Leading Trends in the Development of the Electric Power Industry

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Abstract Our paper aims at conducting a comparative analysis of the forecasts of the development of electric power and defining of its main trends. It was determined that formation of promising directions of energy development in separate countries should consider world progressive trends and the fuel and energy potential of countries and their specificities of energy consumption. The analytical base of the study composed of: foresight for the development of world energy of leading international institutions and energy companies (International Energy Agency (IEA), US Energy Information Administration (EIA), Japan Institute for Energy Economics (IEEJ), Institute for Energy Studies of the Russian Academy of Sciences, British Petroleum , Exxon Mobil), as well as strategic and policy documents of Ukraine on the development of the country's energy sector. The study analyses the dynamics of the vectors of energy development in the world, the EU, Eastern Europe and Ukraine in 2015-2025. The discrepancy between Ukrainian forecast trends and global trends was determined. The dynamics of the structure of electric power generation in the world, the EU, Eastern Europe and Ukraine in 2015-2025 was analysed in accordance to its sources: thermal power plants/combined heat and power plants; nuclear power plants; hydroelectric power stations/pumped storage power plants; bioelectric power stations; solar power plants; wind power stations; renewable energy sources. The strategic and program documents of Ukraine on the development of the electric power industry were studied, especially prospects and problems of their implementation considering the current situation was analysed. The main trends that will determine development of the electric power industry for the period up to 2035-2040 were identified based on analysis of the world and domestic foresights.

Keywords: *electric power industry, energy consumption, sustainability, leading technologies*

1 Introduction

Nowadays, the prospects for development of the global energy system is the subject of researches and practitioners' and scientists' discussions. Foresights aimed to determine the energy picture of the future are being developed by leading international institutions and energy companies. Among the main: Forecast of the worlds' energy by International Energy Agency (IEA), World Energy Outlook 2016, United States Energy Information Administration (EIA) (International Energy Outlook 2016), World and Russian Energy Development Forecast until 2040 Institute of Energy Studies of the Russian Academy of Sciences (ERIRAS 2013), Institute of Energy Economics of Japan (IEJ) (World Energy Outlook 2015), British Petorlem (BP) (BP Energy Outlook 2016), and Exxon Mobil (2016).

The horizon of most foresighs except BP is 25 years, which makes possible to adequately assess the picture and economic efficiency of projects and to see the consequences of made decisions (as a rule, it takes up to 10 years from the moment of making an investment decision to putting large energy facilities into operation, payback period may exceed 15 years).

A number of works by scientists are also devoted to studying the problems of energy development in the world and in separate countries. For example, Smil (2018) examines how the energy has greatly shaped a society, from pre agricultural societies up to actual civilization, using fossil fuels. The author considers changes in energy research over the past two decades. Studies by Ang et al. (2015), or Lilliestam and Patt (2012) are devoted to the analysis of energy development considering the problem of ensuring the energy security of countries. Newbery et al. (2018) study the high-renewables European electricity system.

The study by Kyzym et al. (2018) is devoted to substantiating the priority directions of structural and technological modernization of the Ukrainian electricity generation segment, taking into account changes in the national economy and the trends of worlds' modern energy development including restorational. Another study by Lisin et al. (2018) focuses on the sustainable development of regional power systems and the consumption of electric energy.

The study by Strielkowski et al. (2016) is devoted to assess the provisions on climate changes and on the formation of the EU position on the sustainable development of countries, including the energy sector.

Khaustova et al. (2018) investigates the problem of forming an energy policy based on the concept of energy security. The authors propose to consider the energy supply, energy conversion and energy consumption subsystems as components of the energy security system, the performance assessment is proposed to be carried out by energy dependence system indicators, energy efficiency and energy saving. The study is also prooving that the constant existence of the energy system is ensured by such a component of energy security as energy resistance. Another study by Streimikiene et al. (2016) focuses on the energy dependency and sustainable regional development.

At the same time remains a whole range of unresolved issues of energy development, both in terms of the effective application of modern technologies and primary fuel and energy resources (Pper), and issues of ensuring electric energy security, as one of the most important components of the energy security to ensure the sustainable development of world countries.

Definition of promising directions of energy development in separate world countries should consider global progressive trends, and to consider the fuel and energy potential in countries and their characteristics of energy consumption. Thus the purpose of this study is a comparative analysis of forecasts of the development of electricity in the world and Ukraine and the definition of its main trends.

2. Materials and methods

The analytical base of the study consists of: foresights for the development of world energy of leading international institutions and energy companies (International Energy Agency (IEA), US Energy Information Administration (EIA), Institute of Energy Economics of Japan (IEEJ), Institute for Energy Studies of the Russian Academy of Sciences, British Petorlem , Exxon Mobil), as well as strategic and policy documents of Ukraine on the development of the country's energy sector. Given the goal methods of analysis and comparisons, groupings were used herein.

3. Main results

In according to above, the development of country's energy should consider global progressive trends, the national fuel and energy potential and the characteristics of energy consumption. In the table below, Figure 1 that follows shows the comparative dynamics of the vectors of energy development in the world, the EU, countries of Eastern Europe and Ukraine, which allows us to draw conclusions as for conformity of these trends.

As it can be seen from Table 1 that follows below, there is a discrepancy between Ukrainian forward-looking trends with the worldwide. Thus, the average annual growth rate of total primary energy supply in Ukraine until 2020 pledged below than EU. Since the region-wide objective of the EU is to reduce energy consumption by 20% of the base level of the forecast until 2020 such a sharp decline in primary energy supply in Ukraine would be possible only by further reducing the volume of economic activity in the national economy.

The forecast for electricity production in this period is unchanged compraing to the levels of 2015, while this indicator for other regions of the world is growing: general, in the world - by 1.9%, in the EU - by 0.4%, in Eastern Europe - by 1.0% in year.

Therefore, it can be assumed that the period until 2020 is predicted to be recessive for Ukraine, it will be difficult to obtain significant structural and technological shifts in the direction of reconstruction of the energy sector during this time.

In 2020 - 2025 it is projected the recovery of economic growth in the country and average annual growth rate of primary energy supply that even exceed the global 1.1% per year against 1.0%. While electricity generation growth determined at a moderate level - 1.7% per year against 2.0% a year in the world.

Table 1. Comparative dynamics of energy development vectors in the world, EU, Eastern Europe and Ukraine in 2015-2025

Index	Retrospective	Forecast		Average growth, %	
	2015	2020	2025	2020-2015	2025-2020
World					
Total primary energy supply, mio t.	13647	14576	15340	1,3	1,0
Production of electricity, GWh	24344	26698	29540	1,9	2,0
EU					
Total primary energy supply, mio t.	1586	1547	1492	-0,5	-0,7
Production of electricity, GWh	3234	3299	3355	0,4	0,3
Eastern Europe /Eurasia					
Total primary energy supply, mio t.	1106	1120	1152	0,3	0,6
Production of electricity, GWh	1726	1815	1908	1,0	1,0
Ukraine					
Total primary energy supply, mio t.	90,1	82,3	87	-1,8	1,1
Production of electricity, GWh	163,7	164	178	0,0	1,7

Source: World Energy Outlook (2016); Ministry of Energy and Coal Industry of Ukraine (2017)

In general, the gap between the average annual growth rates of electricity production in 2015-2025 is predicted at the level of 1.1% in the EU, and at 1.0% in the world, while in Ukraine - at 0.5 % per year. Consequently, the significance of electricity for Ukrainian national economy is predicted to be lower than in the world and / or its generation efficiency is lower. This leads to the conculsion that the structural and technological development of Ukraine has not been given due attention in national forecasts. This statement is confirmed by the mismatch of structural changes in power generation with global trends (Fig. 1).

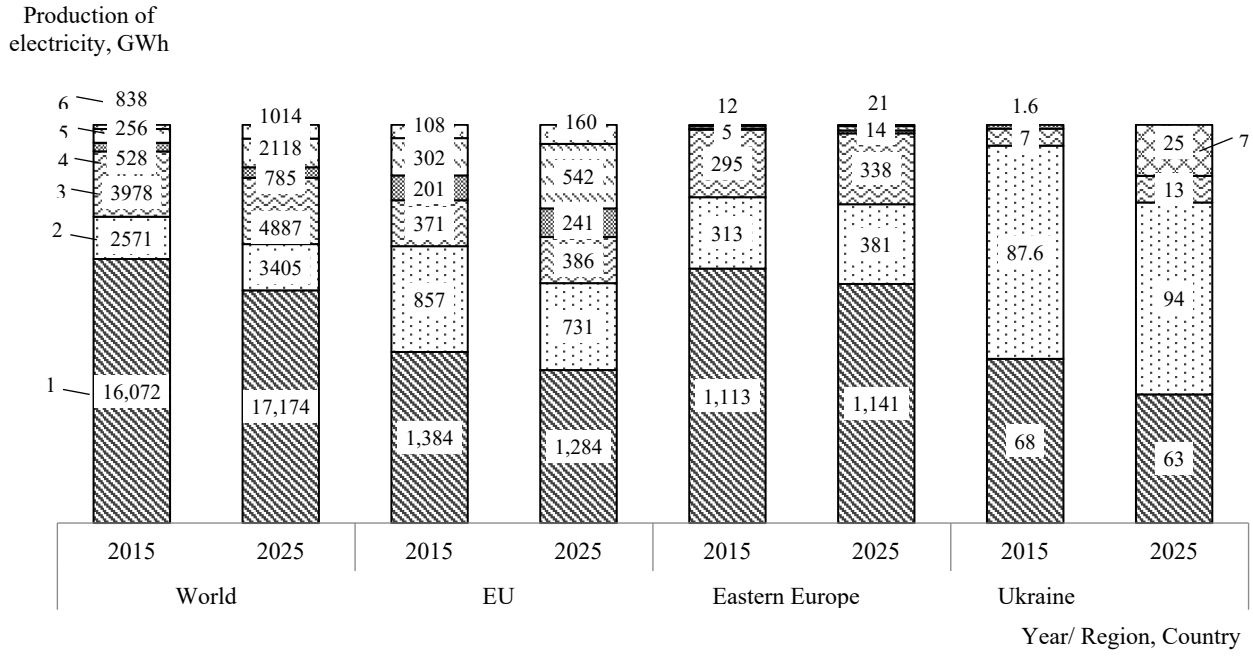

Fig. 1. Comparative dynamics of the structure of electricity generation in the world, the EU, Eastern Europe and Ukraine in 2015-2025

Note: 1 - thermal power plants (TPP) / cogeneration plants (CHP); 2 - nuclear power plants (NPP); 3 - hydroelectric power plants (hydroelectric power stations) / hydroelectric power plants (HPP); 4 - Bioelectric Power Plants (BioPower) 5 - solar power plants (SES); 6 - wind power plants; 7 - RES renewable energy sources (for Ukraine)

Source: World Energy Outlook (2016); Ministry of Energy and Coal Industry of Ukraine (2017)

The basis of the world's electricity in 2025 still be thermal power generation, however it will lose 8 percentage points (pp), whereas nuclear and hydroelectric power generation will increase the specific gravity by 1pp each compared to 2015 Renewable Energy (BioES/SPP/WEC) in 2015 was only 7% whereas its specific gravity is planned to increase to 13% in 2025. Wind energy will be the main source of renewable energy for electricity generation.

Greening the EU's energy development will lead the reduction of scpecific gravity to a 5 pp for thermal energy, and nuclear energy - by 1 pp (some EU countries plan to abandon nuclear energy after 2020. Others revise their safety standards), hydropower will remain almost unchanged both in absolute volume and in specific gravity (development of hydroelectric and hydroelectric power plants limited by the Water Directive providing for river return to the natural condition) compared to the basis year. While renewable energy will increase its specific gravity from 19% in 2015 to 28% in 2025, the largest increase will be demonstrated by wind farms, increasing by 7 pp, while the share of solar power plants will increase by 2 c. p., and BioPP - by 1 p.p. Such proportions in the EU energy sector is possible only through the establishment of a unified regional electricity market, which will allow free flows and balancing supply and demand in integration associations in general.

It is predicted that the countries of Eastern Europe and Eurasia will develop with their traditional way without the rapid development of renewable energy. The basis of their energy systems will continue to be thermal energy, however it will reduce its weight by 4 pp, while nuclear energy will grow by 2 pp, and hydropower by 1 pp. Renewable energy will be 2% of of total electricity production in 2025, that includes 0.7% as biomass, and 1.1% is wind power generation.

The energy strategy of Ukraine for the period up to 2035 "Safety, energy efficiency, competitiveness" (hereinafter referred to as the EU-2035) (Ministry of Energy and Coal Industry of Ukraine 2017) predicts a decline in the volume of thermal power generation in 2025 by 4.5 GW * h / year, i.e. in the structure this type of power generation will lose 8 pp (Corresponds to global trends). Atomic generation should grow by 6.4 GW * h however, it will lose its 4 pp of specific gravity. In spite of the hydropotential being sufficiently developed, Ukraine is forecasting an increase of hydropower volumes by 6 GW * h / year, that means that its value will increase by 3 pp (the largest increase of specific gravity compared with the world, the EU and Eastern Europe). At the same time, the specific gravity of RES is forecasted, which in 2025 should meet 13% of the electricity needs (corresponds to world trends), that is an increase by 15 times or 12 pp compared to 2015. (Such growth of the volume even exceed the EU figures).

Henceforth, Ukraine is planning a revolutionary way of changing the structure of electricity generation. However, the EU-2035 does not share its volumes according to the initial fuel and energy resources and renewable energy sources. The above makes the possibility of balancing supply and demand in the future questionable. The rapid development of non-guaranteed renewable electricity generation (solar and wind), that depends on weather conditions, is not supported by the shunting capacities of thermal energy, including using biomass.

It should be noted due to technological development, the due attention is not paid to the current program documents of Ukraine. Only the Development Plan of the UES of Ukraine of the SE NPC Ukrenergo (Ukrenergo 2016) takes into account the actual power generating stations projects that do already have positive decisions for further implementation.

The main objectives of the technological development of nuclear energy in Ukraine is to extend the life of existing nuclear power units, increase the efficiency load capacity and the construction of the 3rd and 4th Khmelnitsky NPP units with a capacity of 1 GW each Ukrenergo (Development Plan of the United Energy System of Ukraine for 2017 -2026, 2016). Note that all of them meet international technological priorities for the development of nuclear energy, mentioned in the IEA roadmap (World Energy Outlook 2016; IEA 2019). However, certain barriers arise with their implementation. And the most important of them is related to the need for special repairs for service llife extension.

IEA and International Atomic Energy Agency see the possibility to extend their service life up to 55 years with a periodic safety checks. Therefore, the safety of NPP operation in Ukraine and the reliability of the United Energy System of Ukraine will depend on the completeness of the operation of measures to extend their service life.

Improving the efficiency of use of nuclear power is considered to be one of the significant technological areas that will increase the production of nuclear electricity. However, the implementation of this direction is closely related to another priority of technological development - Hydro power capacity expansion and increase of pumping up to 7 hours. There is currently a shortage of PSH capacities in Ukraine.

The construction of new facilities to replace those planned for decommissioning after 2030 is an important element in meeting the long-term demand for electricity.

Despite the rapid growth of non-guaranteed renewable energy capacities (SES and WPP), hydropower in Ukraine's forecasts is regarded as the only kind of maneuvering capacity, which is designed to meet peak demand and reverse the volatility of electricity from RES. By a decree of the Cabinet of Ministers of July 13, 2016, the Hydropower development program for the period until 2026 (Supreme Council of Ukraine 2016) was approved, which activities are laid down in the EU-2035 and the development plans of the SE NPC Ukrenergo.

The said program cost-effective hydropower potential of Ukraine is estimated at 17.5 TW * h / year, which uses about 11 TW * h. The indicated type of power generation is also considered as substitution of TPP electricity production, which will allow to obtain coal savings of 90.7 thousand tons, or $ 8.2 million (Hydropower Development Program until 2026).

Promising projects for the new construction and reconstruction of hydro-generating facilities are provided in the Program (Hydropower development program until 2026, 2016). The implementation of these projects will ensure a sufficient maneuverability. However, there are significant risks of an economic (high construction cost), social (resettlement of the population of flooded areas), as well as environmental (destruction of reservoir ecosystems) nature, that do not allow these projects to be considered as responding to global technological development trends.

According to the foresight of technological development, the most appropriate development technologies for Ukrainian hydropower are the construction of a cascade or single HPP downstream (Run-of-River (RoR)), which are environmentally friendly water ecosystems lower reaches, renewal of hydropower facilities, and transformation of existing HPP at the PSH.

Ukraine's thermal power plays secondary role in the future, whose share in total electricity generation should decrease from 41% in 2015 to 32% in 2025. The forecasts of SE NPC Ukrenergo envisage its extensive development by reconstruction of power units, which will lead to an increase in capacity by 1,428 MW, and will decommission physically worn-out power units with a total capacity of 1745 MW. Consequently, a negative increase in the capacity of the thermal power industry is forecasted. Specific technologies for such reconstruction are not defined.

In terms of their level, TPPs in Ukraine are morally and physically obsolete. Such low efficiency of the Ukrainian heat power system is a consequence of a set of negative factors: a great age of existing plants, low quality of the produced steam, low quality coal, production discipline in operation and maintenance, as well as rejection to implement the new technologies. The efficiency of conversion of primary fuel and energy resources to electricity at TPPs in Ukraine in 2015 amounted to 33%, while the average value in the EU is 39% (counted only other bituminous coals).

Domestic heat and power generating capacities mainly operate by steam-turbine technologies on subcritical steam parameters, while the global development trend is implementation of technologies of supercritical and ultra-supercritical steam parameters (Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation). The most efficient TPPs in the world:

- in China, Guodian Taizhou II unit 3 with a capacity of 1000 MW, with an efficiency of 47.8%;
- in Nimmechchini RDK 8 with a capacity of 912 MW, whose efficiency is 47.5%;
- in the Netherlands, Maasvlakte Power Plant 3 with a capacity of 1100 MW, with an efficiency of 47% (Dodgson 2016).

Therefore, modern heat and power generating capacities should be built in a way to meet modern achievements in energy efficiency of power generation. Supercritical and ultra-critical technologies must be used in the construction of new thermal power facilities based on steam turbine installation.

At the same time, the technology of supercritical and ultra-supercritical steam technologies are intended for basic operation mode. Whereas gas-turbine (GTU) and steam-gas-turbine (SGTU) power generation is a kind of peak and half-peak power.

Basically the lack of attention to GTU and SGTU is associated with the use of natural gas as fuel for electricity generation, the dependence of which Ukraine seeks to overcome. However, according to IEA (2019) data, there is a diversity of fuels that are suitable for these technologies - coal gasification, biogas and fuel oil - which can be used for these technologies in Ukraine. Therefore, GTU and especially SGTU should be considered as important thermal power generation, which will ensure the national economy maneuvering capacity.

Another problem of technological development of Ukrainian thermal power industry is the lack of diversification of its capacities by sources of primary fuel and energy resources. Almost all TPPs in Ukraine (except 3.8 GW of natural gas, which are now mothballed) produce electricity from anthracite or other bituminous coals, whose energy depends on imports in 2015 was 6% and 31% respectively. While fossil fuels such as brown coal are not mined or used in the national economy, although its reserves are 2,9 bln tons or 1,7 bln tons of oil equivalent. (2.2 times the reserves of natural gas).

So far, neither the EU nor the IEA foresight neglect this component in power generation despite the greening of energy development. Brown coal provided 15.7% of total electricity generation in the EU, while its conversion efficiency was 37.4% in 2015

Same for coal, the IEA predicts the deployment of supercritical and ultra-supercritical technologies for lignite power generation, and also demonstrates the lignite drying technology in a full-scale power plant until 2020 (Technology Roadmap: High-Efficiency, Low-Emissions Coal-Fired Power Generation).

Thus, the due attention is not paid to thermal energy in the forecasts for the development of Ukraine, which requires their revision in the light of the world advanced technologies, as well as the existing energy potential of Ukraine.

Bioenergy plays a residual role in Ukraine's future energy industry, while current EU trends, as well as IEA foresight, paying particular attention to it as a necessary source of distributed power generation (Fig. 2).

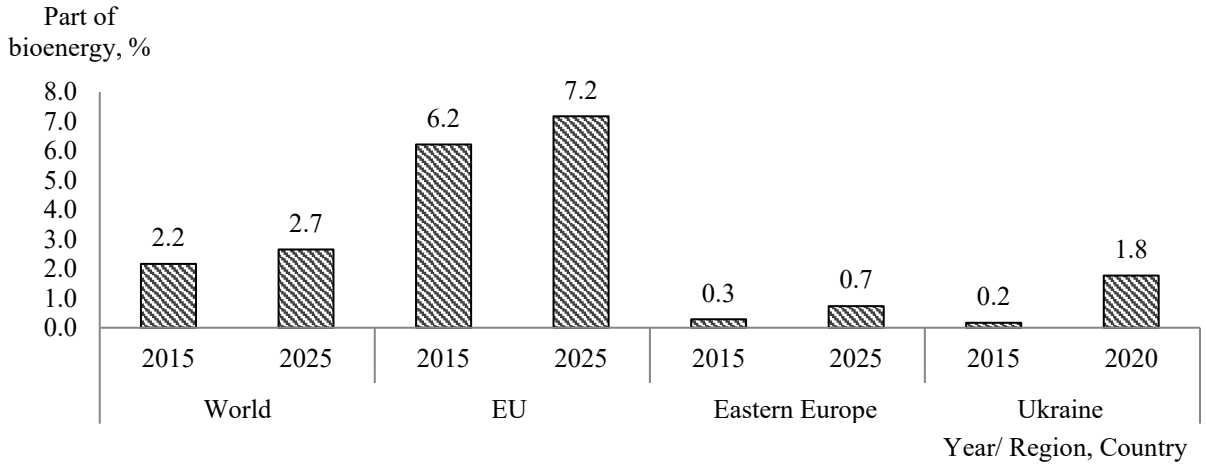

Fig. 2 Comparative importance of bioenergy in the world, EU, Eastern Europe and Ukraine in 2015 - 2025
Source: World Energy Outlook (2016); Supreme Council of Ukraine (2014)

Based on fig. 2, the EU countries are most interested in the development of bioenergy, which forecast to increase its share in 2025 up to 7.2%. While Ukraine, having a significant share of agriculture in GDP, has sufficient forestry, as well as the unsolved problem of utilization of municipal solid waste, predicts the bioenergy specific gravity growth up to 1.8% in 2020.

3. Discussions

The National Renewable Energy Action Plan till 2020 indicates that the potential installed capacity in the bioenergy segment may be 15 GW, however, taking into account the existing restrictions, biomass electricity production can be increased to 3450 MW * h., of which 2415 MW * h. - solid biomass, 1035 MW * h. - biogas (with a total capacity of 950 MW, of which 660 MW - solid biomass, 290 MW - biogas) in 2020 (Supreme Council of Ukraine 2014). Thus, the use of only 6% of the total bioenergy potential is predicted.

In the EU-2035 (Ministry of Energy and Coal Industry of Ukraine 2017), the main measures for the structural and technological development of bioenergy as a type of electricity generation are informational and promotional and related to:

- promoting the use of biomass as fuel in enterprises where biomass is a residual product;
- promoting the creation of competitive biomass markets.

However, it should be noted that according to Eurostat, Ukraine acted as a net exporter of biomass in 2015, exporting 537 thousand tons, at own domestic consumption of 2105 thousand tons. At the same time, SE NPC Ukrenergo, which draws up the development plan for the UES of Ukraine for the announced projects, predicts the establishment of capacities of 164.1 MW. The main contractor for these projects is EIG ENGINEERING, which plans to build 20 MW stations at local levels (the cost of construction of one station is UAH 895 mio), which will purchase non-liquid wood from local state forestries and wood processing enterprises (see Ukrenergo 2016).

Despite the insufficient attention to biomass as a raw material for electricity generation (World Energy Outlook 2016: ETSAP 2020; Technology Roadmap: Delivering Sustainable Bioenergy), it is advisable to revise Ukraine's structural and technological development forecasts, including such global bioenergy trends as:

- co-combustion of biomass in coal-fired power plants (the technology of integrated coal gasification in the combined cycle allows the use of up to 10 - 20% of biomass);
- anaerobic conversion of wet biomass (waste) to CHP which produces biogas.

These technologies can be implemented at the community level depending on their size (since typical projects for IGCC from 250 MW, whereas ADCHP from 0.5 MW (ETSAP 2020) and serve as an autonomous source of coverage both for their base load and maneuver capacities.

EU-2035 is predicted that RES will account 13% of gross electricity generation in 2025 (Ministry of Energy and Coal Industry of Ukraine 2017). Consequently, Ukraine intends to introduce the European experience in expanding green energy, but at a more accelerated pace. According to the National Renewable Energy Action Plan, 2.3 GW and 2.4 GW of wind and solar power should be installed as early as 2020 (Supreme Council of Ukraine 2014).

To finance these activities, it is necessary to provide financing for wind energy of $ 3.12 bln, and for solar - $ 2.22 bln, that is, 1.5% of GDP at the PPP of Ukraine in 2016 (Supreme Council of Ukraine 2014).

However, as it is believed based on a comparison with global foresight, these investments will not be enough, since simultaneous expansion will require maneuvering capacities to balance supply and demand.

Therefore, the pace of development of renewable non-guaranteed energy in Ukraine is clearly overestimated and requires significant investment. Renewable energy is can and should be considered as an important element of distributed and private electricity generation, which will increase the number of prosumers (consumers who are also producers) of electricity in the national economy.

4. Conclusions and implications

Based on the above analysis of world and domestic foresights for the development of the electric power industry for the period up to 2035-2040. The following conclusions can be made: First of all, the growth rate of world electricity production will slow down by the constant consumption of primary energy resources for its generation due to energy efficiency of power plants and a decrease of capacity utilization. Second, the coal generation will remain the main source of electricity generation in the world, but the following trends will be observed in it:

- The growth rate of global coal consumption will decline;
- The increase in coal generation capacities will outstrip the generation of electricity from this type of energy source, which will decrease the efficiency of the former;
- Increased energy efficiency of coal generation will slow down by reducing the supply of advanced coal technologies

Moreover, the value of gas power generation will increase, which leads to occur the following trends:

- Accelerate the growth rate of gas consumption and gas generation;
- The energy efficiency of natural gas conversion into electricity will be nehanced through the introduction of the latest gas generation technologies;
- Low utilization of gas generation capacities will be observed because of their use to cover peak demand.

After a period of sharp reduction in nuclear electric power in the world, there will be a process of growing interest in it, which will observe the following trends:

- Extension of service life of nuclear reactors to achieve their safe long-term operation for a period of 60 years or more;
- Optimization of III generation nuclear reactors to improve their designs (simplification and standardization) and reduce costs;
- Market launch of small modular reactors (SMR) with a capacity of 25-210 MW;
- Development of IV generation nuclear reactors and construction of 1-2 prototype fast neutron reactors (type FBR);
- Implementation of atomic cogeneration projects.

Despite the potential of hydropower resources, limited by environmental criteria and socio-economic factors, the growth of hydropower production is projected, and the following trends will occur:

- The energy efficiency of hydroelectric generation technology will remain unchanged;
- Due to the highly maneuverable nature of the use of hydro generation capacities, the congestion of others is projected at 40%;
- The main efforts in the development of hydropower will be focused on the design and construction of hydroturbines, which are more sustainable and environmental, by reducing the adverse impact on aquatic ecosystems of the lower reaches;

- Development of small hydropower plants along rivers as a source of distribution electricity, which has less impact on ecosystems of water basins;
- Construction of new PSPPs of open or pumping cycles based on the reconstruction or restructuring of old HPPs.

The main stage in the development of bioenergy is the period until 2020 followed with a significant slowdown in the growth rate of electricity from renewable energy sources with the following trends:

- The fastest growing source of renewable energy generation will be solar and wind energy;
- The bioenergy development envisages separation of such directions: a) independent generation at TPPs and CHP from biomass; b) co-combustion of biomass at coal-fired power plants; c) anaerobic conversion of wet biomass (waste) to a CHP plant to produce biogas.

The accelerated deployment of RES is possible by reinforcing them with the shunting and free capacities of guaranteed sources of power generation, considering the cheaper technologies, as well as the development of high-voltage cross-border transmission networks.

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