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ENGINEERING FORMATION OF A NUCLEAR POWER PLANT SAFETY SYSTEM

Alexander Khorin
Department of Accounting, Analysis and Audit, Lomonosov Moscow State University
Moscow. Russia.

Oleg Pichkov
Department of International Economic Relations and External Economic, Moscow State Institute of International Relations
Moscow. Russia.

Alexander Brovkin
Accounting, Statistics and Audit Department, Moscow State Institute of International Relations,
Moscow. Russia.

Yulia Potanina
Accounting, Statistics and Audit Department, Moscow State Institute of International Relations,
Moscow. Russia.

ABSTRACT

At present, both in the world and in some countries, the issue of sustainable energy development and energy security is acute. The international community requires a conceptual approach to strategic planning, as well as to safe energy, since the rational use of natural energy resources by people is the main factor determining the level of modern civilization. One of the reasons for the technological reform of the power industry is the need to reduce greenhouse gas emissions. At the same time, nuclear energy (AE) is considered to be the most promising type of energy production, as it is more a "technological resource" than a natural one and does not depend on the geographical location of the country.

Key words: innovation, new construction.

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1. INTRODUCTION

From the analysis of many studies it is concluded that the AE under certain conditions can become a source of large-scale, clean and safe energy for many centuries, thereby solving part of the energy problem. But for this it is necessary to master and implement a series of fast neutron reactors (bn) of commercial level and to establish an infrastructure for the processing of irradiated and production of fresh fuel of bn reactors on an industrial scale, that is, to implement a closed nuclear fuel cycle (SNF) [1].

Work in the field of system and scenario studies of long-term development of nuclear energy is actively supported by the IAEA and Rosatom. Scenarios formulate environmental requirements and long-term resource and technological goals of nuclear power systems, and system studies allow to cover the composition of research areas and correctly assess nuclear power systems, taking into account their specific features of the time and material and technical plan. Examples of such studies, which are widely used scenarios and system analysis, can serve as a joint, including with Russia, INPRO projects: SYNERGIES and KIND; work on multi-criteria assessment of the competitiveness of the bn-1200 power unit.

2. EXPERIMENTAL SETUP

From the perspective of mathematical modeling of material flows is a necessary element in the problems of energy development, a tool of strategic planning.

Currently, the IAEA MESSAGE software package is widely used to predict the development of the energy system and to obtain the resulting summary balances of energy consumption and production. The result of the program - the optimal structure of energy production under given constraints. The optimization criterion is the minimum of the costs for the development of the system for the entire forecast period. Software systems MESSAGE CYCLE, DESAE were used in the work of the international project INPRO — IAEA [2].

The software allows CYCLE under given scenarios input of thermal and fast reactors, power plants spent nuclear fuel processing to calculate the flow of nuclear materials and the various characteristics of the fuel at all stages of the nuclear fuel cycle (NFC) with the closure of the nuclear fuel cycle for uranium, plutonium and minor actinides.

Existing software products of similar purpose supported by the IAEA (NFCSS, MESSAGE, DESAE) do not currently have this capability. This can lead and leads to the wrong construction of scenarios for the development of nuclear energy. In this dissertation work, an attempt is made to improve the algorithms laid down in MESSAGE and to take into account the features of the closed fuel cycle of fast neutron reactors using preliminary calculations by the CYCLE code [3].

The MESSAGE software package solves the problem of linear programming.

The technical reactor characteristics and input data of the respective fuel cycles for scenario simulations in MESSAGE are presented in table 1 below.

The purpose of the study, set out in the second Chapter, is to maximize the approximation of the model of the flow of nuclear materials in the MESSAGE program to the results of the cycle calculation scenarios in the construction of scenarios for the development of nuclear energy based on fast and thermal neutron reactors. Verification of the implemented combined method was carried out in two stages [4].

At the first stage in the MESSAGE and the CYCLE was investigated in three simple script:

- commissioning, operation and withdrawal of one fast reactor;
- commissioning, operation of one thermal reactor and its withdrawal;
- commissioning of one fast and 10 thermal reactors, their operation and subsequent output.

At the second stage, one of the possible scenarios for the development of energy in Russia until 2100 was considered. The element base of the reactor Park was based on the data on the time of commissioning and the planned operating time of the existing and planned units of the Russian sample in accordance with the Energy strategy of Russia.

Figure 1 shows the output of the Russian phase II scenario. The results of modeling the regional model of AE development are obtained from the program complexes CYCLE and MESSAGE.

Figure 1-Russian scenario. SNF unloading from reactors

Figure 1 shows that the SNF discharged from the reactors differs by an average of 4% in the programs. The maximum deviation is 11% in 2013. Such deviation is due to the fact that in the CYCLE is used for detailed modeling of nuclear reactors, and MESSAGE average, the results of the CYCLE.

If there is no averaged data for the MESSAGE script, the difference in the calculation results is significant. This is most characteristic when accounting for plutonium in stock in global scenarios.

The performed computational modeling of the real scenario of AE development on the example of Russia has shown that the preparation of correct averaged data on reactor facilities and stages of NFC has a significant impact on the results obtained by the MESSAGE code.

International projects play an important role in promoting commercial Russian technologies on the world market. They allow specialists from different countries with different levels of development of innovative technologies to consider possible regional and global scenarios for the development of nuclear power plants, including taking into account inter-state relations. Therefore, the Chapter briefly shows the role of international projects in the development of innovative technologies and promotion of Russian technologies on the world market; the Russian INPRO project and its subsidiaries (joint) projects are presented in detail [5].

The main feature of INPRO is the flexibility of the project; the research topic is selected every two years. Other international projects the objectives are more tightly.

In the INPRO methodology, a holistic approach was used, which assumes the priority of the whole in relation to its parts: the whole is always more than the sum of its parts.

I have INPRO collaborative projects: INPRO□SYNERGIES and INPRO□ KIND.

They relate to the consideration of different scenarios for the development of countries and the world on the basis of innovative technologies.

The goal of the SYNERGY project is to study and analyze the possibilities of transition to sustainable nuclear power systems of the future, on the basis of regional cooperation. This transition is conditioned by the growing role of the economy, rational use of all types of resources, the possibility of solving the problem of SNF, the need to ensure international obligations of countries on non-proliferation of nuclear weapons, nuclear and physical security.

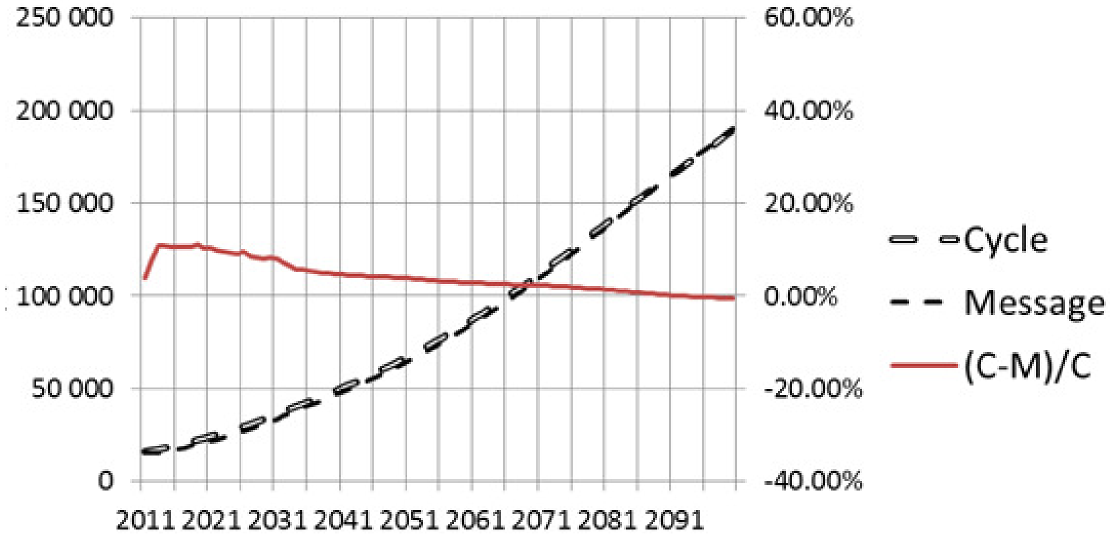

Figure 1 Russian scenario. SNF unloading from reactors

3. THEORETICAL ANALYSIS

3.1 Moving structures at the atomic site

The main purpose of the sensitivity analysis is to justify the rating of alternatives by demonstrating that small changes in the original data do not change the ranks of alternatives.

The study of the sensitivity of the structure of the scenarios of development of the Russian AE to changes in the main economic parameters was carried out within the framework of the MESSAGE software and on the basis of the tables 1-3 of the initial data available in the open domestic and foreign literature.

Figure 2 shows a graph of changes in the share of fast reactors in three scenarios:

- base 1, in the figures marked as " Base» [6];

- additional 2 with 100% increased fuel costs for the fast reactor, in the figure marked as " MOX=3580 $ / kg TM»;

- additional 3 with increased 4 times the fuel cost of a fast reactor, the figure is marked as"MOX=7160 $/kg TM".

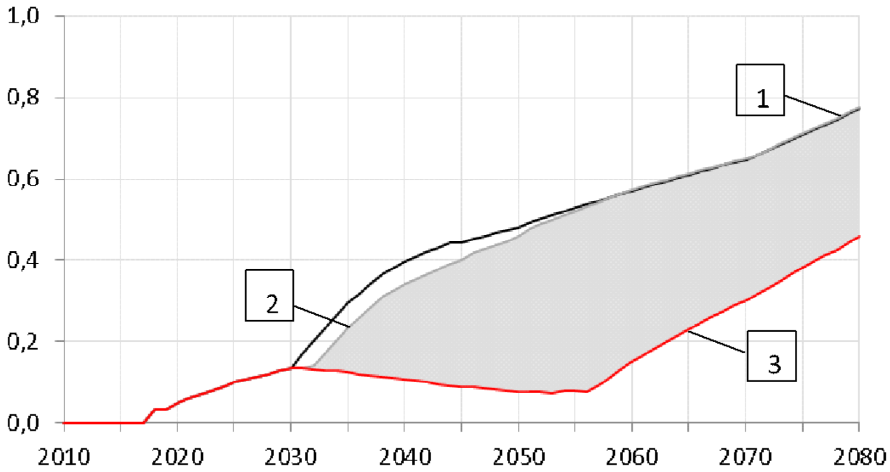

Figure 2 share of bn reactors in the basic and additional scenario 2,

Figure 2-share of bn reactors in the basic and additional scenario 2, 3 of the Russian nuclear power plants the Results presented in figure 2 show that with the increase in the cost of MOX fuel production, the share of fast reactors in the nuclear power industry is decreasing. It should be noted that this parameter is also sensitive to the scale of development of NPS. In addition, with an increase in the cost of MOX fuel to 3580 $/kg TM, it is clear that the share of fast reactors differs from the baseline scenario in the period from 2030 to 2060. After 2060 differences are insignificant.

In addition, the Chapter provides estimated scenarios for accounting for economic R & d costs; the thesis investigated more realistic scenarios for investment in research, in which R & d funding does not stop after the introduction of the first block of commercial nuclear power plants.

3.2. Additional research of innovative structures in the construction of atomic

The calculated studies for the considered groups of countries showed the advantages of mutually beneficial cooperation, which are expressed in reducing the amount of global SNF and the total saving of natural uranium subject to the non-proliferation regime (minimum plutonium in warehouses).

The global model of heterogeneous AE development according to the INPRO methodology (Association of countries into three groups on a non-geographical basis, taking into account the specifics of development) is as close as possible to the real picture of the world.

The first group of countries (NG1) includes countries with advanced fuel cycle technologies — nuclear technology developers. These include countries that consider SNF reprocessing and transition to AES through a closed fuel cycle and fast reactors in their AE development strategies.

The second group of countries (NG2) includes experienced users of nuclear technologies who do not plan to introduce innovative nuclear POWER plants in the near future. In the field of irradiated fuel management, they consider the open fuel cycle, i.e. storage and disposal of spent fuel.

The third group (NG3) includes "newcomer"countries. In these countries there are only reactors, and yet the infrastructure of the nuclear fuel cycle. These countries have not decided on a further fuel cycle strategy: they can choose either open NFC and disposal of irradiated fuel in the second group of countries, or reprocessing of spent fuel in the first group of countries.

The breakdown of countries into groups and determination of development scenarios of AE were made on the basis of analysis of long-term energy projections for each country on the basis of reliable sources (statements by governments at the conferences of the IAEA, forecasts AE IAEA, long-term national programs, strategies, and forecasts on the development of AE in the world's leading international energy agencies) [7].

The trends of development of cooperation in the field of nuclear power, considered in the model, are explained by the fact that only a few countries are technologically capable of providing all stages of the life cycle of nuclear power. For developing countries just starting their national nuclear programme, it is technically and economically difficult to establish and operate the entire nuclear fuel cycle on their own.

In developing the terms of reference for the new SYNERGIES project, it was noted that further research was needed on heterogeneous scenarios for the development of global nuclear power plants, which differ from the baseline (in GAINS) by a different ratio of capacities between groups of countries in order to demonstrate how the scale of development, priorities in the development of reactor and NFC technologies, the existing and planned infrastructure of the NG1 group countries can affect the strategies for cooperation in the provision of nuclear fuel cycle services.

According to the scheme in figure 3 and the inherent model assumption that 50% of the spent fuel from the reactors of the countries NG3 will be received for processing in the country NG1 and the remaining 50% will go into storage countries NG2. Such an arrangement allows the countries of the third group to continue to develop AE, while not having its own production facilities for spent fuel management.

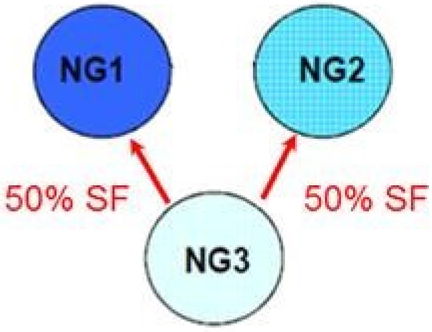

Figure 3 scheme of synergistic interaction of groups of countries NG3-NG1 and NG3—NG2

At present, the trend towards integration of groups of countries is more or less present at all stages of the nuclear fuel cycle, starting with the extraction of natural uranium. All this, as well as concern about non-proliferation, creates prerequisites for international cooperation.

It should be recognized that the development of scenarios for the global development of nuclear power is one of the most difficult tasks in the field of forecasting due to the influence of a large number of factors, including political and temporal [8].

In the course of the work, the results of modeling scenarios for the development of the world nuclear energy with independent and synergetic development in each of the three groups of countries were compared.

The calculations obtained 30 scenarios of AE development with key indicators for each scenario:

- the structure of generating capacity AE, the proportion of BR (figure 4);
- * total consumption of natural uranium;
- * separation works;
- fuel production;
- * fuel reprocessing;
- * plutonium accumulation and consumption;
- * spent fuel in storage (including cooled fuel).

Figure 4 is presented as an illustration of the calculation results. The scenarios are expected to reach 5,000 GW by 2100. The figure shows 5 pairs of columns. Each column represents the share of fast reactors in the 2030, 2050 and 2100 scenario in the NG1 region. If the columns in the pair do not match in height, there is an effect of the interaction. The names of the scenarios are shown on the right.

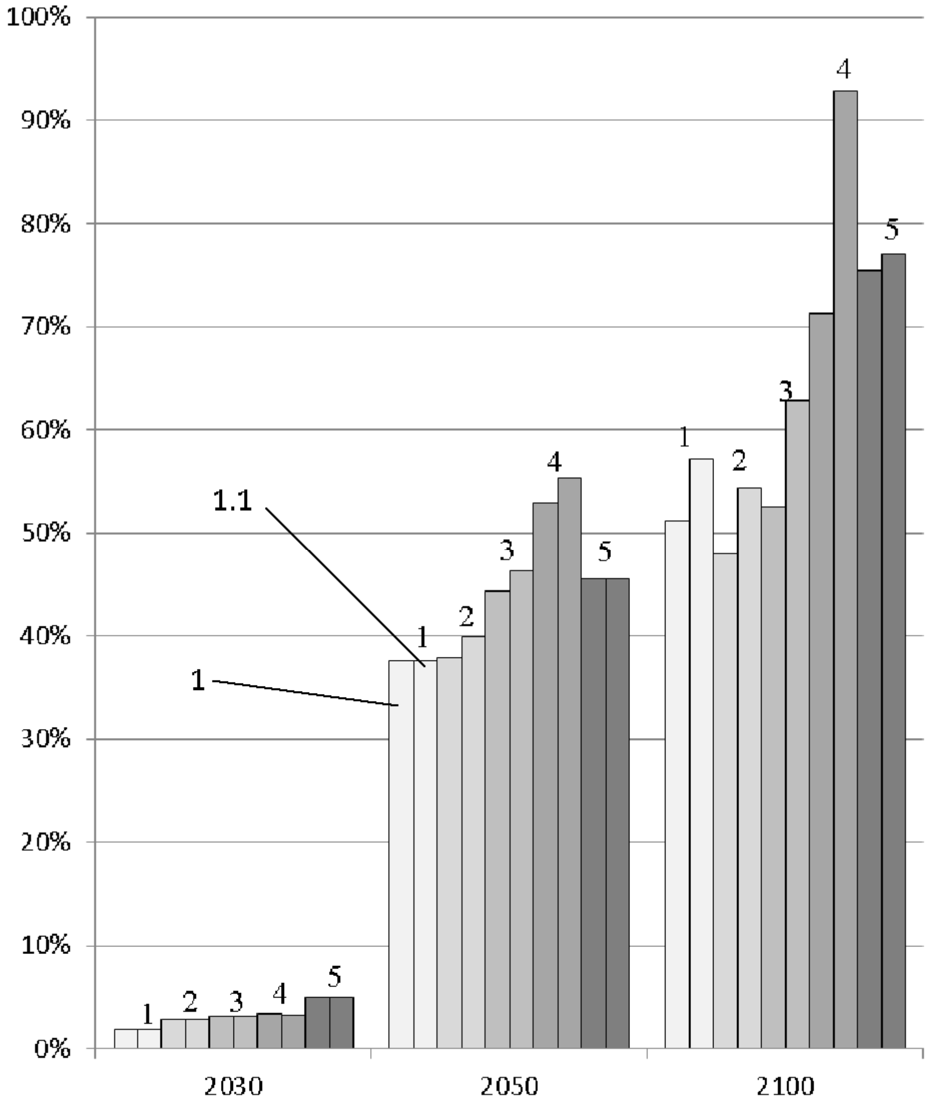

Figure 4 Proportion of BR in the structure of AE countries in the region NG1

Figure 4 shows that in the case of high growth of the world AE capacity (5000 GW by 2100) in all regional development scenarios up to 2030, inclusive, the share of fast reactors in the energy structure of NG1 countries does not depend on whether groups of countries interact or do not interact. However, after 2030 in the second, third and fourth scenarios, you may receive the interference effect caused by a marked increase in the proportion of BR in the countries of NG1. In 2100, the difference between the synergy scenario and the independent development scenario in these five scenarios is 6 %, 6,5 %, 10,4%, 21,6%. and 1.5 %, respectively, in the number of fast reactors. It can also be concluded from the figure that the share of BR in the structure of AES strongly depends on the scenario of capacity building in the first group of countries, as well as on the development of AES in the second group of countries. In General, by 2050, the share of BR in NG1 countries reaches (53-55) % (excluding and taking into account interaction), and by 2100, respectively, (71-93)%, that is, the share of synergy is 21.6% [9].

4. RESULTS AND DISCUSSIONS

The project "KIND" ("Key indicators for innovative nuclear power PLANTS") completed the development of a method of comparative evaluation of innovative nuclear power systems, which are planned for use on a commercial scale. It is shown that the comparative assessment of nuclear

POWER plants significantly depends on the tasks to which the system is focused (economy, readiness of technology for implementation, fuel supply of large-scale development of nuclear power PLANTS, waste management). The analysis of the sensitivity of the NPS potential to the weights of the selected key indicators is presented.

The competitiveness of the BN1200 nuclear power system does not mean that the nuclear power PLANT should be the cheapest option for generating electricity in the country. Decision-making can be influenced by a large number of trends: security of energy supply, stability of annual costs and diversification of energy supply, i.e. energy balance of different technologies. Strategic development and diversification through nuclear technology can also play a significant role. Environmental impacts, both positive and negative, of prevented harmful emissions, safety, sustainability, waste management, use of internal resources such as mineral and human resources, capacity utilization, public opinion and therefore political stability are factors influencing the assessment of the nuclear power system potential.

A tool that can take into account both economic and non-economic factors of production is a system analysis. In the methodology of system analysis, there are two alternative ways of accounting for non-economic factors: in the framework of a single-criteria model and a multi-criteria model.

In the first of them, heterogeneous indicators characterizing different facets of the studied phenomenon are given to one-a monetary indicator. Examples of this approach are the works presented in chapters 2-4 of the thesis.

In the second – the same indicators act as independent from the economy independent factors, which should be given a certain importance in relation to the economic factor, and with this significance they should be considered in the preparation of the decision.

Taking non-economic factors into account in monetary terms is extremely difficult, not to mention the practical side of implementing such an approach. A number of countries are now attempting to implement environmental accounting by imposing taxes to limit the harmful effects of enterprises on the environment or, conversely, subsidizing environmentally friendly industries to stimulate them. However, this activity has not acquired a firm and universal legislative basis and can hardly be taken as a basis for the analysis and evaluation of energy systems in order to select their optimal combination in the future.

5. CONCLUSION

1. An improved technique for modeling of HSCI in the optimization program of energy planning MESSAGE, which takes into account the factor of multi-isotope Pu, is developed and justified. The main purpose of the method was to build a more accurate model of the balance of materials in the optimization program "MESSAGE".

When modeling a closed nuclear fuel cycle, the algorithm for using the MESSAGE economic optimization program must be iterative and combined. The MESSAGE tool, being more flexible, can take on building a set of test scripts. After the first preparatory iteration CYCLE code may be used to adjust the flows of nuclear materials in the calculation of the result script according to the program MESSAGE.

2. We explore the sensitivity scenarios of the development of nuclear energy of Russia to the basic economic parameters given the factor of mnogopoliarnosti Pu. On the basis of the calculated options, the requirements for the accuracy of the determining economic parameters used in the calculation justification of the competitiveness of nuclear technologies are set.

3. Within the framework of the IAEA INPRO—SYNERGIES international project, calculated studies of global scenarios of regional development of the world were carried out. Calculations have shown:

(a) the share of BR in the first region of countries (NG1) depends not only on the rate of growth of installed capacity in the region, but also on the growth of capacity in NG2 countries, reaching 71% by 2100 in the scenario of high growth in the second region without interaction.

(b) In the scenarios of joint development groups of countries, nuclear energy appears the synergy effect, in which the proportion of BR is higher by 21.5% than in the separate development of the regions of the countries for the scenario with high growth capacity by the year 2100.

(c) with the independent development of AE in the regions, the number of SNF decreases only in the first region, and increases in the second and third regions.

(d) Reduction of natural uranium requirements through BR introduced in the first region makes the use of uranium more cost-effective for the second and third regions.

(e) the total amount of spent fuel in all regions by 2100 will be the minimum in synergetic scenario 1.

REFERENCES

[1] Afonso, C. and Rocha, C. Evaluation of the economic viability of the application of a trigeneration system in a small hotel. *Futur Cities Environ,* **2**, 2016, pp. 2

[2] Varaksin, A. Y., Arbekov, A. N. and Inozemtsev, A. A. The trigeneration cycle as a way to create multipurpose stationary power plants based on conversion of aeroderivative turbofan engines. Dokl Phys, 59, 2014, pp. 495-497.

[3] Lozano, M. A., Carvalho, M. and Serra, L. M. Erratum to: Tackling environmental impacts in simple trigeneration systems operating under variable conditions. Int J Life Cycle Assess, 19, 2014, pp. 1468-1472.

[4] Fong, K-F. and Lee, C-K. Application of Desiccant Cooling to Trigeneration Systems. Ventilating, and Air-Conditioning Systems, 1, 2017, pp. 257-269.

[5] Abramov, R.A., Sokolov, M., Surilov, M., Morozov, I. The simulation of the development of innovation systems in the countries- participants of the union state. International Journal of Mechanical Engineering and Technology, 7, 2018, pp. 1112–1119.

[6] Sharma, D., Khatri, K. K., Soni, S. L. and Tanwar, D. Experimental Investigation of CI Engine Operated Micro-Trigeneration System Fuelled with Karanj Methyl Ester-Diesel Blend. Sustainability in Energy and Buildings, 1, 2011, pp. 159-168.

[7] Ahmet, L. and Karim, S. Solar Trigeneration: Electricity, Cooling and Steam from the Sun. Renewable Energy, 1, 2017, pp. 87-94.

[8] Acikkalp, E,. Balli, O., Yamik, H. and Aras, H. Energy and Exergy Analysis of a Trigeneration Facility with Natural Gas Engine. Progress in Sustainable Energy Technologies, 2, 2014, pp. 621-636.

[9] Abramov, R.A. Regional economic policy based on industrial sector clustering in the context of sustainable development. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7, 2016, pp. 2100-2106.