DOI: 10.18372/2310-5461.48.15090

UDC 504+620.9:62-6

M. M. Radomska, PhD, associate professor
National Aviation University
orcid.org/0000-0002-8096-0313
e-mail: m.m.radomskaya@gmail.com;

M. S. Ponomarenko
National Aviation University
orcid.org/0000-0001-9575-3651
e-mail: azallia567@gmail.com;

T. I. Nazarkov
National Aviation University
orcid.org/0000-0002-9971-9423
e-mail: tnazarkov28@gmail.com

THE ASSESSMENT OF UKRAINE'S PROSPECTS FOR THE FOSSIL FUELS PHASE-OUT

Introduction

Commercial energy, or energy sold on the marketplace, is what we are using to complement the energy of the sun. Most business energy is currently derived from the extraction and burning of non-renewable power resources from the Earth's crust, mainly carbon-containing fossil fuels – oil, natural gas, and coal. Approximately 90 % of the world's business energy consumption comes from non-renewable energy resources, 85 % from fossil fuels (oil, natural gas and coal) and 5 % from nuclear power [1]. Compared to most other options, non-renewable fossil fuels are commonly used because they are abundant, transportable, and inexpensive. Since 1982, world power consumption has been rising [2].

There is a strong relationship between energy consumption and economic growth. Likewise, the relation between growing energy generation to meet the demand and pressure on the environment is also clear. Energy consumption is strongly correlated with climate changes, soil and air pollution, biodiversity reduction and natural environment quality degradation [3; 4]. The previous experience proves, that the demand for energy is not going to decrease: even the economic crisis of late 2010s has showed that the trend is still positive, and it is a negative factor for environment safety [5]. Thus, substitution of fossil fuels, which are both running out and damage the environment would be a necessary measure for securing further development and progress.

Problem statement

Ukraine acquired a strong energy industry following the collapse of the Soviet Union. However, this industry is now in a critical condition because of inefficient policy. The decline of energy assets and absence of investment, low energy efficiency and dependence on the import of energy carriers are among the primary issues. Ukraine is one of the world's top least energy-efficient nations [6; 7]. The specific energy consumption per unit of produced good or service in Ukraine is triple of that in Poland, Czech Republic and Slovakia [8].

The present power mix in Ukraine depends strongly on fossil fuels and nuclear power, which together account for more than 90 % of the country's power supply. At the moment, the complete share of renewables is around 8 % (approximately 6 % is hydropower) [8].

Ukraine is one of Europe's largest nuclear power manufacturers: it has 15 nuclear power plants with a capability of over 13 gigawatts, which means that the nation derives around 60 % of its electricity from nuclear power [9].

The Energy Strategy of Ukraine for the period up to 2035 is standing on the position of gradual expansion of nuclear potential of the country by building new blocks and substitution of those, whose service term expires [10]. At the same time, the work on extending equipment life at the existing blocks is also conducted, relying on the results of technical audits.

The reserves of fossil fuels in Ukraine are quite considerable, but they don't cover the needs. In terms of coal reserves, Ukraine ranks 7th in the globe, 12th in terms of uranium and 29th in terms of natural gas.

The lack of investment in exploration, processing and energy effectiveness and complex bureaucratic procedures hinder the growth of the energy industry in Ukraine [11].

Domestically extracted oil volumes are falling each year, and Ukraine is highly dependent on imported petroleum. Most oil refineries in the country are not in operation [9]. Natural gas was mainly supplied from the Russian Federation and is currently substituted with coal and other fuel alternatives. The government is keeping the line of revival and expansion of gas extraction processes within the country, based on its available reserves. This noble task is technically complicated due to lack of modern technologies and investments [12].

Since the 2014 coal has been considered a possible guarantor of Ukrainian independence, due to potential reserves available in the country. But the improvement of coal extraction needs considerable investments, as the dominant share of mines is outdated and dangerous. But domestic reserves have low attractiveness for international investors, particularly in view of new deposits of high-quality coals (Mozambique, Mongolia and Indonesia) and maximal environmental pressure from the use of coal as a fuel [13].

So, Ukraine, just like other countries of the world faces the need to find new sources of energy. Thus, to stimulate the operation and development of renewable energy sources in Ukraine, a "green" tariff, or special feed-in tariff, was introduced in 2009. The feed-in tariff for green projects in Ukraine is one of the highest in the world, which makes investment into this sector very attractive. And during the next years the share of renewable energy sources in Ukraine reached approximately 5 % of total [14]. Considering the global trend towards the reduction of fossil fuels role in favor of alternative energy generation practices it is now a topical question, whether there is a possibility for countries to abandon fossil fuels completely and move towards pure green energy. The aim of the given research is to analyze the options of Ukraine in this direction.

Analysis of the previous research

The environmental cost from burning fossil fuels on the Earth and its natural systems include: destruction of biodiversity; nitrogen cycle disturbance (nitrogen circulation through air, soil and water); and ocean acidification. But the biggest effect is the shift in the chemical composition of the atmosphere by releasing greenhouse gases. Fossil fuel power stations also release many toxic substances into the atmosphere that ultimately fall down as acid rains, killing trees and altering rivers and lakes' ecology. The final receptors of these impacts are living organisms, including humans.

The major environmental and economic concern currently is global warming and climate change. The world economy now produces more than 100 billion tons of CO_2 every three years — which is likely higher than the entire nineteenth-century CO_2 emissions. The first decade in this century (2000–2009) was the warmest decade since 1881 [15]. All the international organizations make their comments, plans and research works in terms of prognosis and adaptation to climate change trends, including UNEP, EU Environment, IPCC, EPA, US Department of Energy, U.S. Department of Commerce, UK Centre for Climate Science and Services, World Resources Institute, etc.

Readiness to pay the price of fossil fuels use with own health has decreased considerably and now most of developed countries are making plans about phasing fossil fuels out. This idea was clearly formulated in the work by Kharecha and Hansen, proving that abandoning fossil fuels will give a great spur to the control over greenhouse emissions [16]. The idea was supported by many international organizations, in particular, Greenpeace and EREC developed their Energy (R)evolution scenario, stating that the world would eliminate all fossil fuel use by 2090 [17]. Later Greenpeace and Climate Action Network Europe released a special report highlighting the need for an active phase-out of coal-fired generation across Europe. They based their results on the data from 280 coal plants and emissions data from official EU registries [18].

The idea was officially formulated in the Paris Agreement under the United Nations Framework Convention on Climate Change, by which Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) agreed to phase-out fossil fuel use by 2100. The aim to stay below the 2 °C global temperature change limit contained in the 2015 Paris Agreement will make all countries decline the production of fossil fuels [19].

In this regard coal use was considered to be the major reason of the problem and it is still supported by the research community [20; 21]. Ramanathan et al, 2019, have also showed that the removal of such emissions will definitely have positive effect on global health status, which in turn will give considerable economic benefits, by reducing disease burden on countries of the world [22]. On the other side, this destination raises questions about post-employment for one of the major job-providing

sectors of the world [23]. But the study, conducted by Overseas Development Institute (ODI) and 11 other NGOs states that building new coal-fired power plants will never make local communities wealthier, but less healthy for sure [24].

As a result, most of the leading countries of the world have already initiated some form of fossil fuels phasing-out to meet the requirements of the Paris agreement (Table 1).

Table 1

Elements of energy sector decarbonization in countries of the world

Country	General strategy	Coal industry phasing out initiatives	Other initiatives
Germany	Phase out of fossil fuels by 2100	plans to phase out and shut down the remaining 84 coal-fired plants on its land by 2038	No registration of ICE vehicles by 2030
France	Adoptedlaw, banning new fossil fuel exploitation projects and closing current ones by 2040 in all of its territories.	plans to phase out its coal capacity by the end of 2022	By 2040 it would prohibit new petrol and diesel car sales
Norway	Phase out of fossil fuels by 2100	phasing out is under consideration	By 2025, only 100 % electric cars will be sold
Canada	Phase out of fossil fuels by 2100	phasing out current unleashed coal generation and implement a moratorium on fresh coal generation without operational carbon capture and storage since 2017; plans to phase out coal-fired electricity generation by 2030	By 2040 it would prohibit any emittingnew car sales
Italy	Decarbonisation of the energy system by 2027	phase out the use of coal in the electricity sector by 2025	Rome and Milano will prohibit using diesel car by 2030
UK	Phase out of fossil fuels by 2100	phasing out current unleashed coal generation and implement a moratorium on fresh coal generation without operational carbon capture and storage since 2017; Scotland closed the last coal powered station in 2016, Wales – in 2019, England – will do that by 2024	Gas heating will be banned for new homes by 2025. New petrol and diesel cars will be banned in 2035 (Ireland – by 2030)
China	Achieving a rich zero carbon economy by 2050.	Ban on construction of new coal fired facilities since 2020	Researching the timetable for prohibiting the sale of new petrol and diesel cars
Netherlands	Phase out of fossil fuels by 2100	Phasing out oil for heating purposes and coal by 2030	By 2030 would prohibit all petrol and diesel car sales
New Zeland	Only RES are used in the construction of new power generation facilities since 2007	Announced a pathway to a coal-free electricity future for New Zealand by 2030	
Spain	Phase out fossil fuels by 2100	The plan to phase out coal by 2030, was managed in 1 year – now less than 2 % electricity is generated by cola burning and it will be ended by 2021	Selling only zero-emission vehicles from 2040

Belgium, Sweden, Austria and Australia closed their last coal power plant in 2016, 2019, 2020 and respectively.

Denmark will do that by 2030. In 2020 Finland maybe the only European country that invested in new coal power in Europe.

Australia, India and South Africa have no phase out plans; however, they invest in the development of certain RES.

The European countries are not all ready to follow the phase out way completely, in particular, Norway being the leader in cutting its greenhouse emissions in community sector, is not planning to stop gas extraction, since this makes a fundamental share of its budget. In contrast, Japan has joined the strategy to phase out fossil fuels by 2011, in particular, in has comprehensive plans to become a hydrogen economy by 2040.

The coal is the core in this process, not only because it is the "dirtiest" fuel, rather it is considered a good starting point, which will quickly give positive results, thus giving a good example to follow in countries, other than the leaders of the process. The Paris agreement, just like other sustainable international agreements is vulnerable to the influence of non-participants and violations. But it will definitely build a new view of the energy economy development, pressing marginal countries to join the process [25].

There are also other challenges to the idea of phasing-out, first of all this is a question of substitution of fossil fuels. The possible ways to break the cycle of demand and degradation are widely discussed during the last 20 years and until now they are limited to few promising options. Renewable non-combustible energy sources take the leading role in the process of mitigating climate change by substituting fossil fuel-based power generation [26; 27].

An intermediate step towards this is the utilization of combustible renewables and waste [28№ 29]. The energy efficiency is also seen as a major pathway to sustainable future [30]. An ambiguous option is nuclear energy expansion, which raises additional environmental concerns and is not considered as a sustainable alternative to fossil fuels [31].

The important question issue is, of course, the price of the electricity generated by new modes, its storage and transportation, which need some legislative and technical solutions [32].

Another serious issue to be accounted is the change of geopolitical situation if the world fully switches fully to renewable energy resources. Former fossil fuel exporters are expected to lose power and new leaders rich in renewable energy resources will appear [33].

The analysis of pros and cons for the fossil fuels abandonment is a complex task, but currently it is the only way to manage the environment condition in the world in a sustainable way.

Considering the situation in Ukraine, we will get more positive outcomes from this process and therefore it is necessary to consider national perspectives and possibilities to join this trend.

Methods and materials

There two major questions to answer in the given research. The first one is whether Ukraine should follow the way of leading countries of the world towards phasing fossil fuels out, as it is obviously extremely complicated task, not easily managed even by the most powerful countries. The second question is the outcome of the first one: if we find it necessary, than which energy provision sources can provide the needs of the country.

The need for abandoning fossil fuels in Ukraine is a strategic question, so it needs considerations of numerous aspects, which could be structured using the method of PESTLE analysis. PESTLE analysis is a tool with the help to assess the influence of external factors and risks for any business or strategy.

PESTEL analysis covers factors having influence on the possibility of a strategy implementation at macroeconomic level:

Political factors include international demands, political situation, tax policies, employment laws, tariff & trade restrictions, consumer protection laws, environmental regulations, political stability of a country etc.

Economic factors include economic growth indicators, inflation rate, interest rates, exchange rates, fiscal policies, unemployment trends etc.

Social factors include cultural aspects, age distribution, level of life, health risks, population growth rate, social situation etc.

Technological factors include rate of technological change, technology incentives, spending on research & development, basic infrastructure level etc.

Legal factors include tax laws, labor laws or any other laws not considered in political factors.

Environmental factors include data about necessary natural conditions for the implementation of the strategy and its effects on the environment condition.

These factors are equally important, but in the case of our work the environmental component is the driver of the process. With this analysis, one can identify potential opportunities and threats associated with the strategy under investigation and figure out ways to take advantage of them and avoid them. In our dynamic world, before any kind of strategy or tactical plan can be implemented, it is fundamental to conduct a situational analysis and repeat it regularly to identify changes in the global and national environment [34].

The next stage is the comparison of possible substitution energy sources. Before the analysis the alternatives must be clearly formulated and described. The objective of comparative analysis is to sharply define the merits and demerits of realistic alternatives, thereby providing decision makers and the public with a clear basis for choosing between options. The key challenge in comparative assessment is to show distinctions objectively, and as simply as possible. The adoption of unnecessarily complicated techniques can confuse decision-makers and exclude the public from effective participation.

The research experience shows that an average person cannot compare more than 5–9 values at once [35]. Therefore, it is better to apply the matrix method, in which all alternatives are graded by the same scale, but for each of the valuable factors/parameters separately.

To make the comparison more formal and objective additional numerical elements can be introduced [36]. Importance weighting of decision criteria may also be used, either in isolation from or in combination with scaling, rating or ranking methods. Ranking entails ordering alternatives from best to worst in terms of potential impacts on decision criteria. Rating refers to the use of a pre-defined rating scheme to rate the significance of decision criteria for each option. Scaling involves the assignment of numeric or algebraic scales to the impact of each alternative on each decision criterion. Importance weighting involves assigning a weighting factor to each decision criterion relative to the other decision criteria

The core element of the given research is the comparison of possible alternatives using special scale with points distributed among the alternatives by each criterion. The grades are then summed up and the rating of alternatives is made.

Results and discussions

Ukraine is partially resourced with its own traditional fuel and electricity, so it requires substantial fuel and power imports (Table 2).

The new energy strategy for Ukraine was introduced in August 2017. The approach sets out three execution phases: by 2020, by 2025 and by 2035. Completing a reform of the gas and electricity industries, increasing national output of natural gas, developing the coal market and reforming coal mining in particular is scheduled during the first phase. Renewables are expected to account for 8% of main power production by 2020. The final phase of execution of the strategy needs Ukraine to introduce a domestic greenhouse gas trading scheme, reduce emissions and boost the share of renewables in total main power production to 25%, the latter one is currently technically non-feasible [37]. As one can see the idea of complete abandoning fossil fuels is not considered as an option in the Strategy. Nevertheless, we believe, that this way is the most correct in term of long-term benefits. However, the PESTLE analysis (Table 3) for the fossil fuelsphasing-out shows a complex set of factors having influence on its implementation.

Table 2

Total primary energy supply and consumption in Ukraine (thousand tons of oil equivalents) [29]

Supply and consumption	Coal	Crude oil	Oil products	Natural gas	Nuclear energy	Hydro-energy	Geothermal, wind and solar	Biofuel/ Waste	Electricity	Heat	Total
Production	2869	2304	–	15175	21244	660	124	3348	–	599	66323
Imports	10617	527	9155	8809	–	–	–	38	7	–	29152
Exports	–495	–25	–24	–	–	–	–	–554	–329	–	–1427
Aviation bunkers	–	–	–157	–	–	–	–	–	–	–	–157
Stock changes	–547	0	–586	1620	–	–	–	–1	–	–	492
Total Primary Energy Supply	32450	2806	8387	25603	21244	660	124	2832	–323	599	94383

Table 3

The results of the PESTLE analysis

Factors to consider	Level of impact	Management	Character	Dynamics	Relative Importance
	H – High; M – Medium L – Low U – Undetermined	M – Manageable NM – Non-manageable P – Partially controlled	Positive + Negative – Unknown	Increasing > Unchanged = Decreasing < Unknown	Critical Important Unimportant Unknown
Political	H	M	–/ +	=	Critical
Economic	H	PM	–/ +	>/ <	Critical
Social	M	PM	+	>	Important
Technological	M	M	+	>	Important
Legal	M	M	–/ +	=	Important
Environmental	H	NM	+	>	Critical

While most of the issues are clearly understandable, we would like to highlight that preparatory research work is one of the most important factors of success, whereas political factors in particular lack of support and will from the national and lower authorities might be even more limiting factor, than economic provisions. The promotional effect of political factors is in turn limited by economic possibilities.

The moderate importance of technological factors is conditioned by the fact, that the study is based on the well known, proven technologies, which are available for use. At the same time the new research results and improvements can make these technologies more attractive and efficient. The most dynamic factor of this system is economic, as it is able to change dramatically over short periods and the work on RES development has fluctuating intensity and success. The legal factors are the reflection of political ones and therefore we attributed them to less important.

The growing environmental and social concerns about the need to move to sustainable pathway of the country make these factors the most important drivers of the process.

While achieving energy self-sufficiency remains unrealistic, this does not mean that Ukraine shouldn't look for the solutions. Self-sufficiency could be done by developing its shale gas reserves, extracting coal bed methane and improving its own existing gas production wells, but in the future priority sources must based on renewables. Three main drivers for using renewable energy: energy security, economic impacts, and CO_2 emission reductions.

There are many forecasts for the development of the renewable energy industry in Ukraine – we will consider the most well known (Table 4): by the Energy strategy of Ukraine, REmap "Renewable Energy Prospects for Ukraine" by the collaboration of the international agencies IRENA, and the National Institute of Technical Research in Kiev. Thus, it is seen that none of the options gives possibility for complete provision of the Ukrainian needs, but this scenarios will look better if we improve the energy efficiency.

Table 4

The structure of energy sector of Ukraine to 2030, MTOE

Description of primary energy source	Energy strategy by the Cabinet of Ministers of Ukraine	Technically achievable potential according to REmap (IRENA)	Technically achievable potential by National Institute of Technical Research, Kiev
Coal	13	–	–
Natural Gas	28	–	–
Oil	7,5	–	–
Nuclear Power	27	–	–
Biomass, biofuel and waste	8	21,7	31
Solar and wind power	5	19,2	34
HPP	1	7	3
Geothermal Energy	1	8,4	12
Total	91	56,3 (only renewables)	80 (only renewables)

Considering the data available, we formulated the list of 6 possible alternatives to be considered in this research: the increase in nuclear energy to the maximum; wind energy capacity building; solar energy capacity building; the use of geothermal energy; bioenergy use; "energy mix" from RES.

Nuclear power is already a known source of low carbon power generation. Whether or not it's an actual source of renewable energy is a debatable. In 2018, the total production at nuclear power plants in the country amounted 22 % of the total energy demand of our country (94,383 Mtoe).

As for the full ability to meet of Ukraine's needs through nuclear energy, this issue is very difficult and even to a certain extent possible with gigantic funding (up to $25 billion) for the construction of at least 11 new NPP [38].

Nevertheless, there are few important issues, which make the alternative of nuclear energy development more attractive. First of all, a year ago the line for processing of radioactive waste was launched in the Chernobyl facility along with the specially constructed long-term storage for radioactive waste. The cooperation with Westinghouse Electric Company has not only provided the diversification of nuclear fuel supply, previously bought from the Russian fuel company "TVEL" only, but the project of constructing nuclear fuel production plant according to the agreement of 2019. This will make Ukraine independent from RF nuclear industry and also gives potential for the improvement of NPP environmental safety due to modernization of the existing installations. Additional, Ukraine has become the part of

consortium with the Holtec International, working on the development of small modular reactors [39]. These modular reactors need more simple on-site construction, but provide increased containment efficiency, and enhanced safety due to passive safety features, as compared with conventional nuclear reactors [40]. One of the possible applications of SMRs is the support of renewable type installations, like wind and solar, which are characterized by irregularity of power generation.

Wind potential in Ukraine is located in the south on the Black and Azov coasts and in the Carpathian and Crimean Mountains. An important factor to consider is the cost of wind power plants construction, which may reach $1–$4 million [11].

Solar is one of the territory's most popular renewables, but it is affected by changes in weather patterns changes in various seasons. The insolation of Ukraine is from 1150 to 1550 kW/m^2 with the maximum in the southern regions — Odessa, Kherson, Nikolaev. Ukraine's position contributes to solar projects; the insolation of our country is far higher than that of Germany — Europe's pioneer in solar power generation [14].

Geothermal energy is suitable for use in the Carpathian mountain area, the highest geothermal gradients (up to 7–8.4 °C/100 m) are observed in the Tran Carpathian basin, on the coast and the Black Sea [41]. Overall, Ukraine is among the countries with medium level geothermal gradient. Under the most optimistic prognosis it may cover up to 10 % needs, demanding considerable investments.

Ukraine has great potential for **biomass** available for energy production, which is a good prerequisite for the dynamic development of the bioenergy sector. 110–120 million tons of biomass feedstock are generated annually in Ukraine (cereal trawl and other crop waste, animal and agro-industrial waste). Of the total amount, about 54 per cent is further processed, 45 percent is wasted and only about 1 percent is used for the production of electricity and heat [42]. For Ukraine, bioenergy is already one of the strategic directions of the renewable energy development; there are already 5 power plants operating on solid biomass and 5 working on biogas of agricultural origin [14].

Energy mix — isa combination of all possible alternatives, available at the territory. As it is seen from the above presented description, in case of Ukraine it is wise to rely on the mix of solar, wind and biomass energy.

It is also possible to involve new types of hydroenergy — small and mini power plants, able to provide the needs of population in mountain and northern-west regions, rich in hydro resources. In general, the idea of energy mix is to develop local and regional potential instead of implementing national one-direction projects. This way needs extensive analysis and research works to find the best alternatives in each area, but it benefits in lower investments with better resulted energy generation.

The appropriateness of using a particular energy sources depends on a variety of factors, including the amount of received energy, environmental, social and economic components. In order to assess the spectrum of advantages and disadvantages of the proposed options the following efficiency criteria were chosen:

- The degree of achieving overall objective of the project – the provision of the state energy needs with substitution of fossil fuels;
- The economic efficiency of the project — the necessary state investments, the need for foreign investments, local/regional affordability;
- The social concerns in the country — the effects on labor market, living standards, cost of living, etc.;
- The environmental negative impacts in the country — ranging from national to local level and their intensity;
- The environmental positive impacts in the country — level and relative value;
- The human health threats for the population of the country from the functioning of each type of power generation instalation;
- The technical feasibility — in terms of available technologies and room for infrastructure development, suitable natural conditions, etc.

After comparing all the possible alternatives (Table 5), it is seen that among the best option are wind and solar energy.

Table 5

Comparative analysis of substitution strategies for fossil fuels phase-out

Alternative	Factors (sequence shown lower)							Total
Nuclearenergy	3	2	0	1	0	1	1	8
Windenergy	2	2	3	3	3	3	2	18
Solarenergy	2	2	3	3	3	3	2	18
Geothermalenergy	2	2	2	3	1	3	1	14
Bioenergy	2	2	2	3	2	2	2	15
Energy mix	3	2	3	3	3	3	2	19

They are the most environmentally friendly, do not carry a risk to human health and can partially satisfy Ukrainian's energy needs. However, their combined potential for substitution is from 19 to 34 MTOE out of the necessary 94 MTOE, which is obviously not enough. The second and third place are taken by bioenergy, which is slightly less clean and geothermal that shows good results, but is more difficult to implement due technical constrains and moderate natural prerequisites in Ukraine, also it has some environmental impact. Nuclear energy showed the lowest score. As a result, the most promising option turned to be energy mix, based on wind, solar and biofuel energy. The most optimistic prognosis of such combination is 80 MTOE, so there is still considerable gap, which must be filled with either import or nuclear energy. The latter one is preferable due to political issues, but its economic characteristics are the worst in terms of necessary investments. But the is a good chance, if the RES are able to provide 70-80 MTOE, there will be no need in the expansion of the nuclear energy capacities above the already planned projects (reconstruction of the existing and construction of 4 new blocks).

The similar results are obtained by G. Kharlamova et al., 2016, when they analyzed the potential of wind, solar and hydroenergy to substitute the fossil fuels, consumed in the country [43]. But this research didn't consider the types of substitution technologies and thus gives more generalized, but still very valuable results. Since that time serious changes have taken place in the field of nuclear energy development, as well as the implementation of a few major RES projects was completed and gave data to make the more accurate prognosis. The national Energy strategy is based on these preconditions. As such we consider the idea of full energy mix the most promising.

If the country's renewable energy sector (RES) continues to grow, it will enhance energy security, market integration and decarbonisation. The path to "greening" Ukraine's energy market has both big challenges and opportunities.

This path must also account improving energy efficiency, as this will give the possibility to bring the target value of the necessary energy supply down to the amount, which can be provided by the renewable sources.

Of course, the country itself is not able to finance such a giant shift in the economic sector, so the prognosis made for 2030 is too optimistic and will be postponed.

Ukraine's renewable energy capacity is not used to its fullest degree. Alternative power engineering is a priority area for development of the Ukrainian economy and a strong place for attracting foreign direct investment, as well as a good driver for the development of new industries and job opportunities inside the country: the producing components and equipment for RES installations is absolutely real and is already implemented (wind power station components are already manufactured in Ukraine).

Conclusion

1. World's dependence on fossil fuels is one of the most important tests for humanity in the struggle for environment and at the same time for provision population with the necessary energy. Now less than 10 % of the world's energy is produced from renewable sources, the rest is based on fossil fuels and nuclear reactors. In Ukraine, the percentage of renewables is even lower, but according to research: "not everything is so bad" — our country has all opportunities to move towards greening energy production.

2. The reduction of fossil fuels reserves, environmental and human health concerns have forced the formation of a range of international collaborations and agreements aiming at seizing the use of fossil fuels. In particular, Germany, France, Sweden, Denmark and other countries have already initiated the plans to abandon the fossil fuels in various sectors of industry, including decommissioning of coal power station and prohibition of cars with internal combustion engines. Returning to renewables will help mitigate climate change and it is an excellent approach to meet future generations' energy demand.

3. Ukraine has been and remains the country dependent on external energy supplies and that is why our country needs to lift the share of renewable energy in the energy mix considerably. Thus, the reduction of the fossil fuels involvement in provision of industry and energy needs in Ukraine is driven by both political and environmental reasons. Clean technologies can also bring substantial indirect economic benefits, by creating new working places and improving living standards. The idea of this research was to analyze, whether Ukraine is able to abandon fossil fuels completely and how it will provide its needs under such conditions.

4. The comparative analysis of the substitutes to fossil fuels considered 6 alternatives, including the increase in nuclear energy to the maximum; wind energy capacity building; solar energy capacity building; the use of geothermal energy; bioenergy use; and the introduction of "energy mix" from renewable energy sources. The results show that the natural potential of the country in the form of energy mix can provide its needs, but considerable investments would be needed and vast territories to be involved — it is unreal under current economic situation.

5. The abandoning fossil fuels for Ukraine is impossible without the nuclear energy input, and as a result careful survey of its development must be done.

The possibility exists to keep implement the proposed gradual renovation of existing reactors by decommissioning of expired and construction of new objects instead. There is a range of international collaboration in Ukraine, which will provide modernization and independence of nuclear sector of Ukraine — this can support the development of RES.

6. The equally important efforts must be invested in the improvement of energy efficiency, as it can reduce the volume of work to be done in terms of decreasing the necessary volume of energy supply.

REFERENCES

1. **Andreoni V.** (2020). The energy metabolism of countries: Energy efficiency and use in the period that followed the global financial crisis. Energy Policy, Vol. 139, pp. 1–10. https://doi.org/10.1016/j.enpol.2020.111304

2. **Global** Energy Statistical Yearbook 2019.

3. **Bilgen S.** (2014). Structure and environmental impact of global energy consumption. Renewable and Sustainable Energy Reviews, Vol. 38, pp. 890–902. https://doi.org/10.1016/j.rser.2014.07.004

4. **Jamel L.**, Derbali A. (2016). Do energy consumption and economic growth lead to environmental degradation? Evidence from Asian economies. Cogent Economics & Finance, Vol. 4, Issue 1, pp. 1170653–1170670. https://doi.org/10.1080/23322039.2016.1170653.

5. **Lyulchak Z.** (2019). Mechanisms of demand and supply formation for the services of energy efficiency. Journal of Lviv Polytechnic National University. Series of Economics and Management, Vol. 7, Issue 4(2), pp. 135–146. doi: 10.23939/semi2019.04.135

6. **Energy** Efficiency Indicators 2020, IEA, Paris. https://www.iea.org/reports/energy-efficiency-indicators-2020.

7. **Kholod N.**, Evans M., Denysenk A., Roshchan ka V. Improving Ukraine's Energy Security: the Role of Energy Efficiency. Washington: Pacific Northwest National Laboratory, 2018. 37 p. https://doi.org/10.13140/RG.2.2.35663.12965.

8. **Sendich E.** Comparison of International Energy Intensities Across the G7 and Other Parts of Europe, Including Ukraine. Washington: U.S. Energy Information Administration, 2014. 20 p. https://www.eia.gov/workingpapers/pdf/international_energy_Intensity.pdf.

9. **Energy** market in Ukraine. Overview of the sector and future projects. Brussels: Flanders Investment and Trade, 2018. 58 p.

10. **Energy** Strategy of Ukraine for the Period up to 2035 “Security, Energy Efficiency, Competitiveness” Approved by the Resolution of the Cabinet of Ministers of Ukraine, 18 August, 2017, No. 605-p, 31 p.

11. **Green** Economy options for Ukraine: Opportunities for greening the energy sector. Policy Brief. Geneva-Kyiv: United Nations Environment Programme, 2018. 36 p.

12. **Antonenko A.**, Nitsovych R., Pavlenko O., Takac K. (2018). Reforming Ukraine’s Energy Sector: Critical Unfinished Business. Carnegie Europe, Zentrum für Osteuropa und Internationale Studien, 14 p.

13. **Snihur V.**, Malashkevych D., Vvedenska T. (2016). Tendencies of coal industry development in Ukraine, Mining of Mineral Deposits, Vol. 10, Issue 2, pp. 1-8. http://dx.doi.org/10.15407/mining10.02.001

14. **IRENA**, REmap 2030 Renewable Energy Prospects for Ukraine. IRENA, Abu Dhabi, 2015. 53 p.

15. **Ritchie H.**, Roser M. (2017). CO_2 and Greenhouse Gas Emissions. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions' [Online Resource]

16. **Kharecha P. A.**, Hansen J. E. (2008). Implications of "peak oil" for atmospheric CO2 and climate, Global Biogeochem. Cycles, 22 (3), pp. 22–30. https://doi.org/10.1029/2007GB003142

17. **Energy** [R]evolution. A sustainable world energy outlook. Amsterdam: Greenpeace International, European Renewable Energy Council, 2010. 260 p.

18. **Jones D.**, Gutmann K. End of an era: why every European country needs a coal phase-out plan. London, UK and Brussels, Belgium: Greenpeace and Climate Action Network Europe, 2015. 22 p.

19. **Muttitt G.** The sky's limit: why the Paris climate goals require a managed decline of fossil fuel production. Washington: Oil Change International, 2016. 60 p.

20. **Gareth A.**, Edwards S. (2019). Coal and climate change, Wiley Interdisciplinary Reviews: Climate Change, Vol. 11, Issue 2, pp. 57–77. https://doi.org/10.1002/wcc.607

21. **Tanaka K.**, Cavalett O., Collins W. J. (2019). Asserting the climate benefits of the coal-to-gas shift across temporal and spatial scales. Nat. Clim. Chang., 9, pp. 389–396. https://doi.org/10.1038/s41558-019-0457-1

22. **Ramanathan V.**, Haines A., Burnett R. T., Pozzer A., Klingmüller K., Lelieveld J. (2019). Effects of fossil fuel and total anthropogenic emission removal on public health and climate, Proceedings of the National Academy of Sciences, 116 (15), pp. 7192–7197. https://doi.org/10.1073/pnas.1819989116

23. **Tvinnereim E.**, Ivarsflaten E. (2016). Fossil fuels, employment, and support for climate policies. Energy Policy, 96, pp. 364–371. https://doi.org/10.1016/j.enpol.2016.05.052

24. **Granoff I.**, Hogarth J.R., Wykes S., Doig A. Beyond coal: scaling up clean energy to fight global poverty. London: Overseas Development Institute, 2016. 24 p.

25. **Burkea A.**, Fishelb S. (2020). A coal elimination treaty 2030: Fast tracking climate change mitigation, global health and security, Earth System Governance, Vol. 3, pp. 1–9. https://doi.org/10.1016/j.esg.2020.100046

26. **Owusu P.A.**, Asumadu-Sarkodie S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation, Cogent Engineering, 3, 1, pp. 79–90. https://doi.org/10.1080/23311916.2016.1167990

27. **Gielen D.**, Boshell F., Saygin D., Bazilian M. D., Wagner N., Gorini R. (2019). The role of renewable energy in the global energy transformation, Energy Strategy Reviews, Vol. 24, pp. 38–50, https://doi.org/10.1016/j.esr.2019.01.006.

28. **Boichenko S. V.**, Shkilniuk I. A., Cherniak L. M., Makarenko Y. S., Karelin Yu. V. (2014). Ecological Aspects of Petroleum Motor Fuels Usage (Review) Energy technologies and resource saving, 5–6, pp. 35–44.

29. **Kothari R**., Tyagi V.V., Pathak A. (2010). Waste-to-energy: A way from renewable energy sources to sustainable development, Renewable and Sustainable Energy Reviews, Vol. 14, Issue 9, pp. 3164-3170, https://doi.org/10.1016/j.rser.2010.05.005.

30. **Kreith F.**, Goswami, D. Handbook of energy efficiency and renewable energy. Second edition. London: CRS Press, 2016. 1765 p. https://doi.org/10.1201/9781420003482.

31. **Pearce, J.M.** (2012). Limitations of Nuclear Power as a Sustainable Energy Source, Sustainability, 4, 1173-1187.https://doi.org/10.3390/su4061173

32. **Green R**.; Staffell I. (2016). Electricity in Europe: exiting fossil fuels? Oxford Review of Economic Policy, 32 (2), pp. 282–303. doi:10.1093/oxrep/grw003

33. **Overland I.**, Bazilian M., Talgat I. U., Vakulchuk R., Westphal K. (2019) The GeGaLo index: Geopolitical gains and losses after energy transition, Energy Strategy Reviews, 26, pp. 100406–413. https://doi.org/10.1016/j.esr.2019.100406

34. **Kim-Keung Ho J.** (2014). Formulation of a Systemic PEST Analysis for Strategic Analysis. European academic research, Vol. 2, Issue 5, pp. 6478–6492.

35. **Ramik J.** (2017). Ranking Alternatives by Pairwise Comparisons Matrix and Priority Vector, Scientific Annals of Economics and Business, 64, pp. 85–95. 10.1515/saeb-2017-0040.

36. **Křovák J.** (1987). Ranking alternatives — comparison of different methods based on binary comparison matrices, European Journal of Operational Research, Vol. 32, Issue 1, pp. 86–95. https://doi.org/10.1016/0377-2217(87)90273-6

37. **Chumak D.**, Prokip A. (2018) Regional stability through energy cooperation: the case of the EU and Ukraine, European view, Vol. 17, Issue 1, pp. 74–-81. https://doi.org/10.1177/1781685818766449

38. **Nuclear** Power in Ukraine: country profile. World Nuclear Association. Retreived from: https://world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine.aspx

39. **Energoatom**, SSTC NRS and Holtec International signed Partnership Agreement for the establishment of international consortium. Retreived from http://www.energoatom.com.ua/en/press_center-19/company20/p/energoatom_sstc_nrs_and_holtec_international_signed_partnership_agreement_for_establishment_of_international_consortium-45069.

40. **Small** Modular Reactors: Nuclear Energy Market Potential for Near-term Deployment. Paris: Nuclear Energy Agency, Organization for Economic Co-Operation and Development, 2016. 75 p.

41. **Morozov Y.**, Barylo A. Geothermal Energy Use, Country Update for Ukraine. Den Haag: European Geothermal Congress, 2019, pp. 1–6.

42. **Janda K.,** Stankus E. Biofuels Markets and Policies in Ukraine. Prague: University of Economics, 2017. 26 p.

43. **Kharlamova G.**, Nate S., Chernyak O. (2016) Renewable energy and security for Ukraine: challenge or smart way? Journal of International Studies, Vol. 9, 1, pp. 88–115. https://doi.org/10.14254/2071-8330.2016/9-1/7.

Радомська М. М., Пономаренко М. С., Назарков Т. І.

ОЦІНКА ПЕРСПЕКТИВ ВІДМОВИ ВІД ВИКОПНИХ ПАЛИВ ДЛЯ УКРАЇНИ

Вичерпання запасів викопного палива і погіршення якості навколишнього середовища сприяли формуванню нового бачення розвитку економіки, заснованого на переході до зеленої енергетики. Важливою частиною цього процесу є закриття підприємств з видобутку і переробки викопних палив, а також повна заборона їх подальшого використання. На сьогоднішній день Україна має ряд серйозних проблем в сфері енергозабезпечення через відсутність внутрішніх запасів енергетичних корисних копалин і залежність від їх імпорту. Більш того, складна геополітична ситуація в регіоні змушує уряд шукати альтернативні джерела для диверсифікації поставок. В результаті в України навіть більше причин для відмови від викопного палива, ніж у інших країн світу. Вивчення існуючих міжнародних угод і національних стратегій, прийнятих в європейському регіоні, показало, що більшість розвинених країн вже приступили до реалізації деяких елементів Паризької угоди про відмову від викопних палив. У більшості випадків це стосується обмеження використання автомобілів з двигунами внутрішнього згоряння в містах та виведення з експлуатації вугільних теплових електростанцій. Плюси і мінуси реалізації державних планів по заміні вуглецевої енергетики на альтернативні стратегії вироблення електроенергії оцінювалися з використанням PESTLE аналізу. Центральною проблемою в процесі відходу від економіки, заснованої на викопному паливі, є пошук ефективної заміни серед поновлюваних джерел енергії з мінімальним впливом на довкілля. Для аналізу переваг можливих альтернатив

використовувався матричний метод. Результати PESTLE аналізу показують, що соціальні та екологічні фактори мають найбільший потенціал для сприяння процесу, в той час як політичні та економічні фактори можуть формувати як позитивні, так і негативні рушійні сили, обмежуючи ефективність інших факторів. Порівняння альтернативних варіантів заміщення, включаючи використання геотермальної енергії, біоенергетики, збільшення ядерної, вітрової або сонячної енергії і їх комбінації, продемонструвало, що саме останній варіант забезпечує найкращі перспективи при менших інвестиціях. Однак необхідним є ретельне планування і локалізація рішень. Інший важливий результат полягає в тому, що відмова від викопного палива для України неможлива без використання ядерної енергії. Таким чином, зроблено висновок про необхідність посилення роботи над підвищенням енергоефективності, оскільки це може знизити обсяг необхідного енергозаміщення.

Ключові слова: зміна клімату; забруднення; навколишнє середовище, PESTLE аналіз; комбінована енергетика; поновлювані джерела енергії.

Radomska M. M., Ponomarenko M. S., Nazarkov T. I.

THE ASSESSMENT OF UKRAINE'S PROSPECTS FOR THE FOSSIL FUELS PHASE-OUT

The running out of fossil fuels reserves and growing degradation of the environment quality have contributed to the formation of new vision of economy development, based on transition to green energy. An essential part of this process is the abandonment of fossil fuels extraction and processing facilities, as well as complete ban on their further use. As of today Ukraine has a range of serious problems in the field of energy supply provision, due to lack of domestic energy minerals reserves and dependence on their import. Moreover, the complicated geopolitical situation in the region makes the state government seek for alternative sources for the diversification of supply. As a result, Ukraine has even more reasons for phasing-out fossil fuels, than other countries of the world. The study of the existing international agreements and national strategies adopted in European region showed that most developed countries have already started to implement some elements of the Paris agreement on the abandonment of fossil fuels. In most cases this refers to limitation on cars with internal combustion engines at cities and decommissioning of coal powered thermal plants. The pros and cons of implementing state plans on changing carbon based energy to alternative power generation strategies was assessed using the method of PESTLE analysis, which defines the influence of external factors and risks for any strategy, in particular political, economic, social, technological, legal and environmental. The central problem in the process of moving away from fossil fuels based economy is finding efficient substitution for them among alternative renewable sources of energy with minimal impacts on the environment. To analyze the benefits of any possible alternative the matrix method was used, in which all alternatives are graded by the scale in relation to a set of valuable factors/parameters. The results of the PESTLE analysis show that social and environmental factors have the highest contributing potential to the process, while political and economic factors may form both positive and negative drivers, limiting the efficiency of other factors. The comparison of the substitution alternatives, including use of geothermal energy, bioenergy, increase in nuclear, wind or solar energy and energy mix, demonstrated that the energy mix is the one with the best outcomes at lower investments. However, it needs careful planning and localization of solutions. Another important finding is that the fossil fuels abandoning for Ukraine is impossible without the nuclear energy input. Thus, it is concluded that there is a need to work thoroughly on the improvement of energy efficiency, as it can reduce the volume of the necessary energy supply.

Keywords: climate change; pollution; environment, PESTLE analysis; energy combination; renewable sources of energy.

Радомская М. М., Пономаренко М. С., Назарков Т. И.

ОЦЕНКА ПЕРСПЕКТИВ ОТКАЗА ОТ ИСКОПАЕМЫХ ТОПЛИВДЛЯ УКРАИНЫ

Исчерпание запасов ископаемого топлива и ухудшение качества окружающей среды способствовали формированию нового видения развития экономики, основанного на переходе к зеленой энергетике. Существенной частью этого процесса является закрытие предприятий по добыче и переработке ископаемого топлива, а также полный запрет на их дальнейшее использование. На сегодняшний день Украина имеет ряд серьезных проблем в сфере энергообеспечения из-за отсутствия внутренних запасов энергетических полезных ископаемых и зависимости от их импорта. Более того, сложная геополитическая ситуация в регионе заставляет правительство искать альтернативные источники для диверсификации поставок. В результате у Украины даже больше причин для отказа от ископаемого топлива, чем у других стран мира. Изучение существующих международных соглашений и национальных стратегий, принятых в европейском регионе, показало, что большинство развитых стран уже приступили к реализации некоторых элементов Парижского соглашения об отказе от ископаемых топлив. В большинстве случаев это касается ограничения на использование автомобилей с двигателями внутреннего сгорания в городах и вывода из эксплуатации угольных тепловых электростанций. Плюсы и минусы реализации государственных планов по замене углеродной энергетики на альтернативные стратегии выработки электроэнергии оценивались с использованием PESTLE

анализа. Центральной проблемой в процессе отхода от экономики, основанной на ископаемом топливе, является поиск эффективной замены среди возобновляемых источников энергии с минимальным воздействием на окружающую среду. Для анализа преимуществ возможных альтернатив использовался матричный метод. Результаты PESTLE анализа показывают, что социальные и экологические факторы обладают наибольшим потенциалом содействия процессу, в то время как политические и экономические факторы могут формировать как положительные, так и отрицательные движущие силы, ограничивая эффективность других факторов. Сравнение альтернативных вариантов замещения, включая использование геотермальной энергии, биоэнергетики, увеличение ядерной, ветровой или солнечной энергии и их комбинации, продемонстрировало, что именно последний вариант обеспечивает наилучшие перспективы при меньших инвестициях. Однако необходимым является тщательное планирование и локализация решений. Другой важный результат заключается в том, что отказ от ископаемого топлива для Украины невозможен без использования ядерной энергии. Таким образом, сделан вывод о необходимости усиления работы над повышением энергоэффективности, так как это может снизить объем необходимого энергозамещения.

Ключевые слова: изменение климата; загрязнение; окружающая среда; PESTLE анализ; комбинированная энергетика; возобновляемые источники энергии.

Стаття надійшла до редакції 17.10.2020 р.
Прийнято до друку 23.11.2020 р.