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Assessment of the Efficiency of Energy and Resource-saving Technologies in Open Innovation and Production Systems

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ABSTRACT

The relevance of this work is determined by the fact that the issues of energy- and resource-saving technologies implementation in open production and economic systems have not been fully addressed yet and require further study and systematization of the determining factors, which is especially important on the back of the transition to a new technological pattern and the use of the emerging technological opportunity windows. The solution of the problems mentioned will reveal new opportunities for qualitative and quantitative growth of production systems by improving the innovation targeting in the field of resource saving and energy efficiency. The purpose of the article is to identify the functional dependence between the industrial production index (IPI) and the indicators describing the energy- and resource-saving system in the industrial complex in order to improve the efficiency of energy- and resource-saving technologies in open innovation and production systems. The main research methods underlying the article include the method of description used to identify trends in the use of energy- and resource-saving technologies across the globe, the correlation analysis method used to identify the strength of the relationship between the IPI and indicators of the energy- and resource-saving system in production, and the regression analysis method used to build a regression model of the dependence between the resource-saving system and production indicators. The article touches upon the aspects of improving the energy- and resource-saving system efficiency in the framework of the innovation model in the field of production. The multidirectional nature of trends in the industrial production and the use of energy- and resource-saving technologies in the industry of developing countries is revealed; the functional relationship between the use of waste in industrial enterprises and shipped industrial products on the example of developing countries is proved. The materials of the article can be used in the development of strategies and programs aimed to improve the energy- and resource-saving system efficiency in petrochemical companies of developing countries, taking into account the emerging technological opportunity windows and technology readiness of the production for innovative transformations.

Keywords: Energy Saving, Resource Saving, Open Innovations, Energy Efficiency
JEL Classifications: O32, L60, L23, D24

1. INTRODUCTION

The global financial and economic crisis predetermined changes in the development pathway of national innovation and production systems. Trends in the economy have shown that the development opportunities of the fifth wave of innovation will soon begin to fade away. There is a need for the emergence of new technologies and re-orientation of economic resources to drive the formation of a new sixth technological wave, where energy- and resource-saving technologies will appear as the key contour. The development of the new technological pattern is based on the production potential created at the previous stage of technical and economic development (Firsova et al., 2019). However, the reproductive contour of the new technological pattern does not

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appear immediately, since at the initial phase of its development, the technological complexes arising as a result of the introduction of basic innovations do not form a self-reproducing entirety and remain for some time associated with the technological complexes of the old technological pattern.

A new wave of innovation is conceived on the back of the previous one still dominating in the economic structure, and its development is constrained by an unfavorable technological, social and economic environment. Only after the dominant technological pattern reaches its growth limits and the profitability of its constituent productions declines, the resources begin to redistribute into the technological chains of the new technological pattern, which is currently observed in the world economic system. Business entities of the countries that were the first to start the implementation of basic productions of the new wave of innovation, accumulating production experience, enjoy relative advantages and win foreign markets, thereby extending the life cycle of the technological pattern.

In this regard, in the context of the world economic system transformation, the criterion for the efficiency of the innovative production systems development becomes the timely re-orientation of resources from technologically backward industries to key sectors that form the core of the new technological pattern. Depending on how quickly and fully technological diversity can be eliminated and breakthrough growth of key sectors can be achieved with appropriate financial, organizational and institutional support provided by the state to the innovative economic sector, the national economic system as a whole can become efficient and competitive.

In this regard, the most important task faced by the world countries becomes the modernization of the economic structure. The promotion and continuity of innovation begin to play a crucial role in the technological development. The focus is shifting towards the introduction of product and process innovations in the companies' resource-saving and energy efficiency systems.

Environmental objectives of production in the energy- and resource-saving system in the context of the new technological pattern should meet the following criteria:
- Prevention of environmental pollution;
- Application of the green chemistry principles;
- Minimization of hazards/risks;
- Reduction of raw material losses;
- The possibility of using renewable raw materials (including energy resources);
- Maximum efficiency and effectiveness of chemical technology systems and supply chains;
- Minimization of emissions and energy consumption in chemical and technology systems and supply chains;
- Goods manufacturing with minimal harmful impact on the environment;
- Compliance with economic criteria.

The main ways to ensure energy saving in industrial enterprises can be systematized as follows: The best use of technological processes' driving force, the best use of raw materials, the best use of fuel and energy resources, the best functional and structural use of devices and machines, the way to improve reliability and safety and reduce risks, the method of rational energy and resource efficient equipment layout, the method of water recycling, and the method of logistics control over the energy and resource efficiency of technological systems.

2. LITERATURE REVIEW

The problems of administrative and technological innovations implementation are reflected in numerous works of researchers, for example, the effect of random change on innovation activities (Chen and Adamson, 2015), the use of innovation to overcome the crisis of organizations (McKinley et al., 2014), radical innovation (Alexander and Knippenberg, 2014), innovation in the knowledge economy (Cano-Kollmann et al., 2016), social responsibility of innovation-related activities (Un, 2016), innovative behaviour of project team leaders in companies (Kang et al., 2015), the influence of strategic partnerships on the innovation outcomes (Zheng and Yang, 2015), modelling innovation activities in different types of economic systems (Reznikov et al., 2016), open national innovation systems (Kudryavtseva et al., 2015). Despite sufficient coverage of the aspects associated with the innovations in the industrial complex and their social responsibility, in our opinion, not enough attention has been paid to the specifics of the use of open innovations within the framework of the resource and energy-saving technologies systems that would allow us to consider the technological process of production not as a separate element of production, but as a certain link in the supply chain of final products.

Theoretical and practical aspects of innovation depending on the branch of human knowledge and applications in the economy sectors are presented in detail in the works of the following authors: Elimination of barriers on the way of eco-innovation implementation (Polzin et al., 2016), innovations in biotechnology and agriculture (Mutenje et al., 2016), social capital and knowledge codificability (Vlaisavljevic et al., 2016), diffusion of innovations in management (Scarbrough et al., 2015), collaborative innovation in the industry (Frow et al., 2015), innovations in transportation and manufacturing systems (Shinkevich et al., 2018a), environmental innovation (Klimenko et al., 2018). However, whilst the types of innovation in different sectors of the economy are presented quite broadly, relatively few interdisciplinary approaches to innovation are provided based on the synthesis of different areas of knowledge that can form specific assets in the study area, increasing synergetic effects at different levels of management of the economic system and production complexes represented in its framework.

Management of the innovation costs in the innovation and production systems is thoroughly discussed in the following researches: Reducing innovation costs and the role of patent intermediaries in the market efficiency improvement (Agrawal et al., 2016), evaluation of content innovation (Guo and Easley, 2016), and the impact of service innovation on enterprise value (Tong et al., 2016). The problem of the innovation cost calculation, in our opinion, should be considered along with the assessment of innovation costs and results, which requires accounting for time lags between these indicators in the innovation management model as well as identifying mechanisms to achieve their balance.

The problems of greening the industry and improving the resource-saving systems efficiency through innovation are reflected in the following studies: environmental certification and technical efficiency (Sahu and Narayanan, 2016), planning of highly hazardous component inventory (Brezavšček, 2016), innovative developments in oil and gas production (Carpenter, 2016), flexible solutions in production systems (Narandja et al., 2015), and digitalization of open innovation systems as a factor of their efficiency improvement (Kudryavtseva et al., 2018; Kvon et al., 2019). According to the works mentioned, today, on the back of technological modernization, industrial production is focused on innovative technological systems that can provide high economic efficiency, resource saving and quality improvement. At the same time, it becomes obvious that in order to address the task of improving the production system organization efficiency, we have to identify and develop necessary control mechanisms that are of particular importance for the industrial sectors with a high proportion of energy-intensive industrial products, such as the petrochemical complex. In our opinion, the development of resource management models should be based on the identification of the internal potential of innovation and production systems, depending on the specifics of the industry, in which they operate, as well as the institutional and technological environment, which is not fully represented in the research dedicated to this topic.

In addition, notwithstanding the availability of an extensive theoretical and methodological array of data and practical solutions, there is still no single methodology for the open innovation and production complexes management in economic systems, which would combine the latest achievements of modern management science and take into account the peculiarities of the prerequisites needed for the emergence of a new technological pattern in the global economic system. In most cases, the studies mentioned are controversial and fail to duly account for the technology readiness and emerging technological opportunities for the improvement of the resource-saving system efficiency and the competitiveness of the industry.

3. STATISTICAL FRAMEWORK OF THE STUDY

The examples of international comparison on resource and energy-saving show a significant gap between developing countries (Russia, China) and developed economies. For the purposes of comparative analysis, the industry data of the following states was used: USA (the industrial output accounts for 18.6% of the global production), China (14.9%), Japan (8.1%), Germany (7.1%), France (4.3%), and Russia (2.1%) (World Bank, from: http://data.worldbank.org/indicator).

According to the latest statistics calculated using the World Bank's methodology, the gross value added (GVA) energy intensity of industrial enterprises in Russia made up 8.4 MJ/USD in 2017 at purchasing power parity (PPP) of 2011, which is by 4.2 MJ/USD below the level of 2000. It should be noted that this is the maximum value in the group of countries considered. A similar situation was observed in 2000. At the same time, we can mention as a positive factor that the greatest decrease in energy intensity in the Russian industry occurred in 2000-2017. In addition, in the period of global industrial and financial crises (2007-2012), the energy intensity of the Russian industry was below that of China, but in 2012, this picture changed and switched to the pre-crisis trend (Figure 1). This situation can be explained by the "curtailment" observed in the Russian industry during the crisis, which facilitated further energy intensity reduction in the economy as a whole. Until 2010, the Russian industry showed a decrease in its energy intensity, but then the trend changed to an upward one, which was not typical for other countries under consideration.

The alternative indicator, i.e., the GVA of industrial enterprises per unit of energy consumption, amounted to 5.2 from the constant PPP 2011 per kg of oil equivalent in the Russian industry in 2017, which is the lowest value for the industrial countries under consideration. The indicator had maximum value in Germany — 11.5. The overall dynamics of this indicator in the industry of the countries in question was positive (Figure 2).

It is noteworthy that in terms of energy consumption, Russian industry falls behind the US industry — 4943 kg of oil equivalent per capita against 6798 in 2017. However, compared to 2000, the value of this indicator for the Russian industry has increased by 17%, while in the US it has decreased by 15.6%. Reduction of energy consumption per capita was also observed in Japan (16%), France (10.8%), and Germany (6.8%). China recorded a 2.5-fold increase in 2017, if compared to 2000 (Figure 3).

Resource saving and energy efficiency imply the introduction of renewable energy sources as one of the key vectors in this field.

According to the World Bank, in 2017, the share of renewable energy in the total energy consumption of the Russian industry accounted for 3.3%, which basically corresponds to the value of 2000 — 3.5%. At the same time, the level of renewable energy consumption is lower than that of Germany by 4.3 times, France — by 4.1 times, China — by 3.8 times, the US — by 2.6 times, and Japan — by 1.9 times. For industry, the share of renewable energy consumption was growing, with the exception of China, where this indicator decreased from 29.7% in 2000 to 12.4% in 2017. The indicator for Russian industry remained almost unchanged for the entire period under review, and no pronounced trend was observed (Figure 4).

However, in terms of the renewable energy output, the situation in Russia (15.9%) is similar to the situation in France (15.9%), Japan (16%) and is superior to the index of the US (13.2%). The maximum share of renewable electricity output was recorded at the end of 2017 in Germany — 29.2%. The negative factors include the decrease of this indicator in Russia's industry by 2.9 percentage points from the level of 2000, while other industrial countries showed a positive trend (Figure 5).

Figure 1: Energy intensity of gross value added of industrial enterprises (MJ/USD at purchasing power parity of 2011)

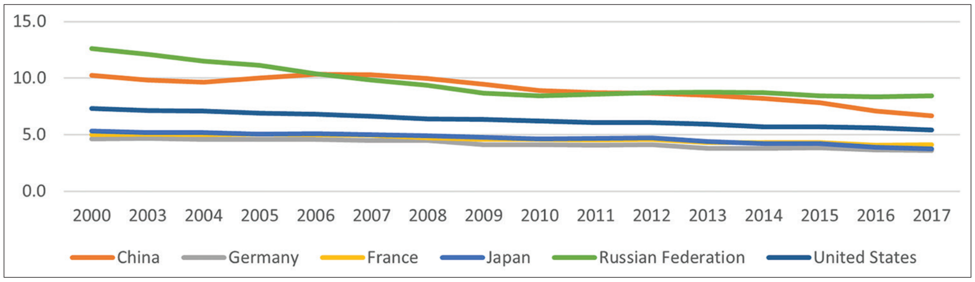


Figure 2: Gross value added of industrial enterprises per unit of energy consumption (constant purchasing power parity 2011 per kg of oil equivalent)

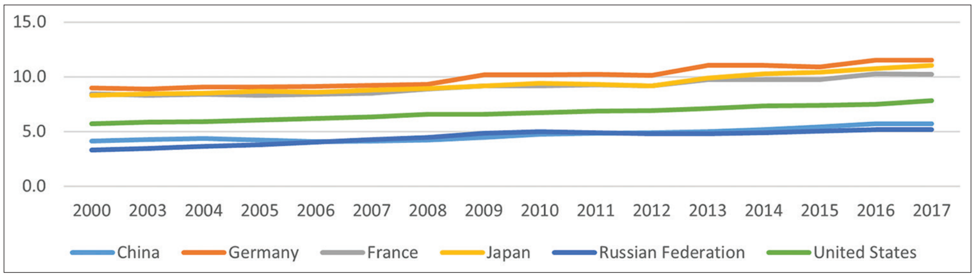


Figure 3: Industrial energy consumption (kg of oil equivalent)

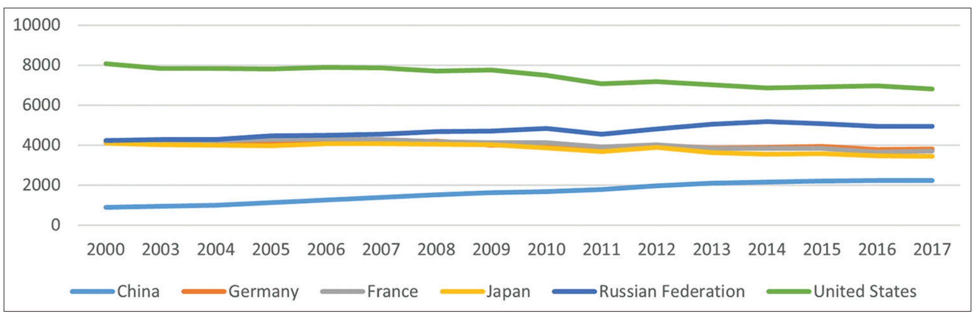


Figure 4: Renewable energy consumption in industrial enterprises (% of total final energy consumption)

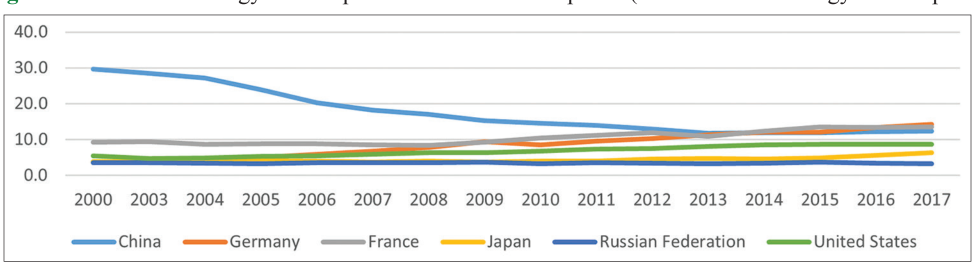
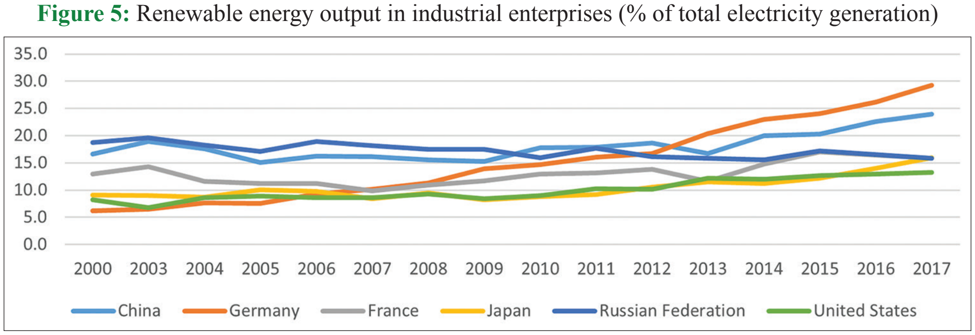


Figure 5: Renewable energy output in industrial enterprises (% of total electricity generation)



Issues of the transition of a state towards new technological pattern are mainly determined by the chance of rapid development that appears in conditions of the global crisis in technologically lagging countries. Within the framework of this innovative development paradigm the following works tend to be the most interesting from the scientific point of view: Perez and Soete (1988), Sheree and Ross (1997), Tsinopoulos et al. (2018), Shinkevich et al. (2018b) regarding emerging technological possibilities for catching-up countries at the change of technological patterns related both with technological inertness of leaders and with relatively low entry barriers at the stage of emergence of fundamentally new industries. In particular, new emerging industries and sectors of the economy and their rapid acquisition transfer economies of the developing countries to a qualitatively new wave of growth. The growing structural imbalances in the world economy require to mobilize resources for advanced development and the introduction of technologies aimed at the resource saving and energy efficiency improvement.

4. METHODS AND MODELS

To build an analytical model of the relationship between the energy-and resource-saving system in open innovation and production systems, we propose to use the following methods:

1. The correlation analysis method used to identify the strength of relationship between the energy- and resource-saving indicators in industrial production;
2. Regressive analysis, which allows building a regressive model of dependence between resources saving system and production indicators.

In order to find the linear Pearson correlation coefficient it is necessary to find the sample average x and y and their mean-root square deviations σ_x=S(x), σ_y=S(y), and then use the formula:

$$r_{xy} = \frac{\overline{xy} - \overline{x} \cdot \overline{y}}{\sigma_x \sigma_y}$$

In our case: y —IPI; x – energy-and resource-saving indicators in industrial enterprises.

To test the direction of the relationship, a hypothesis test is selected using Pearson correlation coefficient with further verification of fidelity using t-criterion. Estimation of statistic importance of r_{xy} correlation coefficient is done using t-criterion, which is calculated using the following formula:

$$t_r = \frac{r_{xy}\sqrt{n-2}}{1-r^2_{xy}}$$

The obtained t_r value is compared with the critical meaning at the definite level of importance and a number of degrees of freedom $n-2$. If t_r exceeds $t_{critical}$, the conclusion about the statistic importance of identified correlation could be done.

The most important task is to determine a form of relation with the following calculation of equation parameters or, in other words, to find a constraint relation (equation of regression). In our case, the polynomial trend (second order parabolic curve) will be used:

$$\overline{y}_x = a_0 + a_1 x + a_2 x^2$$

y_k – dependent variable,
x – independent variable;
a_0, a_1, a_2 – coefficients of elasticity of regression equation.

The ratio of the explained part of the variable (y) dispersion to the total variance, or determination coefficient, is used to characterize the quality of the regression equation or corresponding model of relation. The ratio between explained and unexplained parts of total variance could be represented in the alternative:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_t)^2}{\sum_{i=1}^{n}\left(y_i - \hat{y}\right)^{2'}}$$

y_i –value of the observable variable;
$\overline{y}$ –average value of the observable data;
$\hat{y}_t$ –model values built according to the estimated parameters.

If the determination coefficient exceeds 50% at its statistical meaning, in our research we will suppose that the received model is adequate.

5. RESULTS AND DISCUSSIONS

The analysis revealed that none of the resource efficiency and energy saving indicators in the industry of developing countries correlate with the IPI, which suggests a multidirectional nature of the resource and energy efficiency policy with changes in the production rates of industrial products (Table 1).

Table 1: Interconnection of the IPI and energy- and resource-saving indicators in the industrial complex

Indicator	IPI, %	GVA energy intensity of industrial enterprises, MJ/USD	Energy consumption, kg of oil equivalent per 1 industrial enterprise	Renewable energy consumption in industrial enterprises, % of total final energy consumption
IPI, %	1			
GVA energy intensity of industrial enterprises, MJ/USD	0.13	1		
Energy consumption, kg of oil equivalent per 1 industrial enterprise	–0.27	–0.86	1	
Renewable energy consumption in industrial enterprises, % of total final energy consumption	–0.07	0.27	–0.16	1

IPI: Industrial production index, GVA: Gross value added

We suppose that in the new technological pattern a special place in innovation and production systems will be taken by resource-saving technologies which allow reducing the emission of pollutants during production process and consumption of industrial products, as well as raising competitiveness and effectiveness of the whole chain and supply chain in an industrial complex.

An analysis of dynamics of the ratio of waste utilization per one industrial plant and shipped industrial products per one enterprise on average in the industry of the developing countries has shown the presence of a polynomial trend between two indices with average level of relation (World bank, from: http://data.worldbank.org/indicator). At the end of 2017 waste utilization per one industrial company made 1756 thousand tons. Compared with 2016, this figure has increased 5, 1 times, compared with 2010–6.3 times (Table 2).

The model of a relation between indexes of shipped industrial products per one company and waste disposal per one industrial company allowed to determine negative relation with negative elasticity coefficient, that made "minus" 0,43. Subsequently, the increase of disposed wastes per one industrial enterprise is accompanied by a decrease of shipped industrial products. The coefficient of model determination made 50% (Figure 6).

A similar negative dynamic of relation was noted between the use of waste per one industrial company and volume of shipped industrial products. A polynomial trend with negative elasticity coefficient was also revealed which made "minus" 10,4 respectively, the increase of the shipped industrial products was accompanied by the decrease of the amount of the used wastes per one industrial enterprise. Model determination coefficient made 76% (Figure 7).

Thus, the analysis allowed to establish multiple directions of changes in the volume of the shipped industrial products and waste usage per one industrial company which allows to assert low effectiveness

Table 2: Dynamics of waste disposal and products shipped in industrial enterprises

Year	Waste disposal per 1 company, thousand tons	Shipment of industrial products per 1 company, mln rubles
2010	277	286
2011	759	366
2012	193	419
2013	176	480
2014	128	546
2015	277	555
2016	341	728
2017	1756	855

Figure 6: The ratio between waste disposal per one industrial company and shipped industrial products

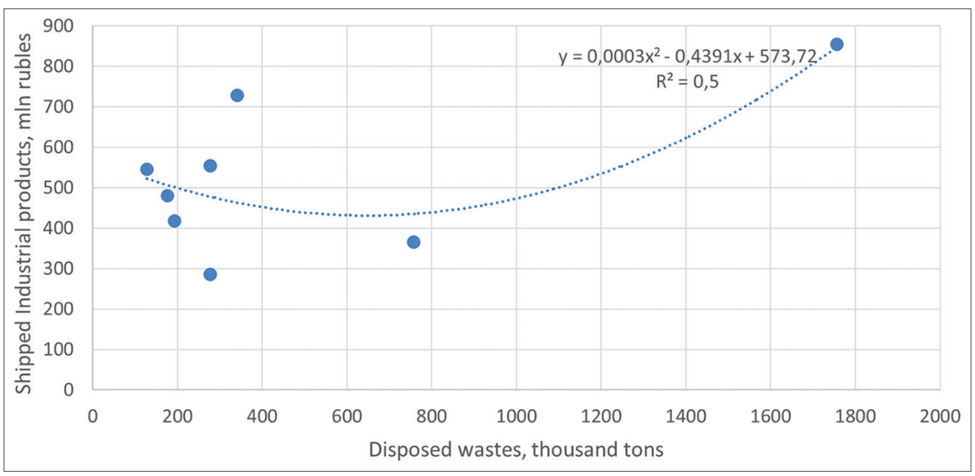
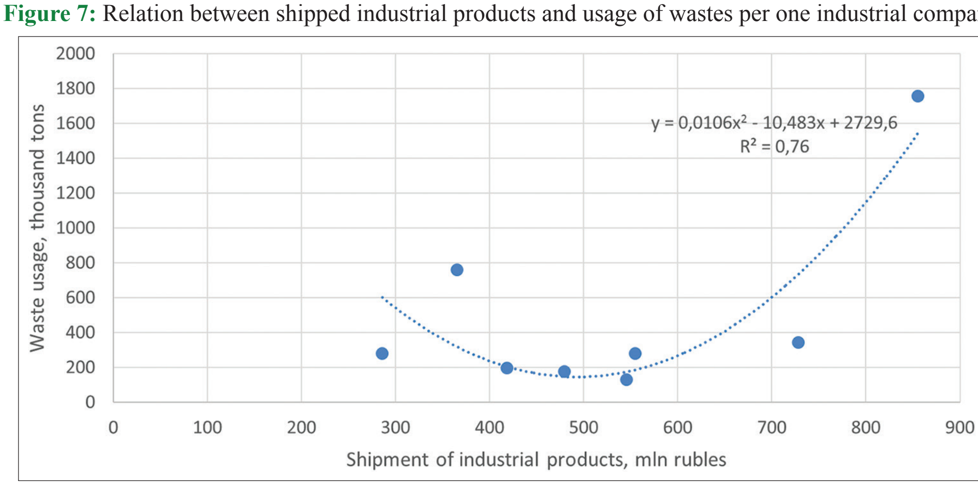


Figure 7: Relation between shipped industrial products and usage of wastes per one industrial company



of the resource-saving system in the industrial sphere. The system was analyzed with regard to the results in volume of the shipped industrial products, which characterizes industrial production in the industry of developing countries as partially closed.

6. CONCLUSION

Thus, the innovative development breakthrough in the industry of developing countries becomes possible subject to the change of technological patterns, passing through the first and the fourth phases of the life cycle of the technological wave, which is characterized by emerging technological windows of opportunities with the primary focus on energy-and resource-saving technologies. At the same time, we consider it to be the most appropriate if the technological leap is achieved with the use of an open innovation model that helps utilize the emerging technological windows more effectively and efficiently in order to improve the energy and resource efficiency of industrial production.

It should be assumed that the core of the further technological pattern for developing countries will be formed by directions which possess considerable capacity of fundamental and applied researches, as well as industries having high technological positions in terms of the implementation of energy- and resource-saving technologies: nuclear power, aerospace and aviation, nuclear physics, and selected armament systems. Fragmentary innovative elements in the use of energy- and resource-saving technologies are present in raw material industries – oil production, gas production, petrochemistry as well in process management. But, as a rule, the issue is in increasing effectiveness of separate production chains and not of the industry as a whole, labor safety or ecological technologies. One of the innovative transformation vectors of the industry sector in the emerging technological windows of opportunities can be considered the energy- and resource-saving system, which can be improved on the platform of the industrial enterprises operating in capital-intensive and energy-intensive industries. However, the study showed that the predominance of a partially closed-loop production cycle continues to be a limiting factor in its development. The materials of the article can be used in the development of strategies and programs aimed to improve the energy- and resource-saving system efficiency in petrochemical companies of developing countries, taking into account the emerging technological opportunity windows and technology readiness of the production for innovative transformations.

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