D'
Volume of physical waste from the production M_{waste}	The growth rate of M'_{waste} is higher than that of the production program D'	The growth rate of M'_{waste} is lagging behind that of the production program D'
Volume of worn-out products recycling T_{rec}	The growth rate of T'_{rec} is lagging behind that of the production program D'	The growth rate of T'_{rec} is higher than that of the production program D'
Volume of remanufactured products T_{rem}	The growth rate of T'_{rem} is lagging behind that of the production program D'	The growth rate of T'_{rem} is higher than that of the production program D'
Volume of products undergone technical servicing $T_{tech.\ serv.}$	The growth rate of $T'_{tech.\ serv.}$ is lagging behind that of the production program D'	The growth rate of $T'_{tech.\ serv.}$ is higher than that of the production program D'
Production specialization $P_{spec.}$	The growth rate of P'_{spec} is lagging behind that of the production program D'	The growth rate of P'_{spec} is higher than that of the production program D'
Cooperation of production K_{pr}	The growth rate of K'_{pr} is lagging behind that of the production program D'	The growth rate of K'_{pr} is higher than that of the production program D'
Volume of polluting emissions from the production V_{emis}	The growth rate of V'_{emis} is higher than that of the production program D'	The growth rate of V'_{emis} is lagging behind that of the production program D'
Emissions of CO_2 in production	The growth rate of CO_2 is higher than that of the production program D'	The growth rate of CO_2 is lagging behind that of the production program D'
Production sales revenue PR_{rev}	The growth rate of PR'_{rev} is lagging behind that of the production program D'	The growth rate of PR'_{rev} is higher than that of the production program D'
Investments in treatment	The growth rate of IN'_{treat} is	The growth rate of IN'_{treat} is

facilities IN_{treat}	lagging behind that of the production program D'	higher than that of the production program D'
Waste output in production OT_{pr}	The growth rate of OT'_{pr} is higher than that of the production program D'	The growth rate of OT'_{pr} is lagging behind that of the production program D'

Table 2. Additional criteria for investment projects required to form a circular economy of an enterprise

Criteria	Investment projects
$E' - V_{fer}' \rightarrow$ opt max	Investments in electrical production technologies
$V'_{ser} - D' \rightarrow$ opt max	Investments in energy saving production technologies
$D' - M'_{mat} \rightarrow$ opt max	Investments in manufacturing technologies
$T'_{rec} - D' \rightarrow$ opt max	Investments in the development of related production technologies
$T'_{rem} - D' \rightarrow$ opt max	Optimal capacity utilization
$PR'_{rev} - D' \rightarrow$ opt max	Effective marketing strategy
$IN_{treat}' - V_{emis}' \rightarrow$ opt max	Optimization of the investment structure in the development of production
$IN_{treat}' - CO_2' \rightarrow$ opt max	Optimization of the investment structure in the development of production
$D' - OT'_{pr} \rightarrow$ opt max	Investments in manufacturing technologies
$\Delta V_{fer}' > D' \rightarrow$ opt max	Energy efficiency investments

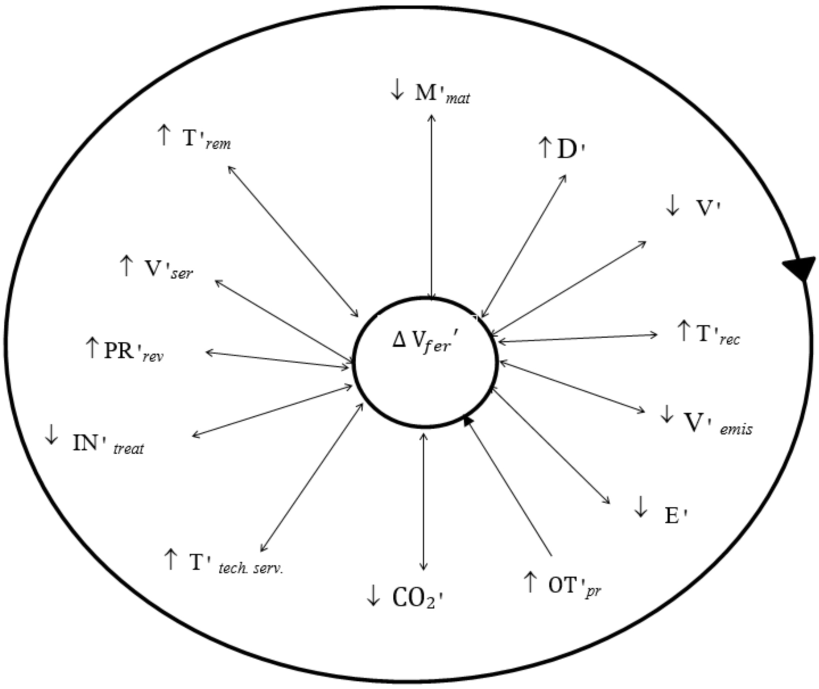

Figure 1. Model of closed large enterprise cycle