DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Kashurnikov, Sergey; Prasolov, Valeriy; Gorbanyov, Vladimir et al.

Article

Nuclear power production : the future or the past?

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Kashurnikov, Sergey/Prasolov, Valeriy et. al. (2020). Nuclear power production : the future or the past?. In: International Journal of Energy Economics and Policy 10 (5), S. 131 - 141.
https://www.econjournals.com/index.php/ijeep/article/download/9765/5268.
doi:10.32479/ijeep.9765.

This Version is available at:
http://hdl.handle.net/11159/7929

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte.

https://zbw.eu/econis-archiv/termsofuse

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence.

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft

IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

EconJournals

International Journal of Energy Economics and Policy, 2020, 10(5), 131-141.

Nuclear Power Production: The Future or the Past?

Sergey Kashurnikov[1]*, Valeriy Prasolov[1], Vladimir Gorbanyov[2], Rodion Rogulin[3,4]

[1]Department of Risk Analysis and Economic Security, Financial University Under the Government of the Russian Federation, Russia, [2]Department of World Economy, Moscow State Institute of International Relations (University), Russia, [3]Department of Mathematics and Modelling, Vladivostok State University of Economic and Service, Russia, [4]Department of Applied Mathematics, Mechanics, Controlling and Software, Far Eastern Federal University, Russia. *Email: kashurnikovserg@rambler.ru/skashurnikov@mail.ru

Received: 10 March 2020 **Accepted:** 13 June 2020 **DOI:** https://doi.org/10.32479/ijeep.9765

ABSTRACT

Over the past 20 years, the share of nuclear energy in global electricity production decreased from 17.6% to 10%. The article highlights the financial challenges of the RW repository, the synergistic combination of all investments, and the development of a forecasting model for the cost of RW storage and disposal. The control and management of cash flows between financial resources in the field of nuclear energy create new development vectors and define trends for the international nuclear industry and markets. The objective of the article is to analyze the future development of nuclear energy by applying a predictive approach in the context of the limited risk distributor (LRD) business management model. The present paper analyses the trends in the global development of nuclear energy, the political background of the RW disposal, types of radioactive wastes, and their burial in Russia. The results achieved allow improving the typical LRD model for managing international nuclear enterprises by limiting the influence of commercial interests. However, a key problem of improving the efficiency of public and private investment was noted. A vague understanding of methods and forms of investment causes inefficiency and a lack of internal logic of the financing process.

Keywords: LRD Management Business Model, Nuclear Energy, Nuclear Waste, Storage and Disposal
JEL Classifications: O13, P28, Q4

1. INTRODUCTION

Nowadays, in the era of technological advancement and information explosion, population growth considerably affects energy consumption. It contributes not only to the improvement of existing methods of producing energy but also to the search for renewable energy mechanisms. Unfortunately, today the prospects for nuclear energy development are limited due to the high cost and requirements for safety. RW disposal remains an urgent problem for many countries. Deep geological disposal continues to be the central strategy for the RW repository in the 21st century. It involves the placement of RW several hundred meters below ground level. For this aim, many European countries have created an independent national regulatory body responsible for radioactive waste management (RWM). Among them are the Federal Office for Nuclear Waste Management (BfKE) in Germany, the Expert Organisation in Nuclear Waste Management (Posiva) in Finland, the French national radioactive waste management agency (ANDRA), and Swedish Nuclear Fuel and Waste Management Company (SKB). Russia, in turn, is continuing discussions concerning the role and functions of the National Operator for Radioactive Waste Management. For the Russian Federation, this issue remains tough since the bureaucratic intervention in the process of RWM. Thus, the nuclear industry occupies an ambiguous position in the country's policy (Agency for Natural Resources and Energy, 2016; Balogh and Jámbor, 2017; Brunnengräber and Schreurs, 2015; Edwards et al., 2019; Hong et al., 2018).

The rapid development of innovative information technologies and the use of block chain both in production and nuclear power

This Journal is licensed under a Creative Commons Attribution 4.0 International License

business fundamentally change the approach to organizing the operational business processes. Therefore, a necessity to review models of financing and business management still exists (NOAA's National Centers for Environmental Information, 2018; Obregon et al., 2019; Ozturk, 2017; Radhakrishnan et al., 2017; Sanders and Sanders, 2019). Since the traditional business organization includes producers, distributors, logistics intermediaries, final costumers, and managing and parent companies, the LRD business models remain the most efficient and widely held.

Peculiarities of LRD structure and functioning continue to be a comparatively recent development. Thus, the understanding of LRD is largely based on limited data. However, increased attention of worldwide business leaders and the optimization of developing countries' tax systems to counteract corporate influence on LRD show, that the examination and improvement of the LRD models in the energy sector are extremely relevant and require further scientific research (İskenderoğlu and Akdağ, 2019; Kim, 2019; Naser, 2015; Ochoa et al., 2018; Şahin and Şahin, 2018).

This study is aimed at examining the most urgent challenges to the nuclear power plant's (NPP) management and financing of RW disposal facilities, given the impact of integration processes in the global economy. Besides, the objective of the current research is to offer opportunities for improving the efficiency of enterprise management in the energy sector.

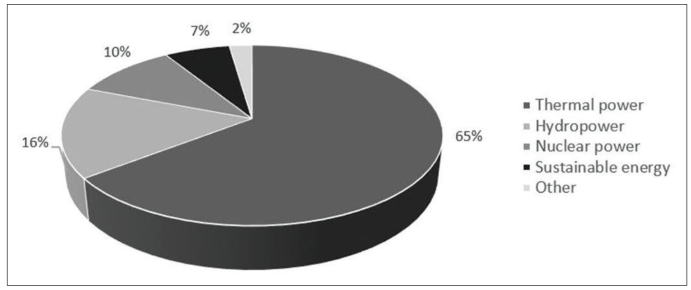
The main goals of the current research may be organized as follows:
1. Analyze the current state and prospects for the development of nuclear energy;
2. Determine the dependence between the development and implementation of programs for the RW maintenance and the increase in the economic efficiency of nuclear energy;
3. Improve the management model of international energy business by establishing parameters that reduce the influence of commercial interests.

2. RESEARCH DESIGN

Nowadays, nuclear energy provides about 10% of the world's electricity from power reactors. In 2018, twelve countries produced at least one-quarter of their electricity from nuclear (Figure 1). France gets around three-quarters of its electricity from nuclear energy, Hungary, Slovakia, and Ukraine get more than half from nuclear, whilst Belgium, Sweden, Slovenia, Bulgaria, Switzerland, Finland, and the Czech Republic get one-third or more. South Korea normally gets more than 30% of its electricity from nuclear, while in the USA, the UK, Spain, Romania, and Russia about one-fifth of electricity is from power reactors. Japan is accustomed to relying on nuclear power for more than one-quarter of its electricity and is expected to return to somewhere near that level.

Currently, there are 450 nuclear reactors in operation over the world. The performance of nuclear reactors has improved substantially over time. Over the last 40 years the proportion of reactors reaching high capacity factors has increased significantly. For example, 62% of reactors achieved a capacity factor higher than 80% in 2018, compared to 28% in 1978, whereas only 7% of reactors had a capacity factor lower than 50% in 2018, compared to 20% in 1978. In addition to commercial NPPs, there are about 220 research reactors operating in over 50 countries, with more under construction. As well as being used for research and training, many of these reactors produce medical and industrial isotopes. The use of reactors for marine propulsion is mostly confined to the major navies where it has played an important role for five decades, providing power for submarines and large surface vessels. Over 160 ships, mostly submarines, are propelled by some 200 nuclear reactors and over 13,000 reactor years of experience have been gained with marine reactors. Russia and the USA have decommissioned many of their nuclear submarines from the Cold War era.

Figure 1: World electricity production for 2017



*Source: Adapted from the World Nuclear Association data (World Nuclear Association, 2020)

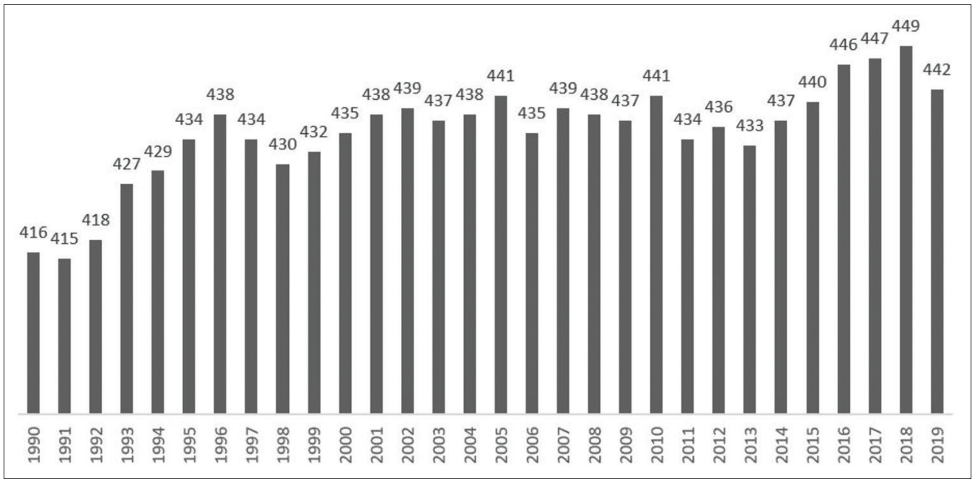
The statistics on the number of operable nuclear power reactors (NPPs) worldwide over the past 30 years are presented in Figure 2. According to data below, the number of nuclear reactors decreased by seven units in 2019 compared to 2018.

Figure 3 shows the statistics on the construction of NPPs from 1954 to 2016. There has been a clear global trend towards increasing NPP construction from 1984 to 1986, a decline from 1992 to 2014, and the resumption of construction activity from 2016. During this period, 3 units in Russia, the USA, and Japan, were decommissioned, and 10 were put into operation.

The strategic goals for modern sustainable development form a new vision of the prospects of nuclear energy. Among them are safety, effective management, cost reduction, and greening (Figure 4).

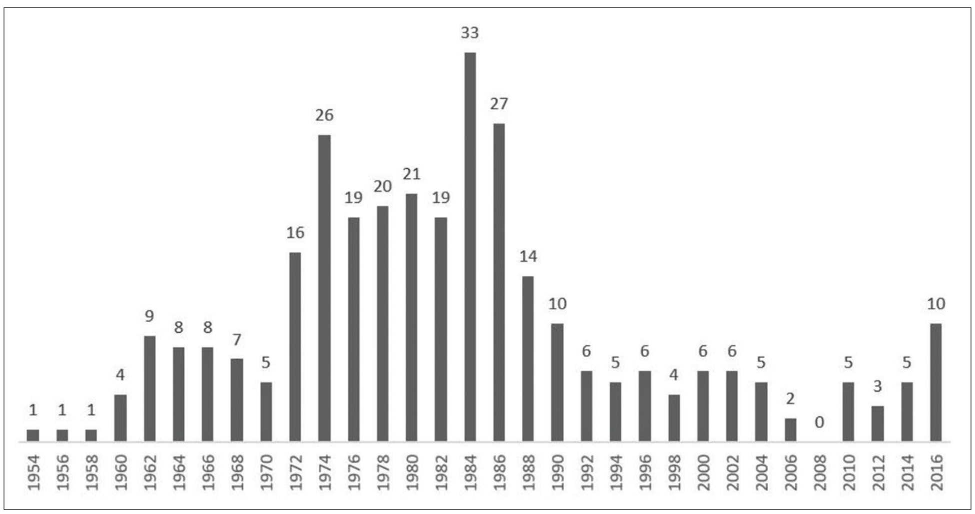
- Greening: It is the most critical aspect of nuclear energy development. Today, the long-term storage of RW increases risks and costs. To diminish hazards an open nuclear fuel cycle is widely used. Its principal advantage is the absence of the main pollution source - the radiochemical plant. However, an open nuclear fuel cycle is also characterized by the expensive construction of long-term storage facilities. Moreover, it carries risks due to contaminating the environment with radionuclides. Many modern countries face the problem of RW disposal, due to the threat posed by this waste to humanity. In case of the absence of active nuclear power growth, the successful introduction and operation of modern repositories can become a solution to this problem.

Figure 2: Number of operable reactors worldwide



*Source: Developed by the author on the World Nuclear Association data (World Nuclear Association, 2020)

Figure 3: Construction of NPP, 1954-2016



*Source: Developed by the author on the International Atomic Energy Agency data (International Atomic Energy Agency, 2020)

- Safety: Nuclear energy always considered a threat to the environment and human health. Such severe accidents as the Three Mile Island accident in 1979, the Chernobyl accident in 1986, and the Fukushima Daiichi accident in 2011 have greatly aggravated the situation. Although modern reactors are reliable, growing concern on the safety of nuclear energy, radioactive materials transportation, and nuclear terrorism can be noticed. Moreover, nowadays, the danger of misuse of various nuclear installations and weapons exists.
- Effective management: These days, nuclear reprocessing is used in many countries of Europe, in Russia, and Japan, and, unfortunately, carries a significant risk of nuclear proliferation. Thus, an open nuclear fuel chain should be implemented to avoid the spread of nuclear weapons.
- Cost reduction: Comparing the cost of natural gas or coal-based energy production and the cost of nuclear energy in the modern market, the latter is proved to be uncompetitive. The key to bringing nuclear costs and project times down is facilitating access to cheap financing, lowering regulatory barriers, and improving industry performance on nuclear construction projects.

Over the last 20 years, there has been a tendency in the world to reduce the use of nuclear energy. Hence, many countries have decided to abandon nuclear technology, shutting down hundreds of reactors (Table 1). According to the report of the International Atomic Energy Agency (IAEA), 46 nuclear reactors that were commissioned between 2005 and 2017 are located in Asia (India, Iran, China, Pakistan, South Korea, Japan) or Eastern Europe (Russia, Romania) (Elektrovesti, 2017).

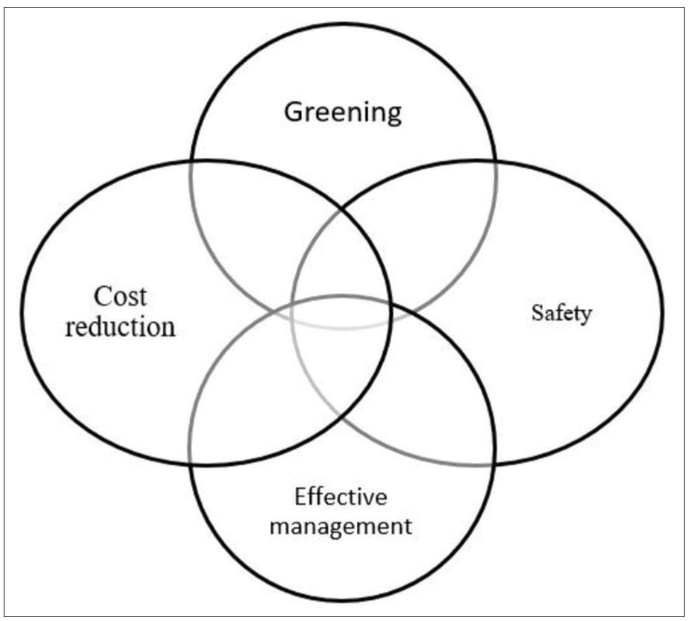
Nowadays, an interesting trend is observed in the world. Some countries try to develop programs and implement innovations to construct NPPs, while the nations indicated above made the final decision on decommissioning NPPs and switching to alternative energy sources. The decision to shut down the NPP corresponds not only with safety but also with further RW storage. Therefore, the largest European countries are going to build repositories for long-term or "perpetual" disposal of wastes. Despite its construction costs, "perpetual" RW disposal will provide new jobs, state subsidies, tax concessions to the country. For this aim, France, Sweden, and Finland plan to build an underground repository designed for at least 100 thousand

Table 1: Countries abandoning nuclear energy*

Country	Characteristics
Austria	Legislation prohibiting NPPs on Austrian territory and the import of electricity from abroad NPPs was adopted by 51% of Austrians as a result of a November 1978 referendum. This brought an end to the nuclear program and the possible construction of 6 NPPs.
Belgium	In 1993, two NPPs with 7 reactors provided 60% of the country's total energy generation. In 1999, a decision was made to phase out nuclear energy, and in 2002, a federal law called for each of Belgium's seven reactors to close after 40 years of operation with no new reactors built. Afterward, Belgium hopes to shut down its last NPP in 2025.
Germany	Some of the 17 reactors are already shut down. In the framework of the "Energy Turn" concept by 2022, nuclear energy will be completely abandoned and replaced with renewable energy sources.
Vietnam	The Vietnamese government has refused to build new nuclear power units, as other energy resources have become less costly, and energy demand has decreased.
Italy	Nuclear power phase-out commenced in 1987, 1 year after the Chernobyl accident. Following a referendum in 1987, Italy's four NPPs were closed down (the last one in 1990). The fourth cabinet led by Silvio Berlusconi tried to implement a new nuclear plan but a referendum held in June 2011 stopped any project.
Spain	The first country to adopt a moratorium on the new NPPs, even though it was one of the top countries to bet on this type of energy. From 2023 to 2028, it is planned to close all NPPs.
Taiwan	In 2014, the construction of two reactors was suspended, and by 2025 it is planned to stop all the units. The country will switch to alternative energy sources. By 2030, wind and solar power plants will be commissioned. Their power exceeds all existing NPPs.
France	Even though France is one of the largest electricity exporters in the EU with 58 nuclear reactors, its anti-nuclear direction become a popular subject of many political discussions. Nuclear gave the major share of electricity in the country, although its cost remained extremely high. NPPs are planned to be abandoned in the next 25 years.
Switzerland	On 21 May 2017, 58% of Swiss voters accepted the new Energy Act establishing the energy strategy 2050 and forbidding the construction of new NPPs. In the next decade, all 5 NPPs will be closed. Most of the companies approve the measures taken.
Sweden	In 1980 decisions were made to phase out NPPs. Some of the reactors were closed in 1999 and 2005, and two reactors at Ringhals NPP are planned to be shut down before 2020. Thus, Sweden has almost fulfilled its plans to abandon nuclear energy.

*Source: Developed by the author on the information retrieved from Abramov and Dorofeev (2017), Nikitin et al. (2017), and Polozkiva (2016)

Figure 4: Prospects of the sustainable development of nuclear energy



*Source: Developed by the author

years, for which four rock formations are suitable: granite, clay, sand, and salt. Among the most critical conditions for organizing underground storage are its seismic stability and the rock layer at least 100 meters. It is worth mentioning that a NPP filled with highly radioactive material from the reactor core and the cooling systems cannot simply be shut down. The NPP requires specific technical and safety measures, therefore, it must be constantly monitored and maintained.

The earliest European waste legislation dates back to 1975 with the adoption of the council directive on waste and the waste framework directive (WFD), introducing a five-step waste management hierarchy:

a. Prevention;
b. Reuse and preparation for reuse;
c. Recycle;
d. Recovery;
e. Disposal.

Tariffs for the RW disposal in the UK in 2016 amounted to 3038 £/m^3, and from \$3300 to \$33300/m^3 in the USA, depending on the waste classification. For more hazardous RW, there is a tendency to increase in cost as projects are implemented. In 2005 French Cigeo repository cost was estimated at €16.5 billion and €34.4 billion in 2014. The Finnish repository Onkalo estimated to cost about €1.72 billion according to data for 2013 (currently about \$3.9 billion) (Pioro, 2013; Wang et al., 2018; 2019).

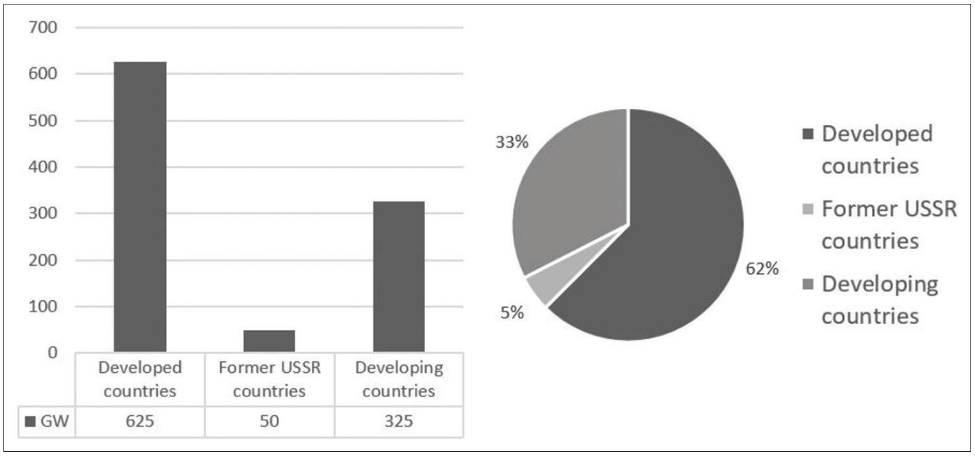
During the examination of further nuclear energy development, a global development strategy that envisages the activity of the USA, Japan, Korea, and some European countries in the construction of new reactors with a capacity of 1000 GW is created. The principal advantage of this strategy is the replacement of a significant number of production facilities that use fossil fuels and are a source of carbon emissions. Under this strategy, the predicted capacity of a reactor by 2050 will be 625 GW in developed countries, 50 GW in the countries of the former USSR, and 325 GW in developing countries. Figure 5 presents the corresponding results of this strategy implementation.

3. DATA ANALYSIS

According to the existing data for 2017, more than 500 million m^3 of various RW types (440 million m^3 of liquid and 72 million m^3 of solid) have been accumulated in Russia. The Russian classification divides RW into 6 Classes (Table 2).

In Russia, the current average annual volume of RW inventory is more than 3.4 million m³ (1.3 million m³ of them correspond to

Figure 5: Predicted reactor power



*Source: Developed by the author on the data retrieved from Nikitin et al. (2017)

Table 2: Radioactive waste classification*

Class	Type of RW	Characteristics	Method of disposal
1	Solid	Materials Equipment Products Immobilized liquid radioactive waste High-level waste with high heat release	Disposal in points of deep disposal of preconditioned radioactive wastes to reduce its heat release.
2	Solid	Materials Equipment Products Soil Immobilized LRW Ionizing radiation sources of the 1 and 2 hazard categories HLW with low heat release Intermediate-level long-lived waste	Disposal in points of deep disposal of nonpreconditioned radioactive waste without in order to reduce its heat exposure.
3	Solid	Materials Equipment Products Soil Immobilized LRW IRS of the 3 hazard category Low- and intermediate-level short-lived waste Low-level long-lived waste	Disposal in points of subsurface disposal of nonpreconditioned radioactive waste to be placed at the depth of 100 m.
4	Solid	Materials Equipment Products Soil Biological objects Immobilized LRW IRS of the 4 and 5 hazard categories LILW-SL LLW-LL	Near surface disposal at the same level with ground surface
5	Liquid	Organic and inorganic liquids Pulps Sludges LILW-SL LLW-LL	Deep geological disposal
6	-	RW generated during mining and processing of uranium ores, as well as during the implementation of activities not related to the use of atomic energy while mining and processing minerals and organic materials with a high content of natural radionuclides	Disposal in points of subsurface disposal of nonpreconditioned radioactive waste

*Source: Developed by the author on the data retrieved from Federal state unitary enterprise 'National Operator for Radioactive Waste Management' (2018) solid and 2.1 million m³ to liquid waste), which are being buried in about 1200 final storages. Most of the RW repositories are located at the facilities of Rosatom State Nuclear Energy Corporation (Figure 6).

These days, liquid radioactive waste (LRW) is generated not only at NPPs (about 4 thousand m³ per year) but also at uranium mining enterprises and the nuclear weapons complexes (about 850 thousand m³). The bulk of solid radioactive waste (SRW) is concentrated at uranium mining enterprises (about 65,363 million m³), at nuclear power plants (7.1 thousand m³ per year), the Mayak nuclear weapons complex (4.5 thousand m³ per year) and the Mining and Chemical Combine (2.25 thousand m³ per year). According to the data presented in Figure 7, it can be argued that the largest storage facility in Russia is the Mayak nuclear weapons complex. Besides, a considerable part of SRW and LRW is also buried by the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) in Sarov and the All-Russian Scientific Research Institute of Technical Physics (VNIITF) in Snezhinsk (Samarov et al., 2016; Sorokin and Pavlov, 2019).

According to the Federal Law on Radioactive Waste Management and Introduction of Amendments in Certain Legal Acts of the Russian Federation dated July 11, 2011, and the Federal Law on RW treatment dated March 20, 2012, a specialized organization responsible for disposal of RW in Russia was established. This organization, called National operator for RW treatment, is responsible for (Figure 8):

- Ensuring the safe management of RW accepted for disposal;
- Ensuring the closure of burial sites;
- Making predictions about the burial volumes;
- Informing the civilians, state bodies, and local government on safety issues in the RWM and on the radiation situation;
- Maintaining all necessary reports on work already done.

In the Russian Federation, RW storage and processing facilities are financed from the government and various private funds. However, the costs for disposal are paid in advance by nuclear waste producers, according to the corresponding tariffs. If RW production is not regular, payments should be made upon the RW transfer. Besides, the polluters should additionally pay for preparing the RW for transportation and disposal (Alekseenko et al., 2018; Bogoviz et al., 2020; Boyarinov, 2018; Kapustin and Grushevenko, 2018; Semin et al., 2019). Figure 9 describes a financial model for RWM in the Russian Federation.

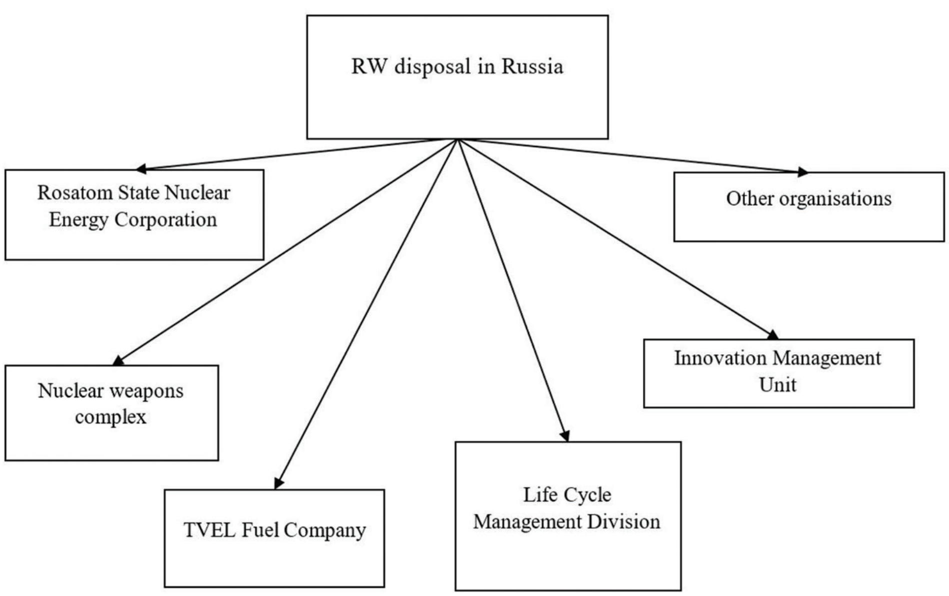
The general income, allowing the government and private funds to finance the RW storage and processing, is formed at the expense of the payment of RW producers for nuclear waste transfer to burial. The tariffs for RW disposal, established by the Ministry of Natural Resources and Ecology of Russia, are reviewed below (Figure 10). The disposal cost of Class 5 RW was not taken into account since it is set individually for the various nuclear waste producers.

The methodology for calculating storage cost is developed under the Resolution of the Government of the Russian Federation on the Procedure for the State Regulation of Radioactive Waste Disposal Tariffs. The cost of implementing the production program for the RW repository include:

- Expenses for disposal site closure and its postclosure maintenance;
- Costs for the construction of new disposal sites;
- Compensation of the property value of storage and repository facilities transferred to the governing body's ownership.

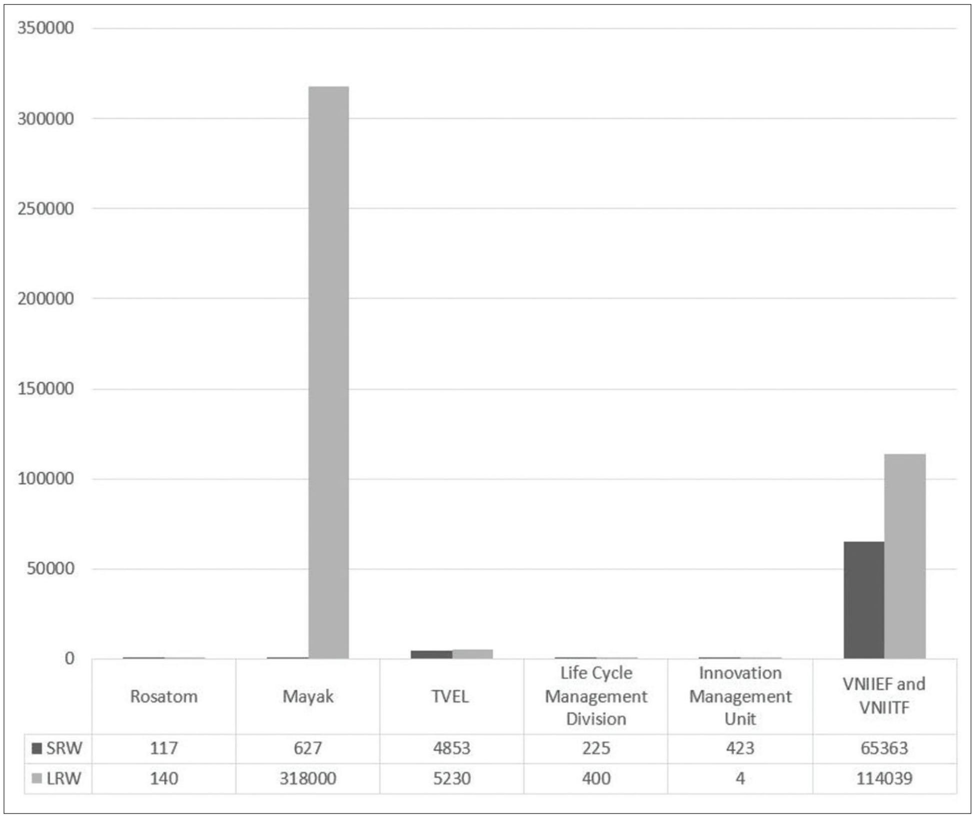
Given the long-term regulatory parameters, for classes 1-4, the tariff is calculated, taking into account the construction of new and the closure of old RW disposal sites. In turn, the method of economic feasibility and the indexing method were used to calculate tariffs for classes 5 and 6. During the assessment of nuclear energy production efficiency, the cost for RW disposal of

Figure 6: RW disposal in Russia



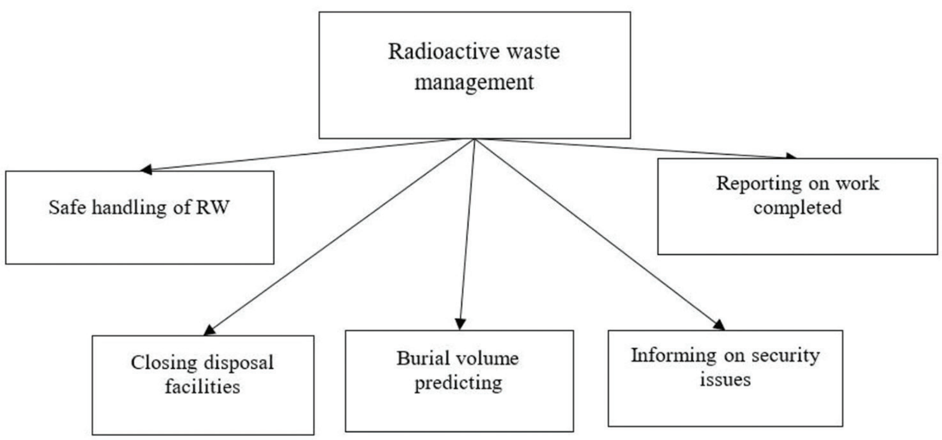
*Source: Developed by the author on the data adapted from Nikitin et al. (2017)

Figure 7: RW location at storage facilities



*Source: Developed by the author on the data retrieved from Federal state unitary enterprise "National Operator for Radioactive Waste Management" (2018)

Figure 8: RWM in Russia



*Source: Developed by the author on the data retrieved from Nikitin et al. (2017)

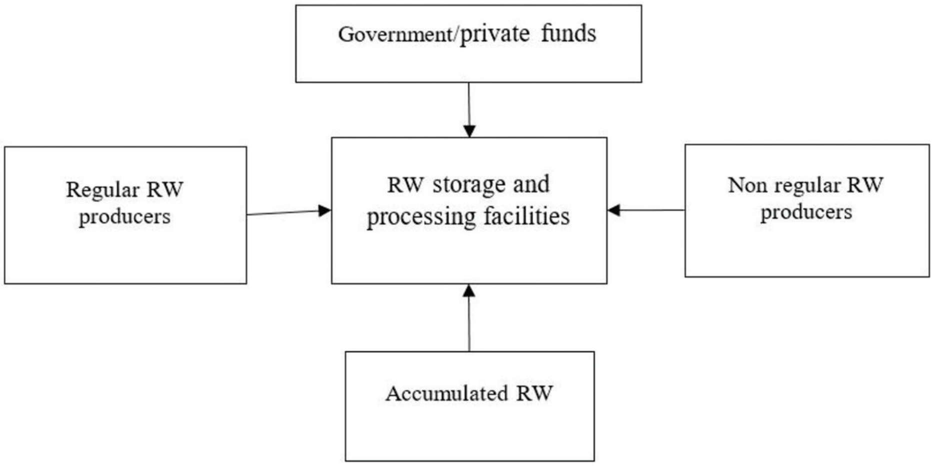
a power reactor was not taken into consideration (Barinov et al., 2016; Belokrylova, 2018; Orazalin and Mahmood, 2018; M. Sanders and C. Sanders, 2019).

The calculations show that RW storage in Russia is much cheaper, mainly due to the less stringent environmental regulations. Consequently, for many countries, the storage of nuclear waste in Siberia would be more affordable and less dangerous than in their own land. Even though the Russian Federal Act on Production and Consumption Waste prohibits the import of nuclear waste for burial or neutralization, at the end of 2019, 600 tons of RW were delivered from Germany to the Russian Federation. As a result, the current state of RW storage in Russia remains a matter of great concern.

4. RESULTS AND DISCUSSION

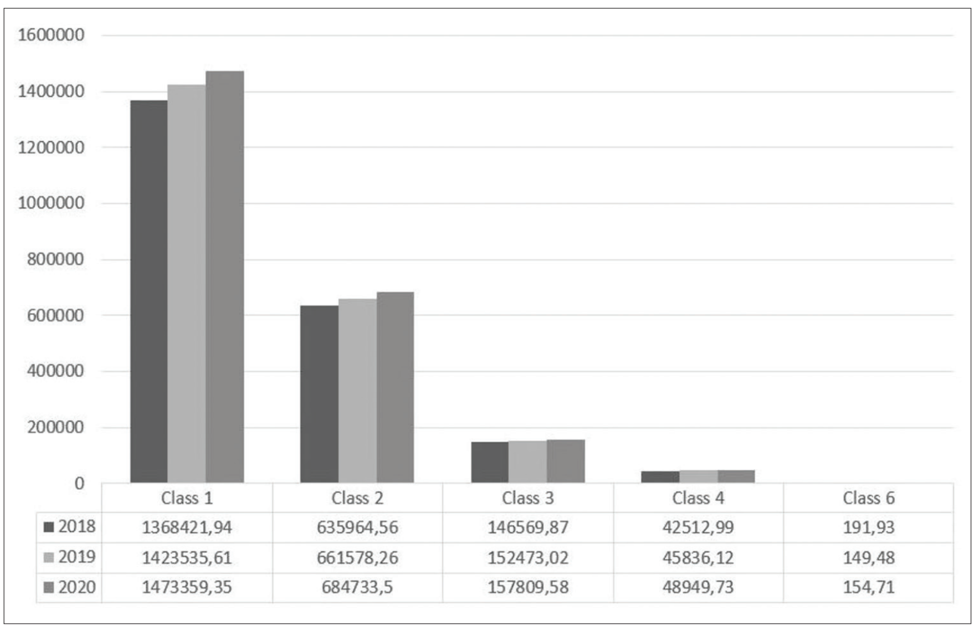
According to the results achieved, several models that characterize the financing and management of RW storage and disposal are developed. The first model is based on the 4E framework of Economy, Efficiency, Effectiveness and Equity. Efficiency assesses the compliance of the activities of RW storage and processing

Figure 9: The financial model for RWM



*Source: Developed by the author on the data adapted from Federal state unitary enterprise "National Operator for Radioactive Waste Management" (2018)

Figure 10: RW storage cost



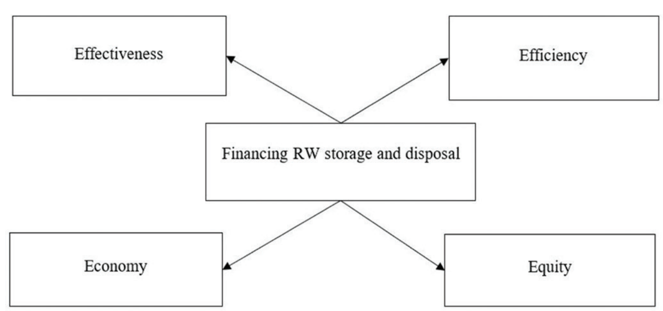
*Source: Developed by the author on the data retrieved from Federal state unitary enterprise "National Operator for Radioactive Waste Management" (2018)

facilities with the goals and state programs, as they are achieved and implemented. Effectiveness calculates the profitability of RW storage and disposal. Economy minimizes the cost of resources used or required during the RW storage, while Equity refers to whether the long-term RW disposal guarantees safety for people (Figure 11).

The focus on the implementation of relevant government programs and principles of global sustainable development, as well as the international partnership in the creation of RW storage and disposal strategies, will contribute to efficient financing (Figure 12).

The second model for managing the nuclear energy sector is based on LRD with the use of a predictive approach (Figure 13). Within this adapted LRD model, necessary prerequisites for a further cost prediction of RWM are analyzed.

Figure 11: The 4E framework for RW storage and disposal

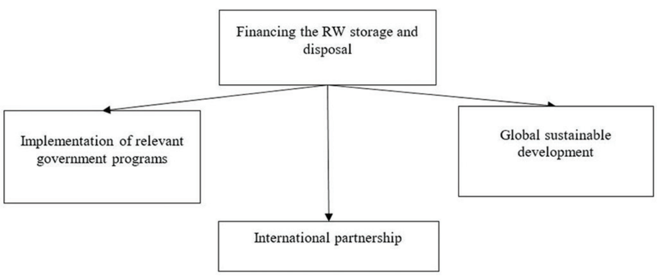


*Source: Developed by the author

The LRD model is based on the mechanism of interaction between production, marketing, and management assets in developing and developed countries. The following peculiarities of the proposed model can be distinguished:

1. Ability to optimize taxation by limiting the risks that enterprises and distributors assume in the process of intra-group international operations (limiting risks can be imposed both on intra-group distributors, associated with the processing of nuclear energy products, and on external distributors);
2. Possibility to control distributors from developed countries to track logistics, and company managers to track daily business processes.

Figure 12: Financing of RW storage and disposal: principles for sustainable development



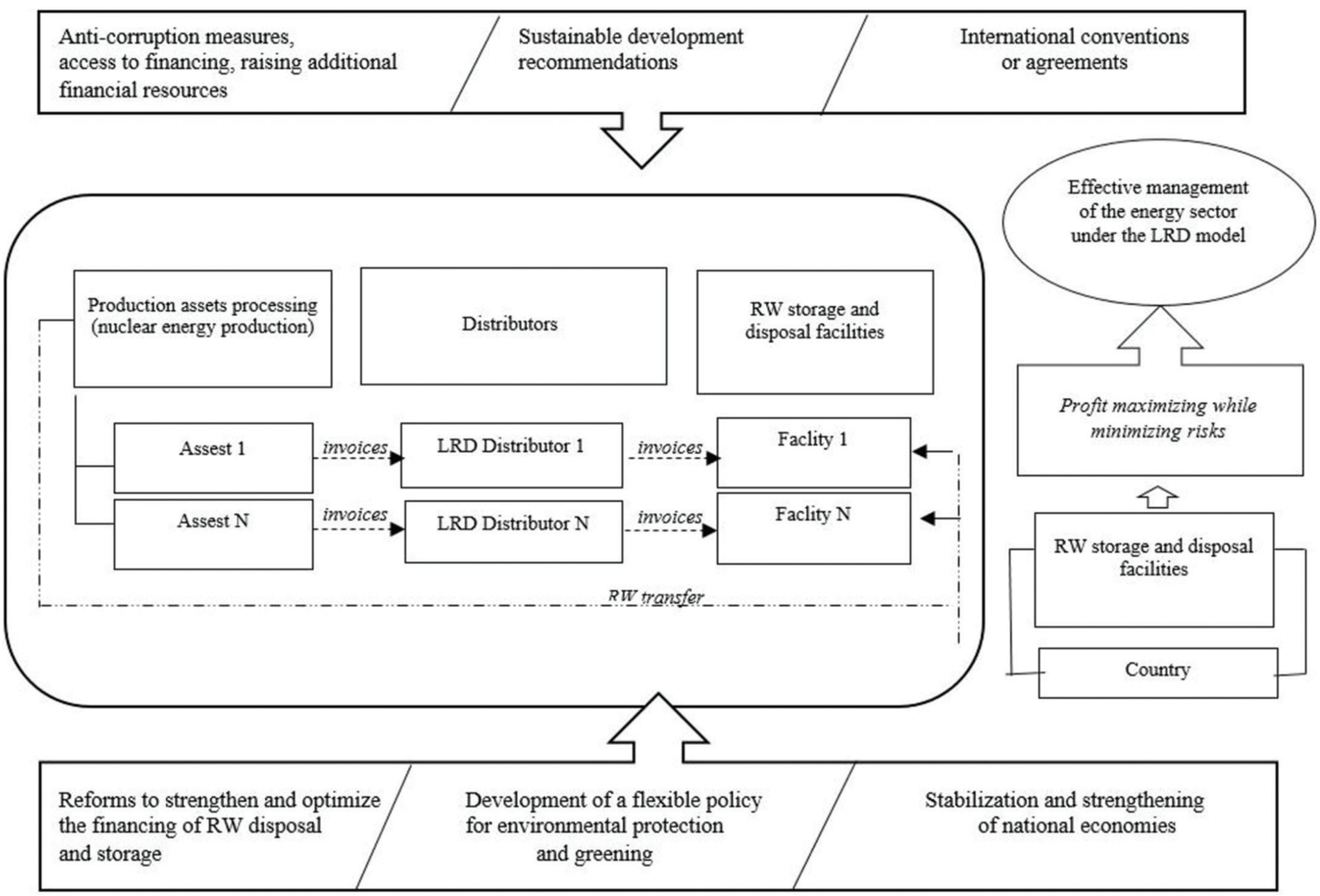
*Source: Developed by the author

The adapted LRD model can be applied to predict the expenses for RWM, which depend on a fixed and variable cost, as well as on the economic and political situation in the country. The developed tariff formation model somewhat corresponds with already existing innovative tariff models, valid for 5 and 6 classes of waste, since it takes into account both investment and production components. The implementation of the modified LRD model will contribute to a lower probability of speculative taxation schemes application, artificial profit reduction, shifting profit to low-tax jurisdictions, and protecting the political and economic interests of the country where production is located.

Through the predictive approach and adoption of the LRD model with additions and modifications, this study provides an innovative approach to obtain more accurate results in contrast to the absence of any schemes, descriptions, and methods. Even though the adapted LRD model is new, one should not diminish its effectiveness within the international nuclear sector. Despite the fact that the description of the structured financing process can be found in the latest industry newsletters and bulletins, no concrete prediction for the cost of RW disposal in Russia was found.

As shown by various studies related to the financing of RW storage and disposal, in the countries, where nuclear energy is coordinated by the public sector (in Russia, Germany, and Bulgaria), tariffs

Figure 13: The model for managing the nuclear energy sector



*Source: Developed by the author

are set by the government. When in developed countries, the companies can create a pricing policy for RW disposal services independently (Agency for Natural Resources and Energy, 2016; Balogh and Jámbor, 2017; Brunnengräber and Schreurs, 2015; Edwards et al., 2019; Hong et al., 2018). Researchers are convinced that new projects and technologies proposed by the Russian Federal Agency on Atomic Energy can cause a high risk. For this reason, the implementation of various nuclear military programs, as well as the construction of new NPPs and the extension of their operating life, is regarded very negatively. The lack of an efficient RWM system provides environmental risks and prevents effective waste disposal. Thus, scholars reasonably emphasize the importance of applying more relevant business models for NPPs' funding (İskenderoğlu and Akdağ, 2019; Kim, 2019; Naser, 2015; Ochoa et al., 2018; Şahin and Şahin, 2018). Consequently, the issues discussed in the current work may constitute the object of future studies.

5. CONCLUSION

The further development of nuclear power is possible since it is an important carbon-free energy source. Nevertheless, atomic energy involves a comprehensive solution to the problem of waste management. Although many nations are phasing-out nuclear power, not a single country in the world has completed a full closure cycle. Consequently, neither the actual dates nor the prices for the closure of NPPs are yet understood. World practice reveals that the most suitable option for further storage of RW is its disposal in designated sites. Even though the innovative solutions that can guarantee the safety of all stages of waste management, the problem of optimizing the financial component remains unsolved.

The results of the study revealed an extremely high degree of dependence between the implementation of new programs for RWM and the increase in the economic efficiency of nuclear energy. On the one hand, an advanced RWM will reduce government expenditures and risks, as well as improve the management of the entire process and profitability. On the other hand, the costs for nuclear power may increase due to the financing of programs for RW storage and disposal.

Unfortunately, there is no evidence on the effectiveness of RW disposal and storage in Russia and no is soon expected. Consequently, there is enough time to compare concepts for RW disposal forecast**.** Current models of RWM highlight the significance of developing both the innovative component and market relations, and allow one to make predictions on the change of priorities in favor of developing countries.

For models of nuclear power sector development to be successfully implemented, it is required to protect international economies from the dependence of national currencies on the dollar, political instability, and weak tax legislation. First of all, measures must be taken to strengthen and optimize tax systems and tariff setting. Besides, it is necessary to develop and implement a flexible policy for protecting property rights to strategic energy resources. These days, a high degree of involvement of developing countries in counteracting the artificial profits shift to low-tax locations may be seen. It is considered as a good practice since it provides the return of money to the national budget and promotes the implementation of international law in the legal and tax systems of developing countries. All the solutions presented above will not only attract foreign investment but also contribute to the development of the economy.

The developed LRD model is proved to be universal and can be applied in the management of atomic energy branch enterprises. The modified model is aimed at enhancing the performance of nuclear enterprises at a global level. Therefore, it can be applied to increase profits from nuclear power production and improve RW storage and disposal.

REFERENCES

Abramov, A.A., Dorofeev, A.N. (2017), The current state and prospects of the RW management system development in the Russia federation. Radioactive Waste, 1, 10-21.

Agency for Natural Resources and Energy. (2016), Energy White Paper 2015. Available from: http://www.enecho.meti.go.jp/about/whitepaper/2015html. [Last accessed on 2020 Feb 27].

Alekseenko, V.A., Bech, J., Alekseenko, A.V., Shvydkaya, N.V., Roca, N. (2018), Environmental impact of disposal of coal mining wastes on soils and plants in Rostov oblast, Russia. Journal of Geochemical Exploration, 184(B), 261-270.

Balogh, J.M., Jámbor, A. (2017), Determinants of CO_2 emission: Aglobal evidence. International Journal of Energy Economics and Policy, 7(5), 217-226.

Barinov, V.A., Isaev, V.A., Lisitsyn, N.V., Manevich, A.S., Usachev, Y.V. (2016), Development of electric power industry, providing energy support for developing systems of Siberia and Far East economics. Energy Policy, 1, 20-25.

Belokrylova, E.A. (2018), Renewable energy sources: Regulations in the Russian federation, In: Martínez, L., Kharissova, O., Kharisov, B., editors. Handbook of Ecomaterials. Switzerland: Springer, Cham. p1-21.

Bogoviz, A.V., Lobova, S.V., Alekseev, A.N. (2020), Current state and future prospects of hydro energy in Russia. International Journal of Energy Economics and Policy, 10(3), 482-488.

Boyarinov, A. (2018), The stimulation of renewable energy source usage: Economic mechanism. In: Syngellakis, S., Brebbia, C., editors. Challenges and Solutions in the Russian Energy Sector: Innovation and Discovery in Russian Science and Engineering. Switzerland: Springer, Cham. p209-216.

Brunnengräber, A., Schreurs, M. (2015), Nuclear Energy and Nuclear Waste Governance Perspectives after the Fukushima Nuclear Disaster, in Nuclear Waste Governance. Wiesbaden: Springer. p47-78.

Edwards, M.W., Schweitzer, R.D., Shakespeare-Finch, J., Byrne, A., Gordon-King, K. (2019), Living with nuclear energy: A systematic review of the psychological consequences of nuclear power. Energy Research and Social Science, 47, 1-15.

Elektrovesti. (2017), Who have Already Abandoned the Peaceful Atom, and Who are Still Going to Do So. Available from: https://www.elektrovesti.net/53115_kakie-strany-uzhe-otkazalis-ot-mirnogo-atoma-i-kakie-eshche-sobirayutsya-eto-sdelat. [Last accessed on 2020 Feb 27].

Federal State Unitary Enterprise National Operator for Radioactive Waste Management. (2018), Tariffs for the Disposal of Radioactive Waste for the Period from 2018 to 2022. Available from: http://www.norao.ru/about/tarify. [Last accessed on 2020 Feb 27].

Hong, S., Qvist, S., Brook, B.W. (2018), Economic and environmental costs of replacing nuclear fission with solar and wind energy in Sweden. Energy Policy, 112, 56-66.

International Atomic Energy Agency. (2020), Available from: https://www.iaea.org. [Last accessed on 2020 Feb 27].

İskenderoğlu, Ö., Akdağ, S. (2019), Comparison of nuclear energy and renewable energy consumption in terms of energy efficiency: An analysis on the EU members and candidates. International Journal of Energy Economics and Policy, 9(6), 193-198.

Kapustin, N.O., Grushevenko, D.A. (2018), Exploring the implications of Russian energy strategy project for oil refining sector. Energy Policy, 117, 198-207.

Kim, K. (2019), Elasticity of substitution of renewable energy for nuclear power: Evidence from the Korean electricity industry. Nuclear Engineering and Technology, 51, 1689-1695.

Naser, H. (2015), Can nuclear energy stimulates economic growth? Evidence from highly Industrialised countries. International Journal of Energy Economics and Policy, 5(1), 164-173.

Nikitin, A., Ozharovsky, A., Kolotov, A., Talevlin, A. (2017), RAW Handling in Some EU Counties and Russia. Sweden, Finland, France, Germany, Russia: Public Participation. Available from: https://www.bellona.ru/publication/rao-eu-russia. [Last accessed on 2020 Feb 27].

NOAA's National Centers for Environmental Information. (2018), Global Climate Report 2018. Available from: https://www.ncdc.noaa.gov/sotc/global/201810#temp. [Last accessed on 2020 Feb 27].

Obregon, L., Orozco, C., Camargo, J., Duarte, J., Valencia, G. (2019), Research trend on nuclear energy from 2008 to 2018: A bibliometric analysis. International Journal of Energy Economics and Policy, 9(6), 542-551.

Ochoa, G.V., Forero, J.D., Quiñones, L.O. (2018), Research progress on sustainable energy: A pest study. Contemporary Engineering Sciences, 11(71), 3523-3530.

Orazalin, N., Mahmood, M. (2018), Economic, environmental, and social performance indicators of sustainability reporting: Evidence from the Russian oil and gas industry. Energy Policy, 121, 70-79.

Ozturk, I. (2017), Measuring the impact of alternative and nuclear energy consumption, carbon dioxide emissions and oil rents on specific growth factors in the panel of Latin American countries. Progress in Nuclear Energy, 100, 71-81.

Pioro, I. (2013), Nuclear power as a basis for future electrical-energy generation in the world. In: Proceedings of ICAPP 2014. p2387-2400.

Polozkiva, A. (2016), Political Confrontation Concerning Belgian Nuclear Power Plants. Moscow: Regnum. Available from: https://www.regnum.ru/news/economy/2149977.html. [Last accessed on 2020 Feb27].

Radhakrishnan, S., Erbis, S., Isaacs, J.A., Kamarthi, S. (2017), Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. PLoS One, 12(3), e0172778.

Şahin, S., Şahin, H. (2018), Nuclear energy. In: Comprehensive Energy Systems. Vol. 1-5. Amsterdam: Elsevier.

Samarov, V.N., Nepomnutshy, V.Z., Komleva, E.V. (2016), Russian modern of disposal of radioactive waste. Science Society State, 4(3), 15.

Sanders, M.C., Sanders, C.E. (2019), A world's dilemma upon which the sun never sets: The nuclear waste management strategy (Part II): Russia, Asia and the Southern Hemisphere. Progress in Nuclear Energy, 110, 148-169.

Semin, A.N., Ponkratov, V.V., Levchenko, K.G., Pozdnyaev, A.S., Kuznetsov, N.V., Lenkova, O.V. (2019), Optimization model for the Russian electric power generation structure to reduce energy intensity of the economy. International Journal of Energy Economics and Policy, 9(3), 379-387.

Sorokin, V.T., Pavlov, D.I. (2019), The cost of radwaste disposal: A foreign assessment. Radioactive Waste, 1(6), 46-55.

Wang, Q., Li, R., He, G. (2018), Research status of nuclear power: A review. Renewable and Sustainable Energy Reviews, 90, 90-96.

Wang, X., Han, Y., Zhang, J., Li, Z., Li, T., Zhao, X., Wu, Y. (2019), The design of a direct charge nuclear battery with high energy conversion efficiency. Applied Radiation and Isotopes, 148, 147-151.

World Nuclear Association. (2020), Nuclear Power in the World Today. Available from: https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx. [Last accessed on 2020 Feb 27].