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Article

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Synergy of Digitalization within the Framework of Increasing Energy Efficiency in Manufacturing Industry

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ABSTRACT

The article contains the results of the study of manufacturing industry in terms of energy efficiency, digitalization and ecology. Interdependencies of the listed aspects are established and the synergetic effect of digitization is determined with the help of economic and mathematical modeling. The aim of the study is to determine the synergistic effect of digitalization, taking into account the improvement of energy efficiency and environmental protection of manufacturing. As a result of application of these methods, the article reflected the results of an analysis of the dynamics of energy consumption by manufacturing enterprises of the Russian economy; economic and mathematical models are proposed in the form of multiple linear regression equations that describe the dependence of environmental and "digital" parameters on energy efficiency indicators, allowing varying independent variables in order to achieve specific values of the resulting indicator; a model for optimizing energy consumption and financing energy efficiency was developed with the condition of minimizing polluting emissions by the manufacturing industry and further digitalizing of the industry. The research materials reflected in the article can be taken into account and applied within the framework of forming strategies and programs to ensure energy efficiency in manufacturing industries.

Keywords: Energy Resources, Energy Efficiency, Digitalization, Sustainable Development, Ecology, Optimization Model
JEL Classifications: L23, M11, Q43, Q52

1. INTRODUCTION

The issues of exhaustibility of natural resources, resource saving and energy efficiency are the central problems of industrial development in Russia. The goal of improving energy efficiency permeates such national documents as the development of energy state program of the Russian Federation (On approval of the Energy Efficiency and Energy Sector Development of the Russian Federation, 2014), the Reproduction and Use of Natural Resources State Program of the Russian Federation (On approval of the Reproduction and use of natural resources State program of the Russian Federation, 2014), A comprehensive plan of measures to improve the energy efficiency of the economy of the Russian Federation (On approving a comprehensive plan to improve energy efficiency of the Russian economy, 2018) and others. But despite the high goals of strategic documents, Russia is still far behind developed countries in terms of energy efficiency. According to a report published by the American Council for an Energy-Efficient Economy (2020), Russia ranks 21st among 25 countries with 34.5 points out of 100, behind Italy, Germany, France, Japan, Brazil and other most developed countries.

The Energy Strategy of Russia for the period until 2030 outlines such strategic guidelines in terms of the studied topics as "energy efficiency of economy," "budget efficiency of energy." Besides, at the third stage of the Strategy implementation it is planned to create "at least 300 million tons of standard fuel per year" (On approval of the Energy Strategy of Russia for the period until

2030, 2009). The government has also set serious goals regarding the energy intensity of GDP - to double by 2030 compared to 2005 levels. These benchmarks appear to be very ambitious and require technological and "digital" ways of concentration. Thus, in terms of innovative development, it is necessary to indicate the technological gap between the Russian economy and developed countries. According to the Global Innovation Index (2019), Russia is only 46th out of 129 countries with an innovation activity level of 37.62 points. The leaders of the rating are Switzerland (67.24 points), Sweden (63.65 points) and the USA (61.73 points) (Global Innovation Index, 2019). In terms of digital transformation, the Russian economy also lags far behind other countries. Thus, in the international rating of Information and Communications Technologies (ICT) development Russia ranks 45th among 176 countries (2017), in the international rating of e-government development - 32nd among 193 countries (2018), in the international rating of cybersecurity - 26th among 175 countries (2018) (HSE, 2020).

Thus, the issues of energy efficiency, ecology, digitalization and technological modernization become particularly important in the context of catching-up development of the Russian economy. There is a need for effective mechanisms for consolidated development in all these areas, thereby ensuring a synergistic effect.

The concept of "energy efficiency" has no clear definition. We take into account the definition set out in the Federal Law "On Energy Saving...:" "Energy efficiency - characteristics reflecting the ratio of the beneficial effect of using energy resources to the cost of energy resources..." (On energy saving and increasing energy efficiency and on introducing amendments to certain legislative acts of the Russian Federation, 2009).

2. LITERATURE REVIEW

The study of industrial energy efficiency is devoted to the works of Russian and foreign scientists, including a conceptual approach to understanding energy efficiency in terms of harmonization of social interests, the impact of implementing energy efficiency principles on society as a whole and on its individual groups (Dunlop, 2019); an institutional approach within the framework of a multi-level model for ensuring energy efficiency allows to take into account not only the peculiarities of the production process, but also the organizational culture of the enterprise (Koenig, 2020); issues of improving the energy efficiency of the economy depending on structural changes in industry, the scale of production and components with added value (Malysheva et al., 2016); modeling the costs of electricity consumption of an industrial enterprise (Mokhov and Demyanenko, 2019); energy efficiency optimization (Meshalkin et al., 2017; Dovì and Meshalkin, 2017; Mukhametshin et al., 2019); optimization of production in order to minimize the required energy costs without exceeding the period of execution (Gong et al., 2015; Baibarin et al., 2016); integral indicators of resource saving assessment (Shinkevich et al., 2018; Podymov et al., 2019); modeling and programming of economic and technical factors affecting energy efficiency, evaluating efficiency based on the authors proposed index - Efficient reliability index (Barzegar et al., 2020).

In the modern economic system, improving industrial energy efficiency is inextricably linked to environmental and sustainable development issues, research and modelling of which is covered by a number of scientific works. In particular, we are talking about sustainable innovative development of economic systems and methods of diagnostics and economic interpretation of a 9-parameter model (Shinkevich et al., 2016), modeling sustainable development in manufacturing sectors of the Russian economy (Lubnina et al., 2016), integrated approach to sustainable development management and supply chains based on structuring the production process (Shamsuddoha, 2015), identification of mathematical dependence of competitiveness on the implementation of sustainable development principles (Chen, 2017), development of a non-linear programming model for the formation of an assortment of products with the aim of increasing the sustainability index (Galal and Moneim, 2015), modeling the enterprise's production processes taking into account the separation of sustainability and development concepts and complementing the principles of reliability (Sirazetdinov et al., 2016), and an assessment index sustainable development based on a five-phase structure and taking into account the circularity of the economy and the cyclical nature of production enterprises (Azevedo et al., 2017).

The greatest results of energy-saving measures can be achieved by mastering digital technologies, the importance of which is also explored in a wide range of studies. The impact of digitalization on the development of the national economy is presented in the works of Frolov et al. (2017) who conducted a systematic assessment of the economic factors of development of Russian manufacturing enterprises within the framework of the industry 4.0. The goals of sustainable development and digitalization were synthesized in the work of Ren et al. (2019) who proposed to combine big data analytics and intellectual production and introduced the sustainable intellectual production term in in the point of view of a product life cycle (Ren et al., 2019). The assessment of the role and place of digitalization in ensuring innovative development of the petrochemical industry and ensuring environmentally friendly production is reflected in the work of Kudryavtseva et al. (2018). Prospects of automation and implementation of the Industry 4.0 concept in petrochemistry were considered in the works of the team of scientists under the leadership of Shinkevich et al. (2019).

Analytical review of scientific research in the field of energy efficiency and energy conservation, ecologization and sustainable industrial development, and digital transformation of industrial enterprises suggests that a wide range of scientific results, including modeling, contain a fragmented methodology for assessing the studied aspects of industrial development, but do not allow to assess and optimize the synergy of energy efficiency, digitalization and environmental sustainability of the industrial sector.

3. DESCRIPTION OF DATA

A comparative analysis of the total consumption of energy resources in the manufacturing and extractive industries in Russia reveals a reduction in energy consumption in both sectors of the

Russian economy. By energy resources we mean natural fuel (oil, gas and coal), products of fuel processing, electricity and heat energy. At the same time, the measurement of consumption volumes is reduced to standard fuel, which is understood as standard natural unit, 1 kg of standard fuel, which is accepted as 29,3076 MJ (Rosstat, 2020). Over the reported period, the efficiency of energy consumption in relation to the volume of shipments increased, as energy costs decreased in both cases: in the manufacturing sector of the economy - by 43.9%, in extractive industry - by 48.5% (Figure 1).

At the same time, we observe an excess of energy consumption in the manufacturing sector over that of the extractive sector. At the end of 2017 we see more than 1.5-fold excess. Thus, there is an obvious tendency to increase the efficiency of energy consumption in the industry of the Russian economy. However, based on the 2015 targets, it can be assumed that both sectors have the potential to achieve the same energy consumption, which suggests that there is the potential for further reducing energy consumption by the manufacturing sector and, consequently, for increasing energy efficiency in production.

For the whole analyzed period the most consumable energy resources of the manufacturing sector were electricity (in 2017 - 38.38% of all energy resources), heat (20.67%), fuel processing products (20.17%) and gas (15.19%); the least consumable combustible side energy resources - (3.33%), coal (2.25%) and petroleum (0.007%) (Table 1).

For some types of energy resources there is also a stable reduction of specific energy consumption in the activities of manufacturing enterprises of the Russian economy (Figure 2). Higher rates of energy efficiency improvement are demonstrated by gas consumption - reduction of specific consumption by 51.2% in 2017 compared to 2011, as well as heat consumption - a 48.1% decrease for the corresponding period.

Result: The presented dynamic analysis of energy efficiency in the manufacturing sector of the Russian economy allows us to assert a positive trend. There is also stable trend of decreasing energy consumption for certain types of energy resources. However, the comparative analysis of energy efficiency indicators by industry (Figure 1) reflects the potential for further reduction. In this regard, it is important to solve the problem of developing energy-saving manufacturing facilities, including through the implementation of digital tools that can provide a synergistic effect along with the implementation of the concept of resource saving. As one of directions of the decision of the problem, capable to provide possibilities of qualitative forecasting and management, we offer economic and mathematical model in the form of a linear programming problem.

4. METHODS AND MODELS

Estimation of synergetic effect of digitization within the framework of increase of energy consumption efficiency in manufacturing industry is carried out by means of economic and mathematical modeling, including:

1. Correlation-regression analysis, which allows to reveal the factors within the framework of sustainable development management and energy efficiency of the manufacturing system, significantly affecting the level of harmful emissions

Figure 1: Changes in Energy Costs in the Extractive and Manufacturing Industry of the Russian Economy (compiled by the authors according to Rosstat, 2020)

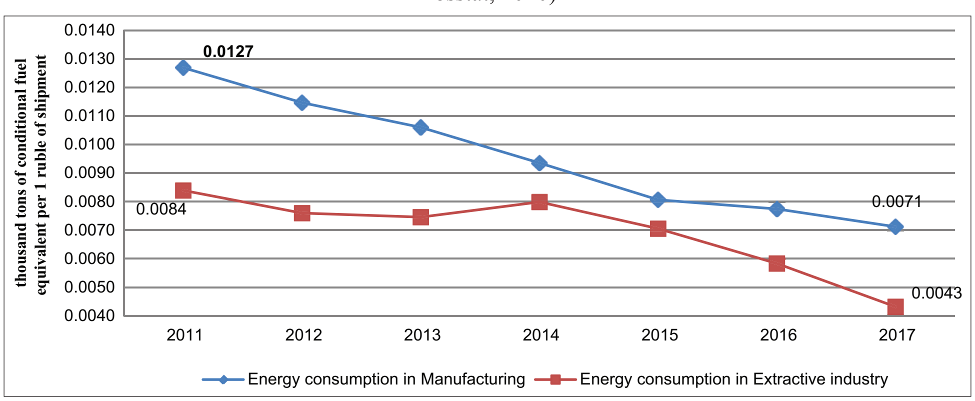
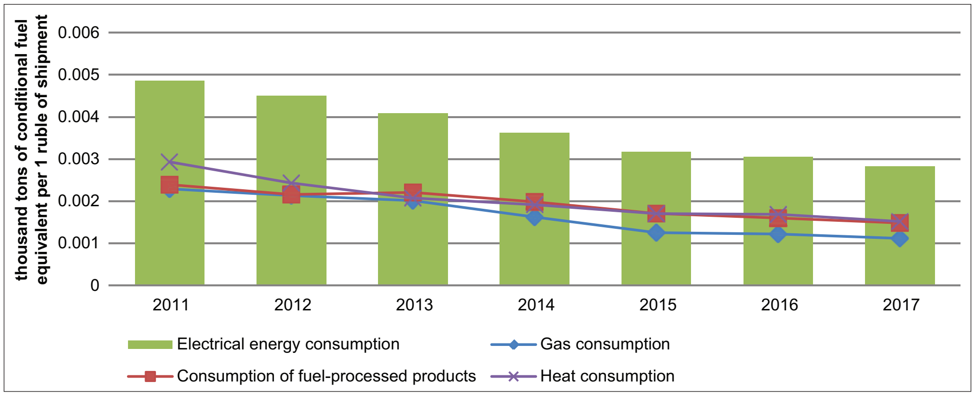


Table 1: The structure of energy consumption in the manufacturing sector of the Russian economy, % (prepared by the authors according to Rosstat, 2020)

Type of energy resource	2011	2012	2013	2014	2015	2016	2017
Petroleum	0.033	0.017	0.010	0.007	0.004	0.003	0.007
Gas	17.11	18.20	18.61	17.00	15.13	15.35	15.19
Coal	1.47	1.87	1.86	2.01	2.59	2.23	2.25
Fuel processing products	17.87	18.44	20.40	20.77	20.64	20.13	20.17
Combustible side energy resources	5.30	2.24	2.17	2.15	2.70	2.70	3.33
Electricity	36.32	38.48	37.78	37.99	38.33	38.35	38.38
Heat	21.89	20.75	19.17	20.07	20.60	21.24	20.67
Total	100	100	100	100	100	100	100

Figure 2: Specific consumption of certain types of energy resources in the manufacturing industry of the Russian economy (prepared by the authors according to Rosstat, 2020)



into the atmosphere from the manufacturing industry enterprises

2. Predicative model of manufacturing industry digital parameters
3. Optimization linear programming problem, which makes it possible to determine the optimal levels of energy consumption and the amount of internal costs for research and development to improve energy efficiency, energy saving.

Economic and mathematical modelling is used to assess the impact of certain indicators on the resulting indicator, to determine the nature of this impact and the interdependence of factors from each other. Correlation analysis allows to reveal the nature and degree of interconnection of data series. The independent variables x_i with dependent variable Y are taken to be significant and have the strength of relationship greater than 0.7, which according to the Chaddock scale reflects a high (0.7-0.9) and very high (0.9-0.99) strength of relationship between the variables.

In our case result of modelling are the equations of multiple linear regression for two variables of a kind:

$$Y = a_0 + a_1*x_1 + a_2*x_2,$$

where a_0 - is free term of the regression equation, Y value at zero independent variables x_i, a_1, a_2 - slope terms, the values by which Y changes accordingly when increasing x_1, x_2 per unit.

The quality of the obtained regression equations is estimated by estimating the determination coefficient R-square, which at values above 0.9 indicates high accuracy of variables selection in the equation. The F ratio is used to evaluate the quality of the regression model in general and by parameters. For this purpose, the resulting F value is compared with the tabulated F value. The latter is determined by the built-in excel FINV function. If the condition is fulfilled $F_{calc} > F_{tabl.}$ accepts the hypothesis that the differences between data groups are not random and the regression equation is significant. Estimation of regression coefficients significance is carried out by comparing the obtained p-values with the level of significance 0.05 and parameters of t-statistics coefficients with the t-student tabulated value, which is calculated on the basis of the built-in Excel TINV function. Excess of calculated values of t-statistics (module) over the tabulated indicates the significance of the obtained regression coefficients.

In our study, 3 regression equations are constructed to assess the synergistic effect of digitalization.

Thus, the first equation characterizes the dependence of indicators of sustainable development of the manufacturing sector of the Russian economy. The variables are selected:

Y_B - emissions of air pollutants from stationary sources in the manufacturing industry, attributable to 1 ruble of products shipped by manufacturing sector enterprises (thousand tons/1 ruble)

x_1 - energy consumption in the manufacturing industry, attributable to 1 ruble of products shipped by manufacturing sector enterprises (thousand tons/1 ruble)

x_2 - internal research and development costs in priority areas of science, technology and engineering development, namely energy efficiency, energy saving, nuclear power (billion rubles)

Linear regression equations describing the influence of these independent variables on "digital" dependent variables are also additionally constructed:

Y_{rds}- internal research and development costs in priority areas of science, technology and engineering, namely, information and telecommunication systems (billion rubles)

Y_{ede} - use by manufacturing sector enterprises of technologies for the electronic data exchange between their own and external information systems (as a percentage of the total number of organizations in the business sector).

At the second stage, in order to optimize the independent variables x_i, as well as to assess the effect of implementation of the developed models, it is necessary to determine the predicted values of the dependent variables Y_{rds} and Y_{ede}. Data extrapolation allows to determine future values of the indicators taking into account the dynamics for the period 2011-2017 and to compare them further with the optimal values.

The third stage is to construct an optimization of linear programming problem aimed at determining the minimum value of the target function with the condition of fulfilling a number of restrictions. The standard expression for a linear function target has a form:

$$Target\ \ function = \sum_{i=1}^{n} c_i X_i \rightarrow min,$$

where:
x_i - required optimal values of variables;
c_i - coefficients with variables.

Restrictions are set in the form of inequalities:

$$\begin{cases} \sum_{i=1}^{n} a_i x_i = b_1, \\ \sum_{i=1}^{n} a_i x_i = b_2, \\ x_i \geq 0, \\ E_i \geq b_3. \end{cases}$$

In our case, the target function is regression equation reflecting the dependence of polluting emissions by manufacturing industry enterprises (which should be minimized) on energy consumption x1 and internal costs of energy efficiency and energy saving x_2. Restrictions are made on regression equations for $Y_{rds.}$

Y_{ede} that express the relationship of dependent variables with x_1 and x_2. Forecast Y_{rds} and Y_{ede} values are taken as restrictions for future periods, and for the variables sought, the best values (less for x_1 and morefor x_2) relative to the 2017 level.

5. RESULTS AND DISCUSSIONS

5.1. Formalization of Dependence of Environmental and "Digital" Parameters of the Manufacturing Industry of the Russian Economy on Energy Consumption and Energy Efficiency Financing

An important problem in the development of the manufacturing sector of the economy is environmental pollution. The industrial enterprise is a source of large amounts of air and hydrosphere pollutants. At the same time, according to statistical data, the volume of polluting emissions has decreasing trend: from 18.8 million tons in 2000 to 17.5 million tons in 2017. (Rosstat, 2020). The positive environmental effect is achieved through increased investment in the rational use of natural resources. Over 17 years (2000-2017), there has been an almost 7-fold increase in investment in environmental protection and rational use of natural resources (from 22 339 to 154 042 million rubles). Thus, environmental protection in the manufacturing sector enterprises of the economy is becoming one of the key tasks to be optimized and digitized, and currently has significant potential.

In connection with the above, within the framework of this study constructed the economic and mathematical model that allowed to determine the most significant factors affecting the level of pollutant emissions in the manufacturing industry. The Microsoft Excel "Analysis Package" superstructure is used, namely the built-in "Correlation" and "Regression" functions. The result is a regression equation:

$$Y_B = 0{,}0199 + 0{,}0217*x_1 - 0{,}00022*x_2.$$

Regression statistics, namely R-square determination coefficient equal to 0.9963, reflect that the regression function describes 99.63% connection between initial values, i.e. the connection between the selected indicators is high. Variance analysis allows to judge about the model adequacy. Comparison of the calculated and tabulated F values (Fcalc = 541.4; F_{tabl} = 6.94; $F_{calc} > F_{tabl}$) allows to assert that the null hypothesis is rejected and the obtained regression is statistically significant. Comparison of calculated values of t-statistics with the tabulated one equal to 2.78 (calculated for the probability 0.05 and degree of freedom equal to 4), also indicates the importance of the obtained coefficients.

Thus, a linear regression dependence is obtained, in which the best predictor is the value of energy costs in the manufacturing industry, the reduction of which will reduce the level of emissions into the atmosphere. Less impact is made by the value of internal costs for energy efficiency as the priority area for financing industry, the increase in which will also reduce emissions of pollutants.

Similarly, regression equations are constructed and evaluated for Y_{rds} and Y_{ede} (Table 2).

The models are evaluated by the determination coefficient, F Ratio and t-student and are significant. The obtained dependencies indicate the strong influence of the level of energy resources consumption on the process of digitalization of manufacturing industry enterprises and are the better predictor for "digital" parameters of the manufacturing system than the level of internal costs for research and development aimed at energy efficiency, energy saving.

In both cases, the reduction of energy costs will contribute to an increase in "digital parameters," that as the result will provide synergistic effect of digitalization. At the same time, in order to better integrate manufacturing enterprises into the external information environment (which, in fact, is the goal of the digital transformation of industry), energy efficiency measures should

Table 2: Qualitative evaluation of the obtained regression equations, % (prepared by the authors)

Coefficient of determination	F-ratio	t-student		
R^2	$F_{calc.} > F_{tabl.}$	$t_{calc.0} > t_{tabl.}$	$t_{calc.1} > t_{tabl.}$	$t_{calc.2} > t_{tabl.}$
$Y_{rds} = 77.9–3.23*x_1 + 0.26*x_2$				
0.98	108.04 > 6.94	4.68 > 2.78	|−3.28| > 2.78	2.80 > 2.78
$Y_{ede} = 274.91–17.19*x_1 – 0.74*x_2$				
0.93	25.16 > 6.94	4.34 > 2.78	|−4.6| > 2.78	|−3.06| > 2.78

be funded by the restraining rate. This dependence confirms the need to find optimal values for energy costs and energy efficiency funding.

Therefore, the correlation-regression analysis has allowed to reveal the factors within the framework of sustainable development management and energy efficiency of the manufacturing system, significantly affecting the level of harmful emissions into the atmosphere from the manufacturing industry enterprises.

5.2. Building of the Predictive Models of "Digital" Parameters for the Manufacturing Industry

Decision-making, development of strategies for the development of the industrial complex involves taking into values the forecasted values of key indicators and focusing on the progress of the predictor values.

Extrapolation of data is performed by contouring trend lines in Microsoft Excel (Figures 3 and 4).

High reliability of approximation is confirmed by R^2 values exceeding 0.9, i.e. trendlines are reliable and can be used for forecasting the investigated variables.

The prognosis is for the next 5 years. Taking into account that Y_{EDI} is a share of organizations, i.e. an indicator in percentage terms, the maximum possible level of this indicator cannot exceed 100%. The forecast results in accordance with the trendlines are presented in Table 3.

In according with the forecast, x_1 growth rate does not exceed 4%/year, x_2 - up to 16%/year, i.e. without additional intervention, without increasing energy conservation investment and energy efficiency, energy consumption will remain at approximately the same level, with low energy efficiency increased.

The set forecast values can be accepted as restrictions in the optimization task of linear programming, as well as for the purpose

Figure 3: Trendlines for dependent variables Y_B, Y_{ITS}, Y_{EDI} (a) Internal research and development costs in priority areas of science, technology and engineering, namely information and telecommunications systems (power trendline) (b) The use by manufacturing sector enterprises of technologies for the electronic data exchange between their own and external information systems (polynomial trendline) (c) Emissions of air pollutants from stationary sources in the manufacturing industry attributable to 1 rouble of products shipped by manufacturing enterprises (polynomial trendline)

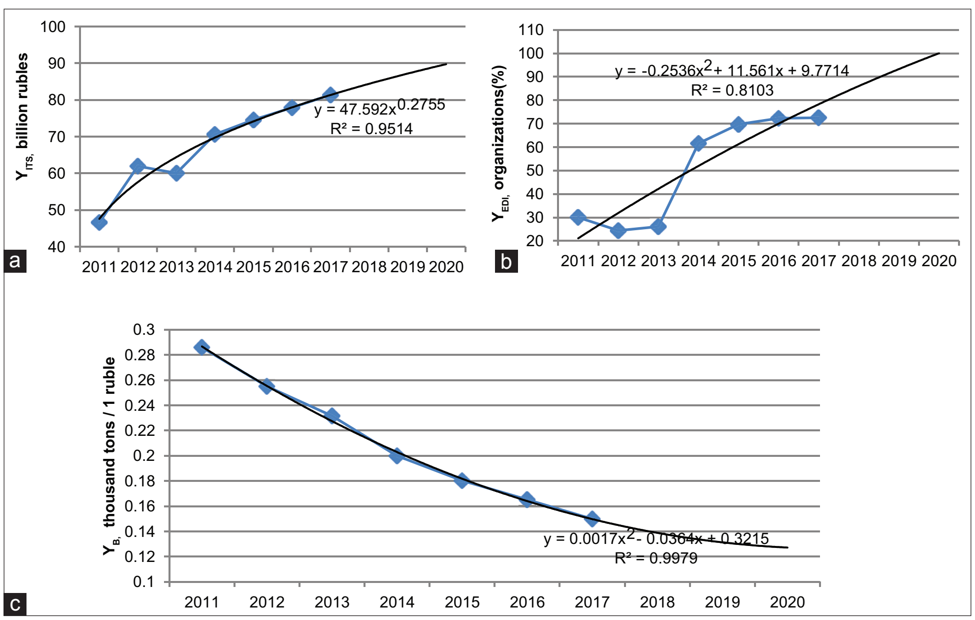
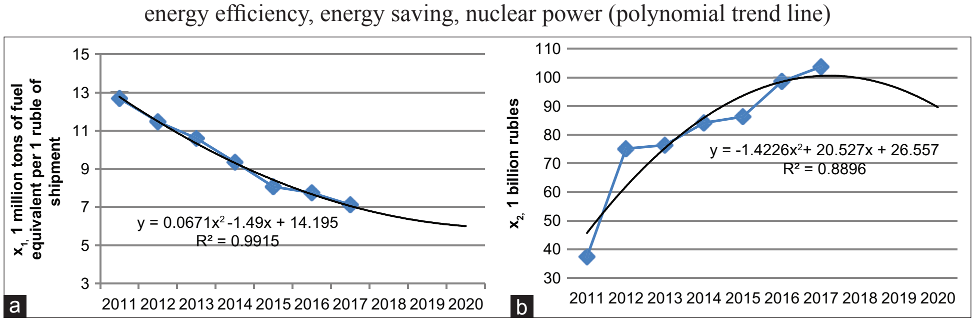


Figure 4: Trendlines for x_1 and x_2 independent variables (a) Manufacturing energy costs per 1 rouble shipped by manufacturing enterprises (polynomial trendline) (b) Internal research and development costs in priority areas of science, technology and engineering development, namely energy efficiency, energy saving, nuclear power (polynomial trend line)



of evaluating the potential effect of the proposed the mathematical economic model approbation.

5.3. Construction of an Optimization Model for Managing Polluting Emissions, Energy Efficiency and Digitalization of the Manufacturing Sector in the Russian Economy

Application of the general principles of solving the linear programming problem allowed to construct an optimization model taking into account the synergetic effect of digitalization within the framework of increasing the efficiency of energy costs in the manufacturing industry. The proposed model of optimization taking into account the predicted values for 2020 has the form:

Target function: $_{B} = 0,0199 + 0,0217.x_1 + 0,00022\,x_2 \rightarrow \min$

$$\text{limitations} \begin{cases} 77,9 - 3,23\,x_1 + 0,26\,x_2 = 89,75, \\ 274,91 - 17,19\,x_1 - 0,74\,x_2 = 100, \\ x_1 \le 7,12, \\ x_2 \ge 103,7. \end{cases}$$

The solution of the linear programming problem with the help of the Microsoft Excel "The Finding Solutions" superstructure made it possible to set optimal values of energy resources costs for the processing sector of the economy and financing of the "Energy efficiency, energy saving, nuclear power" direction for 2020:

$\chi^*_{1(2020)}$ = 5.31 million tons of fuel equivalent per 1 ruble of shipped production

$\chi^*_{2(2020)}$ = 112.97 billion rubles.

Table 3: Predictive values for the dependent variables Y_B, Y_{ITS}, Y_{EDI} (compiled by the authors)

Projection	Legend	2017 (fact)	2018 (prognosis)	2019 (prognosis)	2020 (prognosis)	2021 (prognosis)	2022 (prognosis)
Emissions (thousand tons/1 ruble of shipment)	Y_B	0.15	0.14	0.13	0.13	0.13	0.13
Internal research and development costs in the information telecommunication system (billion rubles)	Y_{ITS}	81.4	84.4	87.18	89.75	92.14	94.37
The use of technologies for electronic data exchange between own and external information systems (organizations %)	Y_{EID}	72.5	86.03	93.28	100	100	100
Energy costs in manufacturing industry (1 million tons of a conditional fuel equivalent/1 ruble of products shipped)	x_1	7.12	6.57	6.22	6.01	5.92	5.98
Internal expenses for research and development in the field of "Energy efficiency, energy saving, nuclear power engineering" (billion rubles)	x_2	103.7	99.73	96.07	89.57	80.22	68.03

Table 4: Models for optimizing pollutant emissions taking into account energy efficiency improvements and the development of digitalization in the manufacturing sector of the Russian economy

Tests	Simulation outcomes
Determination of optimal parameters as of 2021	
Efficiency function	$Y_B = 0,0199 + 0,0217 \,.\, x_{1\,-}\ 0,00022 \,.\, x_2 \rightarrow \min$
Limitations	$\begin{cases} 77,9 - 3,23 \cdot E_1 + 0,26 \cdot E_2 = 94,37, \\ 274,91 - 17,19 \cdot E_1 - 0,74 \cdot E_2 = 100, \\ E_1 \le 7,12, \\ E_2 \ge 103,7. \end{cases}$
$x^*_{1\,(2021)}$	5.05 million tons of fuel equivalent per 1 ruble of shipped production
$x^*_{1\,(2021)}$	119.02 billion rubles
Emissions	0.017054 thousand tons equivalent per 1 ruble of products shipped by the processing sector
Determination of optimal parameters as of 2022	
Limitations	$\begin{cases} 77,9 - 3,23 \cdot E_1 + 0,26 \cdot E_2 = 92,13, \\ 274,91 - 17,19 \cdot E_1 - 0,74 \cdot E_2 = 100, \\ E_1 \le 7,12, \\ E_2 \ge 103,7. \end{cases}$
$x^*_{1\,(2022)}$	4.81 million tons of fuel equivalent per 1 ruble of shipped production
$x^*_{1\,(2022)}$	124.68 billion rubles
Emissions	0.017063 thousand tons equivalent per 1 ruble of products shipped by the processing sector

Table 5: Evaluation of the effect of the implementation of the proposed authorial optimization model

Year	Value	Energy costs in manufacturing industry (1 million tons of a conditional fuel equivalent per 1 ruble of products shipped)	Internal expenses for research and development in the field of "Energy efficiency, energy saving, nuclear power engineering" (billion rubles)	Emissions (thousand tons per 1 ruble of shipment)
		x_1	x_2	Y_B
2017	Actl	7.12	103.7	0.15
2020	Predicted	6.01	89.57	0.13
	Aimed	5.31	112.97	0.017
	Effect.	−0.7	23.4	−0.113
2021	Predicted	5.92	80.22	0.13
	Aimed	5.05	119.02	0.017
	Effect.	−0.87	38.8	−0.113
2022	Predicted	5.98	68.03	0.13
	Aimed	4.81	124.68	0.017
	Effect.	−1.17	56.65	−0.113
Mass effect		−2.31	20.98	−0.113

The emission level will be 0.01706 thousand tons equivalent per 1 ruble of products shipped by the processing sector. Optimization models for 2021 and 2022 are constructed in the same way (Table 4).

The research found that processing industry of Russian Federation has high potential for improving energy efficiency while reducing polluting emissions and enhancing the digital transformation of the sector. The calculation of potential is presented in Table 5.

Thus, assuming that the internal costs of research and development in the field of "Information and telecommunication systems" and the share of organizations using technologies for electronic data exchange between their and external information systems will expand and reach the predicted values (Table 3), the manufacturing industry will achieve a synergistic effect in the form of reduction of specific volume of emissions by 0.113 thousand tons by the end of 2022. For this purpose, by means of economic and mathematical modeling as of 2020-2022 the target indicators of energy consumption level (reduction of energy resources consumption in total should reach 2.31 million tons of fuel equivalent per 1 ruble of shipped production) and the value of research and development costs in the field of "Energy efficiency, energy preservation, nuclear energy" (increase in total should reach 20.98 billion rubles) have been determined.

6. CONCLUSION

The research results enable us to summarize that the "natural" vector of the development of manufacturing industry, energy saving and digitalization is accompanied by slow growth rates, despite the implementation of measures provided by the Energy Efficiency and Energy Sector Development State Program of the Russian Federation (On approval of the Energy Efficiency and Energy Sector Development of the Russian Federation, 2014). The rate of digitalization of the industry is undoubtedly growing, with ICT costs per company increasing from RUB 3.6 million in 2011 to RUB 6 million in 2016 (HSE, 2020). The volume of financing of technological innovations is increasing - from RUB 370 billion in 2011 to RUB 610.2 billion in 2017. Costs are huge, but the intensity of spending on technological innovations in the manufacturing sector is declining - from 2.7% of total shipments in 2013 to 1.9% in 2017 (Rosstat, 2020). And in general, current economic trends influence energy saving processes, but, as it was found out as a result of the modeling, it goes with low performance. In accordance with the task of linear programming, it is necessary to increase the cost of energy-efficient programs, and at a higher rate than is dictated by approximation.

It is important to note the practical value of the research results not only in terms of energy efficiency improvement, but also from the standpoint of sustainable development, since achieving an optimal level of specific energy consumption and energy efficiency costs will contribute to reducing air pollution emissions from industrial facilities of the manufacturing sector.

The research paper reflected in the article can be taken into account and applied within the framework of forming strategies and programs to ensure energy efficiency in manufacturing industries, their sustainable development and digitalization of production processes and the formation of digital platforms for interaction with external actors.

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