The Integrated Approach to Sustainable Development: The Case of Energy Efficiency and Solid Waste Management

Yulia V. Vertakova[1]*, Vladimir A. Plotnikov[2]

[1]Southwest State University, Kursk, Russia, [2]Saint-Petersburg State University of Economics, Saint-Petersburg, Russia.
*Email: vertakova7@yandex.ru

ABSTRACT

The purpose of this article is to explore the possibilities and develop proposals for the integrated solution of some of the problems of sustainable development related to waste processing and improving the energy efficiency of the economy. This purpose was achieved by solving the following objectives: (1) analysis of the problem of energy efficiency and how to solve it; (2) study of the problem of waste management and approaches to its solution; (3) development of proposals for the implementation of energy-efficient waste treatment. The leading methods used in the article were the following: A review of the literature, statistical analysis, expert assessments, systems, technological and institutional analysis, economic modeling. As a result of the study, it was proved that the problems of energy efficiency of the economy and waste management should not be solved in isolation, but in a comprehensive manner. The key idea of the study was that waste may be an unconventional (alternative) energy source. The existing technological solutions for their implementation require significant investments, changes in regulation, as well as transformation of the behavior of the population. Modernization of waste management often comes down to the modernization of landfill management. This is not effective enough (from environmental, economic, energy efficiency positions). The development of new institutional rules and innovative technologies is required. The authors propose to use waste as an energy resource using the technology of thermal catalytic depolymerization. In addition to the beneficial environmental effect, the proposed technology has high energy efficiency.

Keywords: Energy Efficiency of the Economy, Waste, Sustainable Development, Energy Efficient Technology
JEL Classifications: Q01, Q42, Q53

1. INTRODUCTION

The modern world is developing under the influence of conflicting trends. Humanity faces several global challenges. The vectors of their resolution are reflected in the proposed UN Millennium Development Goals (MDGs). The difficulty of achieving these goals lies in their close relationship, complex nature. Goal 7: Ensure Environmental Sustainability occupies an important place in this system of goals. To achieve it, it is necessary to solve the Target 7.A: Integrate the principles of sustainable development. Addressing this challenge, among other things, requires an energy efficiency policy for the economy (Apergis and Danuletiu, 2014; Craig, 2001; Farla and Blok, 2000; Hanley et al., 2009; Kara et al., 2014; Liu and Raven, 2010; Menegaki and Gurluk, 2013; Pearce and Miller, 2006; Schau et al., 2012; Wang et al., 2014; Ma et al., 2019 and others).

Energy efficiency is a difficult problem. Its solution requires the concerted efforts of not only governments of various countries and international organizations, but also functional coordination. Coordination is needed between politicians, researchers, economists, technologists and other specialists at the global, national, regional and local levels. At the same time, according to the authors, improving energy efficiency and reducing energy consumption (both specific and absolute) is not an isolated goal. Obtaining these positive effects should be considered in the context of achieving MDGs.

The principle of the complexity of achieving MDGs presupposes the existence of a multitude of direct and inverse links between measures to improve the energy efficiency of the economy and other areas of the Target 7.A solution. One of the components of the Target 7.A solution is the reduction of environmental pollution. The waste issue is today one of the global problems of human development (Achillas et al., 2013; Alumur and Kara, 2007; Babu et al., 2007; Fehr et al., 2000; Gabriel and El-Halwagi, 2005; Koester, 2014; Melikoglu et al., 2013; Parthan et al., 2012; Vertakova and Plotnikov, 2017 and others). To solve it, various legislative, technological, organizational, educational and other measures are proposed. Despite the success achieved in some cases, in general this problem remains unresolved. For example, according to Eurostat (2018), in 2016, the total waste generated in the EU-28 by all economic activities and households amounted to 2533 million tons; 45.5% of waste were landfilled and 37.8% were recycled.

Waste recycling capacity is not fully utilized. They can act as an unconventional (alternative) energy source. Due to this, both the problems of energy efficiency of the economy and recycling of waste will be solved simultaneously. This line of activity to achieve MDGs is an object of our research interest. The purpose of this article is to explore the possibilities and develop proposals for the integrated solution of some of the problems of sustainable development related to waste processing and improving the energy efficiency of the economy.

2. DATA SOURCES

The study used data from national and international statistics on economic growth, socio-economic development, innovation and technology, sustainable development, waste management, energy efficiency and energy saving. In assessing the state of the problems studied, the authors turned to data from the World Bank, organizations of the UN, Eurostat, Environmental Protection Agency, Rosstat, Rosprirodnadzor, etc. To assess the degree of knowledge of the problems and the level of their analytical work, in preparing the article were used: Scientific publications (articles, reviews, monographs, reports of conferences), business media materials, analytical reports and forecasts prepared by research organizations and individual reputable experts, as well as the authors' own developments (Tikhomirov and Plotnikov, 2018; Vertakova et al., 2017a; Vertakova and Plotnikov, 2017; Vertakova et al., 2017b and other). These materials were processed by standard analytical, econometric and statistical methods. Also, when preparing the materials of this article, the authors used the methods of comparative, retrospective, structural, system and expert analysis, forecasting and modeling.

3. RESEARCH METHODOLOGY

The research methodology was based on the construction of a regression function model for energy consumption. The algorithm for constructing a regression model included the following steps.

1. Determination of the length of the dynamic series of energy consumption in the world, which reflects the representativeness of the data and allows you to use the model for forecasting.

2. Determination of the type of regression model based on the exponential function:

$$f(x) = y = e^y$$

Where y is the endogenous variable level of energy consumption); y-exogenous variable (year).

3. Assessment of the adequacy of the obtained regression model using the following indicators.
   a. The coefficient of determination of the regression model.

The coefficient of determination shows the proportion of the variance of the dependent variable, explained by the dependency model under consideration, that is, the explanatory variables.

The research methodology was based on the construction of a regression function model for energy consumption. The algorithm for constructing a regression model included the following steps.

1. Determination of the length of the dynamic series of energy consumption in the world, which reflects the representativeness of the data and allows you to use the model for forecasting.
2. Determination of the type of regression model based on the exponential function:

$$R^2 = \frac{\sum_i (f_i - \bar{y})^2}{\sum_i (y_i - \bar{y})^2}$$

Where R^2 is the coefficient of determination of the model;
y_i is the observed value of the dependent variable;
f_i is the value of the dependent variable predicted by the regression equation;
$\bar{y}$- the arithmetic mean of the dependent variable.

   b. The null hypothesis is put forward that the equation as a whole is statistically insignificant
H_0: $R^2 = 0$ at the significance level α.

   c. Determine the actual value of the F-criterion (Fisher criterion)

$$F = \frac{R^2}{1 - R^2} \frac{(n - m - 1)}{m}$$

Where F is the value of the Fisher criterion;
n is the number of observation units in the aggregate;
m is the number of independent variables in the model.

   d. The table value is determined from the Fisher distribution tables for a given level of significance, taking into account that the number of degrees of freedom for the total sum of squares (greater variance) is 1 and the number of degrees of freedom of the residual sum of squares (lesser dispersion).
F_{tabl} is the maximum possible value of the criterion under the influence of random factors at given degrees of freedom and significance level α. The significance level α is the probability of

rejecting the correct hypothesis, provided that it is correct. α is assumed to be 0.05.

e.   If the actual value of the F-criterion is less than the table value, therefore, there is no reason to reject the null hypothesis. Otherwise, the null hypothesis is rejected and the alternative hypothesis about the statistical significance of the equation as a whole is accepted with probability $(1-\alpha)$.

Thus, if $F>F_{tabl}$, then the coefficient of determination is statistically significant.

4. RESULTS AND DISCUSSIONS

4.1. Energy Efficiency: The Essence of the Problem, Approaches to Solving

Energy consumption in the world is constantly growing. According to the available data (Figure 1), this increase in the range of 1980-2017 was only 4 times replaced by a slight decrease in energy consumption. This happened in 1981 (-0.72%), 1991 (-1.83%), 1992 (-0.34%) and 2009 (-1.11%). In general, the dynamics of energy consumption (y) in the world with high accuracy ($R^2=0.958$) is described by an exponential trend: $y=266.33\ exp\ (0.0235\ y)$, where y is the year of observation.

At the same time, there is a decrease in specific energy consumption in the world (Table 1). Nevertheless, according to the latest global energy forecast of the International Energy Agency (IEA, 2018b) - the World Energy Outlook 2018, global energy demand growth is expected. Energy demand is expected to grow by about 27% from 2017 to 2040. The increase in energy consumption leads to the exhaustion of world energy resources used to produce it, and creates environmental problems (emissions of CO_2, solid dust, thermal pollution, etc.) and climate change. Therefore, there is a need to improve the efficiency of production, transmission, storage and use of energy. These problems are reflected not only in political decisions, but also in scientific research aimed at finding opportunities for improvement in energy efficiency.

An important role in this is played by special energy policy measures. For example, in Russia, the Federal Law "On Energy

Saving and Improving Energy Efficiency" was adopted on November 23, 2009 No. 261-FZ (currently the wording of the law is valid as of December 27, 2018). It reflects the priorities of state regulation of the efficient use of energy in the economy and the population. In <10 years of this law, it has been amended 35 times. This indicates the attention paid to the problem of energy efficiency in Russia.

Ringel and Knodt (2018) are considering modern mechanisms for managing energy policies in the EU, pointing to the need to modernize energy regulation rules and to combat climate change. We can agree with their position that the regulation of energy efficiency and climate change is transnational in nature. Therefore, it is necessary to coordinate the policies of the EU countries, which will make it more efficient and reduce the costs of its implementation. At the same time, a more active involvement of the local communities in the energy efficiency problems is required.

The problem of energy efficiency is closely related to the problem of climate change. Growth in energy efficiency can be achieved within a single enterprise, territory or country. The effect on climate on a similar scale is impossible. Climate is a global phenomenon. If we assume that its changes are caused by an anthropogenic factor (we note that there are quite reasonable points of view that the influence of this factor is small in comparison with volcanic activity, changes in the luminosity of the Sun, parameters of the Earth's orbit, etc. (Shnitnikov, 1969) neutralization requires effort on a global scale. Study done by de la Cruz-Lovera et al. (2017) indicate the presence of a confirmed influence of international organizations on sustainable development (including climate change) and energy efficiency. The authors analyzed an array of publications in the Scopus sciento-metric database for 40 years (1976-2016) and revealed a relationship in approaches to solving problems of sustainable development, energy conservation, and energy efficiency.

The importance of policy measures in achieving energy efficiency is determined by the fact that economic incentives must be created for it. Economic agents, as you know, seek to maximize their own benefits. Within the framework of neoclassical economic theory, such a "benefit" is profit. But within the framework of institutional

Figure 1: Dynamics of energy consumption in the world (Developed by the authors according to U.S. Energy Information Administration, 2017)
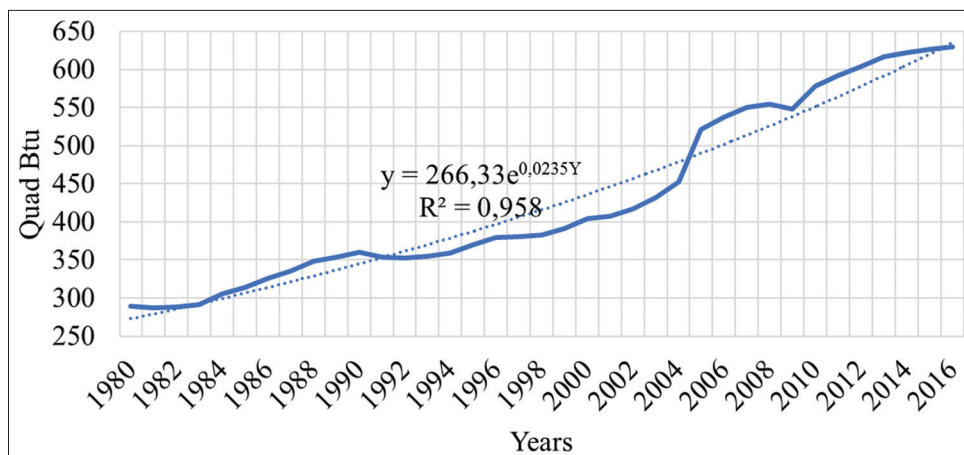
Table 1: Per value added energy intensity (index 2000 - MJ/USD PPP 2010) for manufacturing of some countries (IEA, 2018a)

Country	2000	2005	2010	2011	2012	2013	2014	2015	2016
Australia	100	96	97	98	99	100	101	96	97
Austria	100	106	103	97	95	97	91	90	93
Belgium	100	75	77	74	74	76	73	71	72
Canada	100	97	100	100	97	99	95	94	91
Czech Republic	100	67	45	40	40	40	37	34	30
Denmark	100	100	88	82	75	69	66	65	63
Finland	100	81	78	77	83	83	82	84	85
France	100	96	84	83	81	82	78	77	75
Germany	100	96	95	88	89	88	83	82	80
Greece	100	72	79	84	79	73	79	82	75
Hungary	100	68	58	60	63	71	68	66	67
Ireland	100	87	76	76	77	84	82	41	41
Italy	100	101	84	79	79	73	71	68	68
Japan	100	92	77	78	78	80	77	73	71
Korea	100	75	63	65	64	61	61	59	59
Luxembourg	100	100	142	156	139	117	102	99	105
Mexico	100	112	117	122	116	118	106	107	104
Netherlands	100	97	88	84	83	82	80	79	79
New Zealand	100	85	96	95	95	99	106	100	101
Poland	100	46	27	26	25	27	25	23	23
Portugal	100	89	92	89	79	78	74	72	70
Slovak Republic	100	62	39	36	37	37	33	32	30
Spain	100	110	83	83	83	81	76	72	73
Sweden	100	80	72	66	68	68	66	72	69
Switzerland	100	90	81	72	72	72	68	68	67
Turkey	100	83	76	68	70	60	59	57	55
United Kingdom	100	103	96	88	87	85	82	77	71
United States	100	79	66	65	64	63	61	60	60

economic theory, the firm's profit criteria are modified. And the determining role in this modification is played by the institutional environment. It is formed by both the state and civil society institutions (for example, "Greenpeace").

Energy efficiency investments will only be sustainable if they allow companies to reduce negative externalities and save costs (Allcott and Greenstone, 2012). If externalities of energy consumption are not internalized, and the state does not create financial incentives (special "green" subsidies, tax breaks, etc.) to increase energy efficiency, companies will not invest in improving it. The similar situation of institutional fiasco, for example, was formed in the housing and communal services of Russia. According to available estimates, up to 70% of the country's energy saving potential is concentrated in this area[1]. But, in the conditions of the existing model of tariff regulation, increasing energy efficiency is economically unprofitable for industry operators.

Energy efficiency of the economy can be provided by institutional and engineering measures. The contradictory nature of the institutional environment leads to the fact that investment in innovative energy-saving technologies is unprofitable. Allcott and Greenstone (2012) on an array of empirical data shows that for this reason the number of energies saving investment projects implemented does not correspond to the data of theoretical studies in the field of engineering sciences. Thus, energy efficiency requires institutional support.

The emphasis only on the technical component of energy efficiency, as a rule, does not give the expected result. Installation of smart energy meters, the creation of computer systems for energy consumption, etc., significant funds are spent. But the planned energy savings are often not achieved. The reason is not only the imperfection of formal rules of regulation, but also insufficiently full consideration of the characteristics of human behavior (Carrie et al., 2013). That is, the achievement of goals in the field of energy efficiency requires the modernization of not only formal but also informal institutions (habits, behavioral stereotypes, values of people, etc.).

For many people, especially in countries with stable political regimes and a high level of state paternalism, energy efficiency issues are on the periphery of the value system. They are perceived as something important at the level of the whole society, but do not act as a significant motive for individual behavior. As a result, the Rebound Effect is formed (Gillingham et al., 2016). Its essence is that improving energy efficiency can lead not to a reduction, but to an increase in energy consumption. "Buy a more fuel-efficient car, drive more. That is the most well-known intuition for the rebound effect. Jevons (1865) hypothesized that greater energy efficiency may even lead to a "backfire" of increased industrial energy use" (Ibid, p1). The magnitude of this effect does not have a rigorous quantitative justification, it depends on many factors. Its presence compels policy makers and researchers to be wary of energy efficiency regulation.

Attention should be paid to the complex nature of regulation (Ringler et al., 2013). Energy efficiency is one of the components

---

1   see: https://ido.tsu.ru/energy/files/omsk/Chuykova.pdf

of a more general problem of rational use of resources. It is necessary to jointly investigate the problems of providing drinking water, rational use of energy, land resources, and providing the population with food. This is reflected by the MDGs. Assessments of the interrelationship of these resource problems and approaches to their solution should take into account both the growth of well-being (in economic and social terms) and environmental effects.

Despite the importance of an institutional approach to solving problems of energy saving and energy efficiency, engineering methods play a significant role in its implementation in practice. The specifics of their application vary significantly by industry. For example, Fleiter et al. (2012) analyze the technological processes of the German pulp and paper mills. They account for 9% of the industrial energy demand in this country. The study of the parameters of specific technological processes made it possible to identify the prospects for reducing, by 2035, fuel consumption in this industry by 21% and electricity by 16%. From similar positions, Haraldsson and Johansson (2019) explore logistic processes related to the production of aluminum products in Sweden. The analysis indicated the priority areas for improving energy efficiency (product design, communications, transportation, waste management, etc.). Problems of energy efficiency are particularly acute in countries with developed industry, in particular - in China. Studies on technical, organizational and policy measures to improve the energy efficiency of the country's metallurgical industry (He et al., 2013) indicated a link between energy efficiency, productivity changes and environmental regulation.

Thus, the analysis presented earlier in this section of the article suggests that energy efficiency is a complex problem. Solving it requires the consolidated efforts of various actors: International organizations, national governments, corporate leadership, civil society institutions, and the people themselves. Attempts to solve this problem "in parts," in isolation, within individual sectors or functional areas may not be sufficiently effective. In addition, achieving high energy efficiency should be perceived by people as an absolute value, and formal and informal incentives should be created to work in this direction in the context of achieving MDGs.

4.2. The Problem of Waste and Recycling

The waste problem is one of the major global issues. According to available estimates (The World Bank, 2018), in 2016, 2.01 billion tons of solid waste was produced in cities around the world. This amounted to 740 g per inhabitant daily. According to forecasts, by 2050 the amount of waste will increase by 70%, to 3.40 billion tons. In addition to household waste, there is also industrial, agricultural and other waste. Their volume is continuously increasing, which requires special measures. Particularly acute is the problem of municipal waste management. Many people live compactly in cities. Late removal of waste from their habitat makes cities unsuitable for residents. Efficient waste management is costly. They can reach up to 20-50% of municipal budgets.

In Russia, according to Rosprirodnadzor (the governmental agency of Russia with regulatory functions in the environmental field), 5,441.3 million tons of industrial and household waste was formed in 2016, about 90% of this amount is accounted for by the extractive industries. The volume of generation of municipal solid waste is 55-60 million tons/year. 40% of them are organic waste, 35% are paper, 6% are plastic, 19% are other types of waste (metals, wood, glass, textiles, etc.). On average, about 400 kg of waste/year is produced per inhabitant of the country. Note that the structure of waste in different countries, regions and cities can vary significantly. For example, in Ireland, according to the Environmental Protection Agency (EPA, 2018), the following waste structure is observed: 12.5% - organic waste, 15.3% - paper, 17.2% - plastic, 55% - other.

The problem of efficient waste management is associated with many projects in various countries. For example, since 2000, the World Bank has committed over $4.7 billion to >340 solid waste management programs in all six regions of World Bank engagement. A significant amount of research is devoted to this topic (Cleary, 2009; Guerrero et al., 2013; Nabavi-Pelesaraei et al., 2017; Rodić and Wilson, 2017; Sharholy et al., 2008; Zhang et al., 2010 and other). According to the data given in the literature, the main methods of waste disposal in the world are (all of these methods can be accompanied by the sorting of waste in order to extract valuable components (glass, metals, paper, plastic, etc.) for their subsequent industrial processing):

1. Landfill. This is the most common way. To reduce the harmful environmental impact of waste may be filled with soil. The reason for the widespread use of this method is simplicity and low cost. But it also has significant drawbacks. This is environmental pollution (soil, water, air); unpleasant smell, frequent fires; the need to allocate large areas of land in densely populated areas with a shortage of land; the cost of subsequent reclamation, etc.

2. Natural methods of waste decomposition: Composting (biothermal aerobic fermentation) to produce fertilizers, biofuels, etc.; anaerobic fermentation with biogas production. This method is "natural" from the standpoint of the natural biogeochemical circulation of substances. But it requires considerable time for recycling, accompanied by negative environmental effects (greenhouse gas emissions, for example, methane from landfills represents 12% of total global methane emissions (Hoornweg and Bhada-Tata, 2012); unpleasant smell; soil pollution by rotting). In addition to high costs, this method requires careful sorting and preparation of waste; ensure their regular airing and shoveling.

3. Waste heat treatment.
    a. Burning. This method is very common. The market offers ready-made kits of modern equipment for its implementation. The volume of waste after processing is significantly reduced. Burning garbage produces energy, the use of which reduces its consumption from other sources. At the same time, waste generated after incineration is often quite toxic, and the work of incineration plants is accompanied by emissions of harmful substances into the atmosphere.
    b. Low-temperature pyrolysis. This method includes the liquefaction and gasification of solid waste. Its main technological stages are sorting, drying, dry distillation (pyrolysis) of waste, gasification and burning of coke residue with the release of gaseous products. For its

implementation, considerable preparatory work on waste preparation is required. Equipment is less reliable. The economic and energy efficiency of this technology is low.

c. High-temperature pyrolysis (plasma processing). It is carried out at high temperatures, which leads to baking and vitrification of slag. As a result, environmentally harmful solid residue processing is not allocated. At the same time, the process itself generates significant amounts of energy that can be used in industry, housing and other areas. The main disadvantage of this method is a significant power consumption.

Despite the availability of progressive methods of recycling, the landfill remains the main method in the world. This is typical for Russia. According to Rosprirodnadzor, as of January 2019, 5,526 waste disposal facilities (landfills) are included in the state register. According to Porfiryev (2012), 15–20 million tons of organic waste (30–40% of the total organic fertilizer used by agriculture) goes to landfills every year; 15 million tons of paper and cardboard (3 times the volume of pulp produced); 3.1 million tons of glass (approximately equal to the mass of glass containers produced in Germany), etc. Not >10% of solid household waste is utilized, of which 3% is burned, 7% is sent for industrial processing. The strengthening of the state regulation of recycling looks justified in this regard. On January 14, 2019, the Decree of the President of the Russian Federation No. 8 "On the creation of a public law company for the formation of an integrated system for handling municipal solid waste "Russian Environmental Operator" was signed.

Thus, the analysis presented in this section of the article allows us to conclude that the problem of waste management is acute. Significant resources are allocated for its solution. The growth of waste is one of the key threats of modern humanity. The existing technological solutions for their implementation require significant investments, changes in regulation, as well as transformation of the behavior of the population. Unfortunately, the bulk of waste management improvement projects (Hoornweg and Bhada-Tata, 2012; The World Bank, 2018) require significant investments. Therefore, the modernization of waste management often comes down to the modernization of waste dumps. Waste is an alternative source of energy. Their use as an energy carrier can make a large contribution to improving energy efficiency. However, the relevant projects did not receive distribution.

4.3. Energy Efficient Recycling Technology

We propose an innovative waste treatment technology that is environmentally friendly and energy efficient (Vertakova et al., 2017a; Vertakova et al., 2017b). The technology is based on the method of thermocatalytic depolymerization of prepared solid household waste. Preparation includes the sorting, drying and grinding of organic and polymeric components of the waste. The result of the equipment is scrap (released at the stage of sorting), synthetic oil and solid residue. After further processing, commercial products are obtained from them: Gasoline, fuel oil and cement clinker.

Laboratory experiments confirmed the performance of the proposed technology. Table 2 shows the calculated data of

Table 2: Production volumes of commodity products by an experimental module (tons/month) (Vertakova et al., 2017a; Vertakova et al., 2017b)

Product	Volume of production
Scrap metal	24.0
Synthetic oil (before processing)	86.5
Gasoline (from synthetic oil)	56.2
Fuel oil (from synthetic oil)	30.3
Cement clinker	42.6

production volumes (per month) of commodity products by a standard module designed for processing 10 tons of waste/day. In the simulation, the component composition of a mixture of solid household waste, characteristic of cities in the European part of Russia, was used.

For the project of energy-efficient waste treatment using the proposed technology, its financial model was built (Tikhomirov and Plotnikov, 2018). The model used normative, cost and forecast indicators expressed in rubles (the national currency of the Russian Federation). The following project indicators were obtained (in parentheses are the cost indicators in US dollars calculated at the current official exchange rate): Investment costs - 59.55 million rubles ($ 0.93 million); net present value - 58.83 million rubles ($ 0.92 million); yield index - 1.99; discounted payback period - 2.3 years.

Thus, the proposed technology is commercially viable. The ability to create small-capacity modules for recycling allows you to use it in small cities and settlements. In addition to the beneficial environmental effect (direct - the elimination of landfills; indirect - reduction of greenhouse gas emissions from landfills, recycling of raw materials, etc.), the proposed technology is highly energy efficient. For the operation of the equipment uses the energy obtained during the processing of waste. In addition, synthetic oil is produced, which is an alternative source to produce hydrocarbon energy carriers. According to the authors, this technology deserves replication and wider use. In Russia, it can be implemented by the Russian Environmental Operator public law company established in 2019.

5. CONCLUSION

Modern humanity is faced with several global problems associated with sustainable development. These problems are closely related to each other and cannot be solved in isolation. Our study highlighted such important issues as improving the energy efficiency of the economy and reducing the level of environmental pollution. The possibilities of their joint solution were considered.

The key idea of the study was that waste may be an unconventional (alternative) energy source. The analysis made it possible to establish that the growth of waste is one of the key threats of our time. The existing technological solutions for their implementation require significant investments, changes in regulation, as well as transformation of the behavior of the population. Therefore, the modernization of waste management often comes down to the modernization of waste dump management. New technological

solutions are urgently needed in this area, which are cheap and efficient (including energy efficient).

To ensure the energy efficiency of the economy, the consolidated efforts of various actors are needed: International organizations, national governments, corporate leadership, civil society institutions and the population itself. At the same time, both new institutional rules and innovative technologies are important. The article shows that the use of waste as an energy resource can make a large contribution to improving energy efficiency. The technology of thermocatalytic depolymerization of solid household waste is proposed for their processing. Calculations have shown that this technology is commercially viable. In addition to the beneficial environmental effect, the proposed technology has high energy efficiency. According to the authors, this technology deserves replication and wider use.

6. ACKNOWLEDGMENT

REFERENCES

Achillas, C., Moussiopoulos, N., Karagiannidis, A., Banias, G., Perkoulidis, G. (2013), The use of multi-criteria decision analysis to tackle waste management problems: A literature review. Waste Management and Research, 31(2), 115-129.

Allcott, H., Greenstone, M. (2012), Is there an energy efficiency gap? Journal of Economic Perspectives, 26(1), 3-28.

Alumur, S., Kara, B.Y. (2007), A new model for the hazardous waste location-routing problem. Computers and Operations Research, 34(5), 1406-1423.

Apergis, N., Danuletiu, D.C. (2014), Renewable energy and economic growth: Evidence from the sign of panel long-run causality. International Journal of Energy Economics and Policy, 4(4), 578-587.

Babu, B.R., Parande, A.K., Basha, C.A. (2007), Electrical and electronic waste: A global environmental problem. Waste Management and Research, 25(4), 307-318.

Carrie, A.K., Gupta, A., Shrimali, G., Albert, A. (2013), Is disaggregation the holy grail of energy efficiency? The case of electricity. Energy Policy, 52, 213-234.

Cleary, J. (2009), Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature. Environment International, 35(8), 1256-1266.

Craig, P.P. (2001), Energy limits on recycling. Ecological Economics, 36(3), 373-384.

De La Cruz-Lovera, C., Perea-Moreno, A.J., de la Cruz-Fernández, J.L., Alvarez-Bermejo, J.A., Manzano-Agugliaro, F. (2017), Worldwide research on energy efficiency and sustainability in public buildings. Sustainability, 9(8), 1294.

Environmental Protection Agency EPA. (2018), Household Waste. Characterisation Campaign. Final Report. Available from: https://www.epa.ie/pubs/reports/waste/wastecharacterisation/Household_Surveys_Final_Report1.pdf.

Eurostat. (2018), Waste statistics. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics#Waste_treatment.

Farla, J.C.M., Blok, K. (2000), Energy efficiency and structural change in the Netherlands, 1980-1995: Influence of energy efficiency, dematerialization, and economic structure on national energy consumption. Journal of Industrial Ecology, 4(1), 93-117.

Fehr, M., De Castro, M.S.M., Calçado, M.D.R. (2000), A practical solution to the problem of household waste management in Brazil. Resources, Conservation and Recycling, 30(3), 245-257.

Fleiter, T., Fehrenbach, D., Worrell, E., Eichhammer, W. (2012), Energy efficiency in the German pulp and paper industry a model-based assessment of saving potentials. Energy, 40(1), 84-99.

Gabriel, F.B., El-Halwagi, M.M. (2005), Simultaneous synthesis of waste interception and material reuse networks: Problem reformulation for global optimization. Environmental Progress, 24(2), 171-180.

Gillingham, K., Rapson, D., Wagner, G. (2016), The rebound effect and energy efficiency policy. Review of Environmental Economics and Policy, 10(1), 68-88.

Guerrero, L.A., Maas, G., Hogland, W. (2013), Solid waste management challenges for cities in developing countries. Waste Management, 33(1), 220-232.

Hanley, N., McGregor, P.G., Swales, J.K., Turner, K. (2009), Do increases in energy efficiency improve environmental quality and sustainability? Ecological Economics, 68(3), 692-709.

Haraldsson, J., Johansson, M.T. (2019), Energy efficiency in the supply chains of the aluminium industry: The cases of five products made in Sweden. Energies, 12(2), 245.

He, F., Zhang, Q., Lei, J., Fu, W., Xu, X. (2013), Energy efficiency and productivity change of China's iron and steel industry: Accounting for undesirable outputs. Energy Policy, 54, 204-213.

Hoornweg, D., Bhada-Tata, P. (2012), What a waste. A global review of solid waste management. World Bank Urban Development Series, 15, 98.

IEA. (2018a), Energy Efficiency Indicators; 2018: Highlights. Available from: https://webstore.iea.org/energy-efficiency-indicators-2018-highlights.

IEA (2018b). World Energy Outlook 2018, Paris.

Kara, S., Ibbotson, S., Kayis, B. (2014), Sustainable product development in practice: An international survey. Journal of Manufacturing Technology Management, 25(6), 848-872.

Koester, U. (2014), Food loss and waste as an economic and policy problem. Intereconomics, 49(6), 348-354.

Liu, J., Raven, P.H. (2010), China's environmental challenges and implications for the world. Critical Reviews in Environmental Science and Technology, 40(9-10), 823-851.

Ma, L.H., Hsieh, J.C., Chiu, Y.H. (2019), A study on the effects of energy and environmental efficiency at China's provincial level. Energies, 12(4), 591.

Melikoglu, M., Lin, C.S.K., Webb, C. (2013), Analysing global food waste problem: Pinpointing the facts and estimating the energy content. Central European Journal of Engineering, 3(2), 157-164.

Menegaki, A.N., Gurluk, S. (2013), Greece and Turkey; Assessment and comparison of their renewable energy performance. International Journal of Energy Economics and Policy, 3(4), 367-383.

Nabavi-Pelesaraei, A., Bayat, R., Hosseinzadeh-Bandbafha, H., Afrasyabi, H., Berrada, A. (2017), Prognostication of energy use and environmental impacts for recycle system of municipal solid waste management. Journal of Cleaner Production, 154, 602-613.

Parthan, S.R., Milke, M.W., Wilson, D.C., Cocks, J.H. (2012), Cost estimation for solid waste management in industrialising regions-precedents, problems and prospects. Waste Management, 32(3), 584-594.

Pearce, J.M., Miller, L.L. (2006), Energy service companies as a component of a comprehensive university sustainability strategy. International Journal of Sustainability in Higher Education, 7(1), 16-33.

Porfiryev, B.N. (2012), Green economy: Realities, prospects and growth limits. Economy. Taxes. Law, 5, 34-42.

Ringel, M., Knodt, M. (2018), The governance of the European energy union: Efficiency, effectiveness and acceptance of the winter package 2016. Energy Policy, 112, 209-220.

Ringler, C., Bhaduri, A., Lawford, R. (2013), The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency? Current Opinion in Environmental Sustainability, 5(6), 617-624.

Rodić, L., Wilson, D.C. (2017), Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. Sustainability (Switzerland), 9(3), 404.

Schau, E.M., Traverso, M., Finkbeiner, M. (2012), Life cycle approach to sustainability assessment: A case study of remanufactured alternators. Journal of Remanufacturing, 2(1), 5.

Sharholy, M., Ahmad, K., Mahmood, G., Trivedi, R.C. (2008), Municipal solid waste management in Indian cities a review. Waste Management, 28(2), 459-467.

Shnitnikov, A.V. (1969), Intracircular Variability of the Components of General Moisture Content. Leningrad: Science Publisher.

The World Bank. (2018), Solid Waste Management. Available from: http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management.

Tikhomirov, D., Plotnikov, V. (2018), The minimisation of risks in project finance: Approaches to financial modelling and structuring. MATEC Web of Conferences, 193, 05069.

U.S. Energy Information Administration. (2017), International Energy Statistics. Available from: https://www.eia.gov/beta/international/data/browser/#/?c=4100000002000060000000000000g000200000000000000001&vs=INTL.44-1-AFRC-QBTU.A&cy=2016&vo=0&v=H&end=2017.

Vertakova, Y., Plotnikov, V. (2017), Problems of sustainable development worldwide and public policies for green economy. Economic Annals XXI, 166(78), 4-10.

Vertakova, Y.V., Zvyagintsev, G.L., Babich, T.N., Polozhentseva, Y.S. (2017b), Feasibility basis for use of new solid household waste processing equipment. IOP Conference Series: Earth and Environmental Science, 87(4), 042026.

Vertakova, Y.V., Babich, T.N., Polozhentseva, Y.S., Zvyagintsev, G.L. (2017a), Prospects for development of hydrocarbon raw materials resources reproduction. IOP Conference Series: Earth and Environmental Science, 87(9), 092031.

Wang, Q., Yuan, X., Cheng, X., Mu, R., Zuo, J. (2014), Coordinated development of energy, economy and environment subsystems a case study. Ecological Indicators, 46, 514-523.

Zhang, D.Q., Tan, S.K., Gersberg, R.M. (2010), Municipal solid waste management in China: Status, problems and challenges. Journal of Environmental Management, 91(8), 1623-1633.