An Acad Bras Cienc (2022) 94(4): e20191226 DOI 10.1590/0001-3765202220191226
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ENGINEERING SCIENCES

Efficiency of renewable energy plants in Russia

ALEXEY MIKHAYLOV

Abstract: The aim of this research paper is a complex assessment of the efficiency of power plants in Russia, the basis of their techno-economic processes and indicators and the development of recommendations for their practical use and improvement. Capital expenses for SWH plants with a drain-down system are 1,4-1,6 times lower than traditional SWHs with circulation systems, and their payback period does not exceed 5-5,7 years. Biogas that is obtained from specialized plants of medium and high-power costs $15,000-60,000 per cubic meter. But the price of biogas produced in low energy power plants is about $80,000-270,000, which is cheaper than natural gas. So, the use of biogas is economically justified at the moment.

Key words: Biogas plants, cost of plants, electrical energy, solar water heating plants, thermal energy, wind turbines.

INTRODUCTION

Data analysis of tariffs for thermal and electrical power and the prices for several energy resources like gas, mazut (fuel oil) and coal shows steady growth. That is precisely why energy plants with renewable energy sources, which could economize up to 60-70% of its energy, if not more, will become attractive to consumers. The reasoning is that in certain situations, these factors will help escape dependence from monopolies. We developed a method that evaluates the economic efficiency of power plants. It bases on determining the main techno-economic indicators, like capital investments, the cost of obtained thermal energy and the payback periods of energy establishments: wind turbines, solar plants, biogas plants.

The aim of this research paper is a complex assessment of the efficiency of power plants in Russia, the basis of their techno-economic processes and indicators and the development of recommendations for their practical use and improvement.

Many corporations in Russia are working on the serial production of solar energy plants. They take up an area of 0,8-1,07 square meters and cost $70 per square meter. These plants are the base of SWH plants that have two collectors and a heat-insolated storage tank. The cost is $280. Solar collectors "Konkurent" have technical characteristics that are on par with the best foreign samples. Their area is 1 square meter, and the price is $220. Thus, the unit price of solar installations is approximately $100-300 21 per square meter (Chiemchaisri et al. 2012, Gardner et al. 1993).

And their payback period reaches 8-16 years, which makes them inaccessible to large masses of 23 middle class and low-income consumers (Ahmed et al. 2014, Mikhaylov et al. 2018, Nyangarika et al. 2018).

Capital expenses for SWH plants with a drain-down system are 1,4-1,6 times lower than 26 traditional SWHs with circulation systems, and their payback period does not exceed 5-5,7 years. This 27 makes it possible to use them as a heat supply in low-rise buildings along with gas and electric heaters 28 and high-rise buildings in conjunction with boiler blocks and roof boilers. As a result, the annual gas 29 consumption is reduced by 40-60% (Amini & Reinhart 2011, Bansal et al. 2013).

Axial fittings are widely used for power generation. Their 2-4 aerodynamic blades have a horizontal axis of rotation. Nevertheless, amongst a long list of indisputable advantages, the most prominent of which is a high-efficiency rating, these plants have a significant drawback – their dependence from the wind. Not only that, but when the power is above 3 kW, these establishments require individual devices that help jump-start the machine (Bove & Lunghi 2006, Cai et al. 2011).

In other words, they can't start themselves. This leads to the development of more complex power-up and control systems, which, subsequently, increases the price of the machinery and its maintenance (Denisova 2019, Denisova et al. 2019).

Concerning what has been said, it would be best if most autonomous devices used orthogonal (on 40 a vertical axis) installations (Nyangarika et al. 2019a, b).

They are very beneficial, as their performance does not depend on the direction of the wind, and they operate at the low wind speeds of 2-3 meters per second (Mikhaylov 2018a, b).

Because of these characteristics, the average energy production of wind power installations and wind turbines is 2-2,5 times better when compared to other devices with similar power. Besides, orthogonal bases do not generate noise or infrasound (Kranina 2021).

However, they are more prone to vibrations. In general, though, the rotor is one of the most effective establishments in the world factors (Meynkhard 2019).

MATERIALS AND METHODS

The article uses data about the average marginal levels of unregulated electricity power prices of Mosenergosbyt to legal entities in Russia as of May 2019. This data is the foundation of the articles' estimates of payback periods for solar and biogas establishments and wind turbines.

The following universal formula can determine the payback period of solar power plants:

$$Ts=k*I/E*C*V \tag{1}$$

where I is the share of investments in solar panels in the total of investments in solar installations; k is the coefficient of investments, that depend on the type of solar installation; E is the specific annual amount of solar energy that solar installations receive, GJ/(m^2·year); C is the energy efficiency of the solar establishment; V is the cost of the replaced heat energy, rub/GJ.

The coefficient I depends on the type of solar collector, the design of the heat power bank, the model of metallic structures and circulation pipelines. An analysis of past research shows that the coefficient I in Russia is equal to 2,0. Formula (1) can be used to choose an optimal design of an SWH plant depending on the structure of the solar collector. The efficiency of a solar collector depends on the average annual amount of energy that is received by a solar collector. This hinges on the solar collector's geographical location and the cost of the replaced energy, which revolves around the type of alternative energy source and the price of this energy supply (Mikhaylov 2019a, Mikhaylov et al. 2019).

Techno-economic indicators of Russia's wind turbines comply with techno-economic indicators of the very best foreign stations with renewable energy. Over the past 20-30 years, capital expenditures in renewable energy (ki) decreased by five times and are currently at $800-1000 per kW.

We can get formulas for techno-economic indicators by generalizing this data. The following formula can determine the payback period in particular:

$$Tw=ki/U*T*P \quad (2)$$

where ki is the average capital cost in renewable energy; U is the coefficient of power consumption; T is the annual operating time of wind turbines and installments, hours per year; P is the cost of the replaced energy, USD/(kW·hour).

Next, we will use formulas to calculate the payback period of bioenergy plants. We can determine the empirical relation of capital expenditures to the volume of bioenergy installations (in $1,000) by generalizing and analyzing the data on capital expenses:

$$Tb=k_b/V_b \quad (3)$$

where k_b is the average capital expenditures on; V_b is the volume of the bioreactor, м^3.

RESULTS

In the United States and Europe, efforts are being made to concentrate scientific efforts in the development of scarification technologies for cellulose. Thus, in the 7th framework program of the EU, funds for the development of renewable energy increased by 50% compared with the 6th framework program.

We have already mentioned the efforts of the United States under the Energy Policy Act. Interestingly, large international oil companies are also interested in developing the scientific foundations of biofuel technology. For example, BP (British Petroleum) is ready $ 500 million to finance a new scientific studies r Yale Center, organized on the basis of the University of Berkeley (California, USA), as well as the work of national laboratories, Lawrence (LBNL Lawrence National Laboratory) and the University of Illinois (Urbana-Champagne).

Firms Shevron and Conaco Philips also started to finance the development of biofuels, mainly based on lignocellulosic feedstocks. However, the scale of financing is still small (tens of millions of dollars).

Thus, we can assume that in the medium term (about 7-8 years), bioethanol production in the world will grow rapidly based on the use of agricultural plants: sugar cane in Brazil and other tropical countries; corn - in the USA; wheat, rye, barley - in Canada, Australia, Eastern Europe and the CIS countries (Fig. 1).

Within 5-7 years, it is expected to develop a technology for the cost-effective production of fuel biodiesel from fatty acid, rapeseed, soybean and palm (Fig. 2-5).

If it is possible to sufficiently reduce the price of ethanol from plant materials, it can be used not only as fuel, but also for processing into ethylene, polyethylene and other compounds, replacing petrochemical products in this sector.

The technical properties of biodiesel are very close to the properties of diesel fuel derived from oil. In Europe and Canada, I get biodiesel from rapeseed oil, in USA – from soybean, in Malaysia and Indonesia – from oil of palm oil. The properties of biodiesel depend on the fat and alcohol used for esterification. Therefore, in the case of isopropyl alcohol, I get r biodiesel having a low freezing point, which can be used in frosty weather.

World production of biodiesel, mainly from rapeseed, in 2006 amounted to 9.7 million tons (2.5 tons of rapeseed are consumed per 1 ton of biodiesel). In 2007-2008 in the world it is planned to get 19.5 million tons of rapeseed, including 17.45 million tons in Europe. Today, the main producer and consumer of biodiesel is

Figure 1. **Indian bioethanol price. Source: Thomson Reuters.**

Europe, where it is made almost exclusively from rapeseed oil. Although biodiesel production in the United States is incomparably lower than in Europe, it is growing rapidly (from 2 million gallons in 2000 to 250 million gallons in 2006).

In this country, soybean oil and a higher cost is used as raw material. A number of reviews are devoted to this topic. The price of glycerin is lower than the price of glucose obtained from starch, and it can be used as a raw material in microbial synthesis. Microbial synthesis products may include ethanol, succinic acid, 1,3-propanediol and many other useful substances. The theoretical yield of ethanol when used as a carbon source for the cultivation of microbes glycerol can reach 95% and its cost can be 40% lower than when obtaining ethanol from grain. Oil palm has a high potential for biodiesel production. In the countries of its cultivation (Indonesia, Malaysia), there are extensive plans for the production of biodiesel. For the economy of biodiesel production, the processing and marketing of related products -rapeseed meal and glycerin is important. The use of rapeseed meal is not a problem, as it is a complete feed with a high protein content (about 25%), which successfully replaces soybean meal in feeding farm animals.

Currently, the United States launched a plant for the production of 1,3-propanediol using microbial synthesis from glucose. The cost of the product thus obtained is much lower than in chemical production.

The processes of producing butanol, propionic acid and succinic acid from glycerol are being developed. From the 1920s until the end of the 1950s, milestone butanol was obtained using microbial synthesis, using flour and molasses as raw materials.

In recent years, significant efforts have been made and considerable success has been achieved in improving the properties

Figure 2. **FAME (Fatty Acid Methyl Ester) biodiesel price. Source: Thomson Reuters.**

of microorganism strains producing butanol, as well as in improving the corresponding technological process.

There is a method of thermal gasification of plant biomass - its conversion into synthesis gas, consisting of carbon monoxide. It is transformative that is difficult to convert to sugar in plant biomass, for example, coniferous wood. The process of catalytic conversion of synthesis gas into liquid hydrocarbons has long been known.

The results of the calculations for the average of the regions of Russia using Formula (1) with the coefficient I= 2,0, the annual amount of solar energy, that is received by the solar collector during warm periods of the year (from April to October) E= 4.016 GJ (m^2·year), energy C= 0.50. The payback period for south regions of Russia increases from 2 to 25 years, with the increase in unit capital investments in solar collectors k from $100 to $600 per square meter and the decrease of the price of replaced energy V from $400 to $150 per GJ. The cost of acceptable for practical use solar collectors with a payback period of less than seven years and the increase of price of the replaced thermal energy from $150 to $400 per GJ will equate to $100-300 per square meter.

However, it is noteworthy that present tariffs for thermal energy in Russia's southern regions are $200 per Gcal. Thus, the minimal acceptable cost of solar collectors with a payback period of 7 years should not exceed $59 per square meter. This condition must be fulfilled when designing

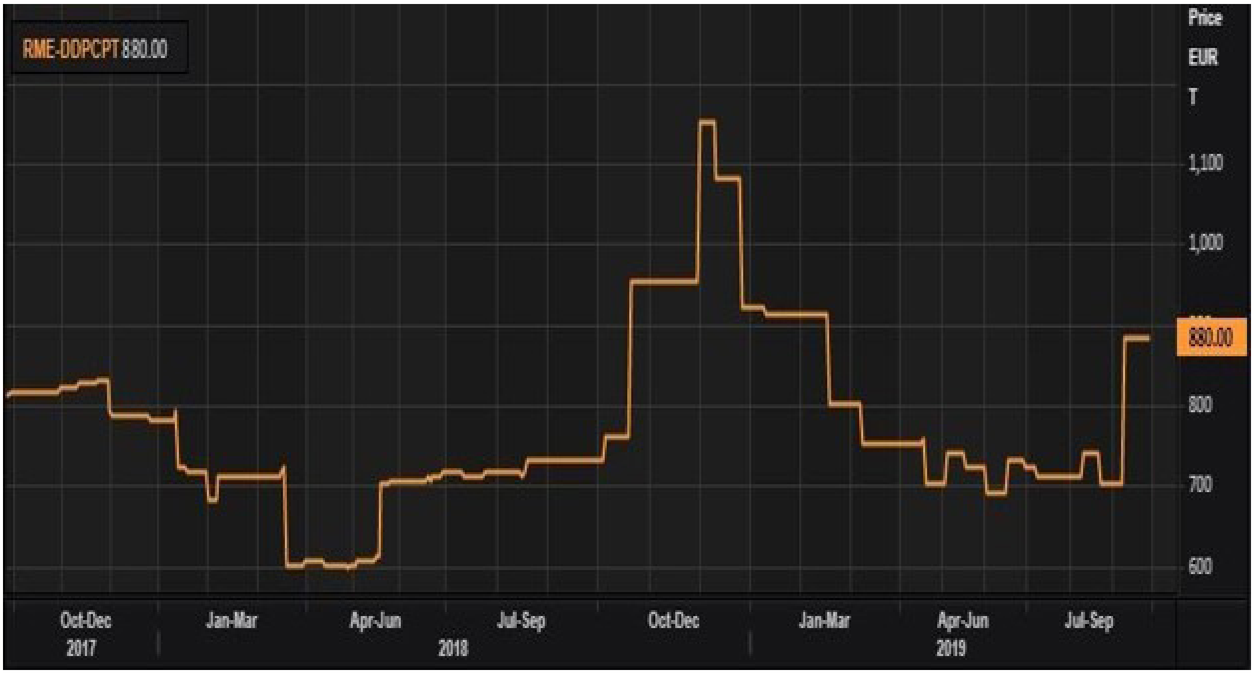

Figure 3. **RME (Rapeseed Oil Methyl Ester) biodiesel price. Source: Thomson Reuters.**

the project and the widespread introduction of solar installations.

Wind installation's payback period increased from 2 to 30 years. At the same time, the average capital investments in wind turbines increased from $400 to $1500 per kW, and the cost of replaced energy decreased. The minimal capital investment in ready-for-practical-use wind installations with a payback period of no more than 7 years and the increase of the price of replaced energy is $400 to $1000 per kW. What's noteworthy is that current tariffs for electricity energy on the south of Russia are lower than the average values throughout Russia. Because of this, the minimal capital investments in wind turbines and 9 wind installations with a payback period of 7 years cannot be more than the average throughout the entirety of Russia.

Techno-economic assessments of different types of wind turbines were carried out and showed high-efficiency rates of wind installations in the energy system of various autonomous facilities. The cost of electricity per kW is estimated to be $0,1 at most. The cost of wind installations without introducing automated production is $950 per kW.

Unit capital costs can be lowered in serial production to a maximum of $1150 per kW, after which these wind turbines will be recommended for exploitation in the southern regions of Russia.

Orthogonal wind turbines with five blades of a similar design of an American manufacturer Falcon Euro with a power of 7.5-20.0 kW are also quite economical. Unit capital costs for them are not more than $1620 per kW.

Capital expenses for the most economical 15 kW in power wind turbines are $1070 per kW. These wind installations can be recommended to be used in the south of Russia today.

In 2018-2019, Thomson Reuters Laboratory in the Financial University conducted studies on the use of renewable energy in Russia.

The cost of biogas obtained from installations of medium power (the volume of the bioreactor is 10-100 cubic meters) and

Figure 4. **SME (Soybean Methyl Ester) biodiesel price. Source: Thomson Reuters.**

high-power (the volume of the bioreactor is 100-1000 cubic meters) is about $15,000-60,000 per cubic meter. This is cheaper than the price of natural gas in the domestic market, which currently costs $120,000 per cubic meter.

The cost of biogas produced by low-power plants and volumes of reactors of 0,3-10 cubic meters is pretty high right now - $80,000-270,000 per cubic meter. When considering the significant capital expenditures on the construction and exploitation of gas networks in rural areas in many regions of Russia, the use of high, medium and low biogas power plants to supply consumers with heat and gas is economically justified.

Solar installments with heat-pumping systems will allow to significantly decrease the consumption of biogas for personal needs and lower the price of low-power biogas plants' product to $30-110 per cubic meter.

DISCUSSION

A comprehensive assessment of the efficiency of power plants using renewable energy sources in Russia allows us to make the following conclusions.

The payback period of SWH plants for south regions of Russia increases from 2 to 25 years, with the increase in unit capital investments in solar collectors from $100 to $500 per square meter and the decrease of the price of replaced energy from $2,500 to $1,000 per GJ. When considering $9 per GJ tariffs on thermal energy, the cost of solar collectors with a payback period

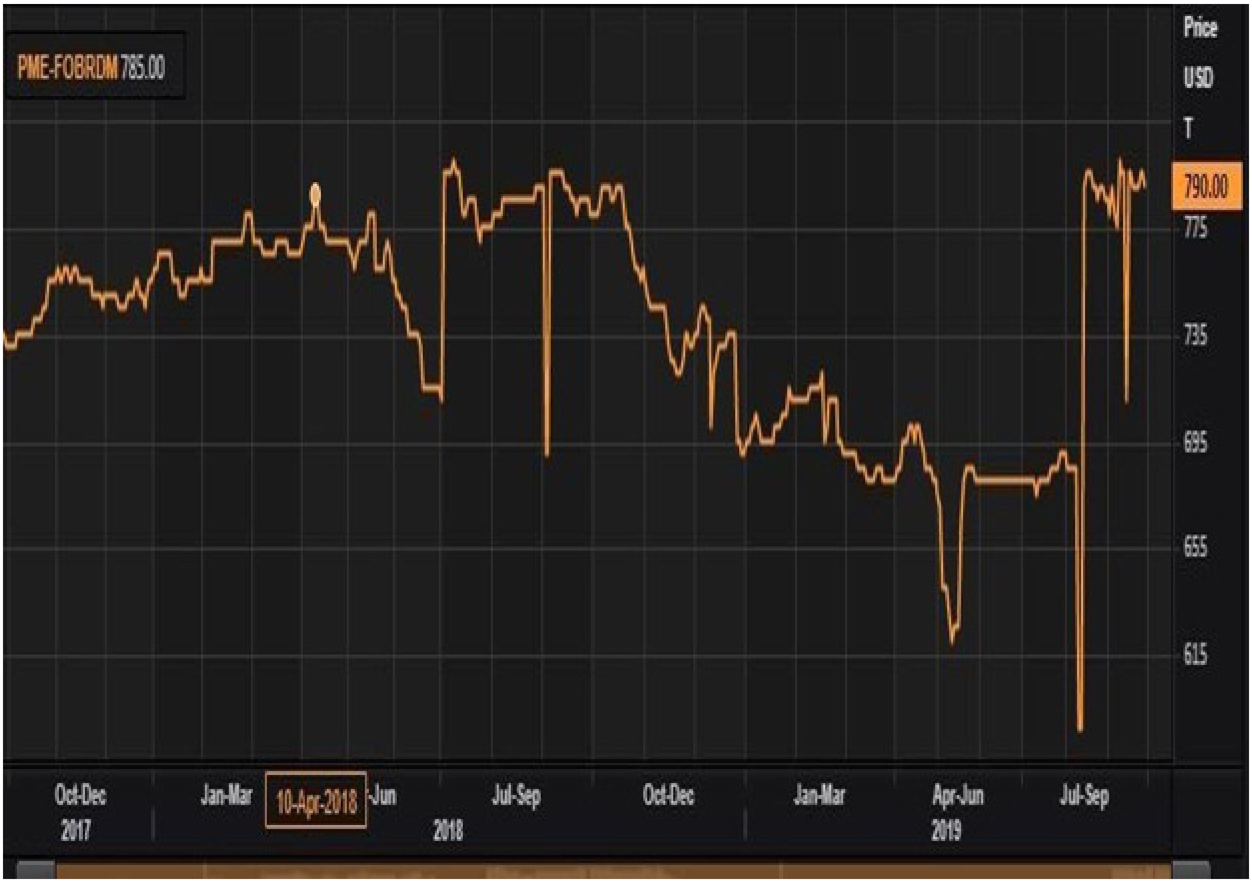

Figure 5. **PME (Palm Methyl Ester) biodiesel price. Source: Thomson Reuters.**

of 7 years cannot be more than $59 per square meter (Jaramillo & Matthews 2005, Lopatin 2019).

Unit price of solar collectors released in Russia and abroad is $100-400 per square meter, and the payback period can be up to 5-16 years. Capital expenses for SWH plants with a drain-down system are 1,4-1,6 times lower than traditional SWHs with circulation systems, and their payback period when using the cheapest solar collectors does not exceed 5-5,7 years. This makes it possible to use them as a heat supply in low-rise buildings along with gas and electric heaters and high-rise buildings in conjunction with boiler blocks and roof boilers. As a result, the annual gas consumption is reduced by 40-60% 54 (Milbrabdt et al. 2014, Morgan & Yang 2001).

It would also be best if most autonomous devices used orthogonal (on a vertical axis) installations. They are very beneficial, as their performance does not depend on the direction of the wind, and they operate at the low wind speeds of 2-3 meters per second. The payback period of renewable energy increases from 2 to 30 years when increasing unit capital expenditures for wind installations from 2 to 5 rubles per kW·hour. The minimal permittable unit capital investments in renewable energy with a payback period of 7 years cannot be more than $1,150 per kW.

Unit capital costs for orthogonal wind turbines Falcon Euro are not more than $1620 per kW. Capital expenses for the most economical 15 kW in power wind turbines are $1,070 (43,000 rubles) per kW. These wind installations can be recommended to be used in the south of Russia today.

The cost of biogas obtained from installations of medium power (the volume of the bioreactor is 10-100 cubic meters) and high-power (the volume of the bioreactor is 100-1000 cubic meters) is about $15,000-60,000 per cubic meter. This is cheaper than the price of natural gas in the domestic market, which currently costs $120,000 per cubic meter.

The cost of biogas produced by low-power plants and volumes of reactors of 0,3-10 cubic meters is $80,000-270,000 per cubic meter. Recommended design schematics that use them with heat-pumping systems will allow to significantly decrease the consumption of biogas for personal needs and lower the price of low-power biogas plants' product to $30-110 per cubic meter.

REFERENCES

AHMED SI, JOHARI A, HASHIM H, MAT R, LIM JS, NAGADI N & ALI A. 2014. Optimal landfill gas utilization for renewable energy production. Env Progr Sust Energy 34(1): 289-298.

AMINI HR & REINHART DR. 2011. Regional prediction of long-term landfill gas to energy potential. Waste Manag 31(9-10): 2020-2026.

BANSAL A, ILLUKPITIYA P, SINGH SP & TEGEGNE F. 2013. Economic competitiveness of ethanol production from cellulosic feedstock in Tennessee. Renew Energy 59: 53-57.

BOVE R & LUNGHI P. 2006. Electric power generation from landfill gas using traditional and innovative technologies. Energy Convers Manag 47(11-12): 1391-1401.

CAI X, ZHANG X & WANG D. 2011. Land availability for biofuel production. Environ Sci Technol 45(2): 334-339.

CHIEMCHAISRI C, CHIEMCHAISRI W, KUMAR S & WICRAMARACHCHI PN. 2012. Reduction of methane emission from landfill through microbial activities in cover soil: A brief review. J Crit Rev Environ Sci Technol 42(4): 412-434.

DENISOVA V. 2019. Energy efficiency as a way to ecological safety: evidence from Russia. Int J Energy Econ Policy 9(5): 32-37.

DENISOVA V, MIKHAYLOV A & LOPATIN E. 2019. Blockchain Infrastructure and Growth of Global Power Consumption. Int J Energy Econ Policy 9(4): 2229.

GARDNER N, MANLEY BJW & PEARSON JM. 1993. Gas emissions from landfills and their contributions to global warming. Appl Energy 44(2): 166-174.

JARAMILLO P & MATTHEWS HS. 2005. Landfill-gas-to-energy projects: Analysis of net private and social benefits. Environ Sci Technol 39: 7365-7373.

KRANINA EI. 2021. China on the way to achieving carbon neutrality. Financ J 5: 51-61.

LOPATIN E. 2019. Methodological Approaches to Research Resource Saving Industrial Enterprises. Int J Energy Econ Policy 9(4): 181-187.

MEYNKHARD A. 2019. Energy Efficient Development Model for Regions of the Russian Federation: Evidence of Crypto Mining. Int J Energy Econ Policy 9(4): 16-21.

MIKHAYLOV A. 2018a. Pricing In Oil Market And Using Probit Model For Analysis Of Stock Market Effects. Int J Energy Econ Policy 2: 69-73.

MIKHAYLOV A. 2018b. Volatility Spillover Effect between Stock and Exchange Rate in Oil Exporting Countries. Int J Energy Econ Policy 8(3): 321-326.

MIKHAYLOV A. 2019. Oil and Gas Budget Revenues in Russia after Crisis in 2015. Int J Energy Econ Policy 9(2): 375-380.

MIKHAYLOV A, SOKOLINSKAYA N & LOPATIN E. 2019. Asset allocation in equity, fixed-income and cryptocurrency on the base of individual risk sentiment. Invest Manag Financ Innov 16(2): 171-181. doi:10.21511/imfi.16(2).2019.15.

MIKHAYLOV A, SOKOLINSKAYA N & NYANGARIKA A. 2018. Optimal Carry Trade Strategy Based on Currencies of Energy and Developed Economies. J Rev Glob Econ 7: 582-592. DOI: https://doi.org/10.6000/1929-7092.2018.07.54.

MILBRABDT AR, HEIMILLER DM, PERRY AD & FIELD CB. 2014. Renewable Energy Potential on Marginal Lands in the United States. Renew Sustain Energy Rev 29: 473-481.

MORGAN SM & YANG Q. 2001. Use of landfill Gas for electricity generation. Practice Periodical of Hazardous, Toxic, and Radio Waste Management 5(1): 14-24.

NYANGARIKA A, MIKHAYLOV A & RICHTER U. 2019a. Influence Oil Price towards Economic Indicators in Russia. Int J Energy Econ Policy 1(6): 123-130.

NYANGARIKA A, MIKHAYLOV A & RICHTER U. 2019b. Oil Price Factors: Forecasting on the Base of Modified Auto-regressive Integrated Moving Average Model. Int J Energy Econ Policy 1(6): 149-160.

NYANGARIKA A, MIKHAYLOV A & TANG B-J. 2018. Correlation of Oil Prices and Gross Domestic Product in Oil Producing Countries. Int J Energy Econ Policy 8(5): 42-48.

How to cite
MIKHAYLOV A. 2022. Efficiency of renewable energy plants in Russia. An Acad Bras Cienc 94: e20191226. DOI 10.1590/0001-3765202220191226.

Manuscript received on October 7, 2019;
accepted for publication on March 22, 2021

ALEXEY MIKHAYLOV
https://orcid.org/0000-0003-2478-0307

Financial University under the Government of the Russian Federation, Financial Faculty, Leningradsky avenue, 49, Moscow 124167, Russia

Correspondence to: **Alexey Mikhaylov**
E-mail: alexeyfa@ya.ru