Analysis of Current Use of Renewable and Alternative Energy Sources by European Countries

Stepan Shapoval[1], Stepan Mysak[2], Pavlo Shapoval[3], and Halyna Matiko[2(✉)]

[1] Institute of Building and Environmental Engineering, Lviv Polytechnic National University, Lviv, Ukraine

[2] Institute of Power Engineering and Control Systems, Lviv Polytechnic National University, Lviv, Ukraine

halyna.f.matiko@lpnu.ua

[3] Institute of Chemistry and Chemical Technologies, Lviv Polytechnic National University, Lviv, Ukraine

Abstract. The paper considers the contribution of renewable and alternative energy sources in gross final energy consumption for some European countries. In particular, the share of biomass, biofuel and waste, wind energy, solar energy, energy from heat pumps, and geothermal energy in gross final energy consumption was analyzed for the Netherlands, Germany, France, Poland, and Ukraine. Data on various renewable and alternative sources for these countries are also compared. In addition, the prospects for increasing the use of these energy sources in gross final energy consumption of the specified European countries are analyzed and compared. The technique for analyzing the data of climate and energy programs of studied countries has been developed, which can be used for further similar research. The obtained graph-analytical dependences are of scientific and practical importance because they helped to analyze the achievements of the leading European countries in using renewable and alternative energy sources and further prospects for their development.

Keywords: Emission reduction · Greenhouse gases · Energy and climate strategy · Energy saving · Energy efficiency

1 Introduction

The consequences of recent climate changes regarding the impact of high rates of global warming on safe modern life, forced the world to look for ways of solving these problems. In 2015, the Paris Agreement was adopted as a part of the UN Framework Convention on Climate Change (UNFCCC) to increase the ability to adapt to the negative effects of climate change, to prevent an increase in the average global temperature of more than 2 °C (if possible, no more than 1.5 °C) relative to the indicators of the pre-industrial era [1]. The countries and associations of countries that signed this agreement have committed to develop their national plans following the policy of reduction in greenhouse gas (GHG) emissions into the atmosphere, to implement them in their economy, and update them every 5 years to ensure sustainable development [2].

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According to the goals of the European Green Deal [3], in 2019, the Clean Energy for All Europeans Package was adopted and implemented into the legislation of the EU member states to fulfill the commitments made within the framework of the Paris Agreement. In addition to the main goal of reducing GHG emissions by at least 40% from the volume of emissions in 1990 defined in the 2030 Climate and Energy Framework of the EU [4], this set of energy rules contains the following most important goals by 2030:

- according to the EU Directive 2018/2002 on energy efficiency, increasing the energy efficiency over the current level by at least 32.5%;
- according to EU Directive 2018/2001 on encouraging the use of energy from renewable energy sources (RES), ensuring the share of energy from RES in gross final energy consumption at the level of 32%;

In August 2021, a set of proposals "Fit for 55" was presented to review and update EU legislation, as well as the implementation of new initiatives to ensure compliance of the Union's policy with climate goals [5]. This package requires by 2030:

- reduction of GHG emissions by at least 55% compared to the level of emissions in 1990;
- increasing the share of produced energy from RES from 32 to 40%;
- reduction of the share of primary energy consumption to 39–41%, and final energy consumption—to 36–37%;
- to reform the EU Emissions Trading Scheme (EU ETS), etc.

Because of the aggression of the Northeastern neighbor to Ukraine on February 24, 2022, and the destruction of the international energy market, the European Commission approved the plan for energy saving, clean energy production, and diversification of energy resources—REPowerEU [6]. This plan aims to increase the energy freedom of EU member states from unreliable suppliers and unstable supplies of imported fossil fuels, speed up the transition to clean energy, and help to solve the climate crisis as proposed in the Paris Agreement. RePowerEU by 2030 offered:

- to increase the share of RES at the level of 40–45% in gross final energy consumption due to more active development of solar and wind power plants;
- the recommendations for the reduction of energy consumption and increasing the all-European efficiency target from 9 to 13%;
- to oblige the installation of photovoltaic panels and solar collectors on the roofs of newly built buildings;
- to increase the production of biomethane and intensify the development of low-carbon hydrogen energy due to the construction of new electrolyzers, the capacity of which will allow the production of 10 million tons of renewable hydrogen; to solve the problems of its transportation and consumption.

Considering these changes, EU member states, according to [7], must submit their updated integrated national energy and climate plans, which will contain developed policies for the implementation of the above goals, for consideration by the European Commission by the end of June 2023.

2 Formulation of the Goal of the Research

Compared to Ukraine, the EU is introducing strict rules for the reduction of GHG emissions. Namely, it is setting high carbon taxes and reforming its Emissions Trading Scheme (EU ETS) to give the industry an incentive to modernize. A flexible credit system (grants for covering part of the funds spent on the purchase of energy-efficient equipment or optimization of technological processes), and support for the European Green Transition initiative allow countries to attract financing on favorable terms.

Therefore, the goal of the paper is to investigate the contribution of renewable and alternative energy sources in gross final energy consumption for some European countries, particularly, to analyze the use of the share of biomass, biofuel and waste, wind energy, solar energy, energy from heat pumps, geothermal energy in gross final energy consumption by such European countries as the Netherlands, Germany, France, Poland, and Ukraine.

3 Analysis of Recent Research and Publications

According to [8, 9], bioenergy has one of the greatest development potentials among all RES due to the good climate, the advantages of the agricultural sector, and the presence of the necessary workforce. Bioenergy is for about 70% of energy consumption from renewable sources. The most popular are agricultural residues formed during harvest gathering and processing, animal manure, as well as energy plants, from which solid fuel and biogas are obtained [10, 11]. According to data for 2020, the dynamics of electricity production from biomass is inferior to the electricity generation by other sources of renewable energy, so the total electricity production from this source of renewable energy was 18% of the planned (actual 755 GW h versus planned 4220 GW h [12]).

Today, new technologies of solar energy are being actively implemented [13–15], and new highly energy-efficient materials for covering solar panels are being developed [16]. Wind energy, energy from heat pumps, and geothermal energy are also promising [8, 17, 18]. According to scientists' calculations, with the maximum use of wind power, it would be possible to obtain electricity in the necessary amount to provide 12% of the total world energy consumption [8, 12].

The authors analyzed numerous documents containing data on shares of biomass, biofuel and waste, wind energy, solar energy, energy from heat pumps, and geothermal energy in gross final energy consumption by such European countries as the Netherlands, Germany, France, Poland, and Ukraine [8–21].

For the Netherlands, biomass energy data were obtained from [19], for Germany—from [20], for France—from [21], for Poland—from [22], and for Ukraine the actual values were obtained from [12], and the forecast values—from [8].

For the Netherlands, wind energy data were obtained from [19], for Germany—from [20], for France, actual values—from [23] and forecasted values—from [21], for Poland—from [22], for Ukraine actual data were obtained from [24] and [12] and forecast—from [8].

For the Netherlands, data on energy from heat pumps were obtained from [19], for Germany—from [20], for France—from [21], for Poland—from [22], and for Ukraine actual values were obtained from [12] and forecast values—from [8].

For the Netherlands, geothermal energy data were obtained from [19], for Germany the actual values—from [24], and the forecast values—from [25], for France—from [21], for Poland—from [22], for Ukraine, the actual data were obtained from [12], and the forecast values—from [8].

For the Netherlands, data on energy from hydropower sources were obtained from [19], for Germany—from [20], for France the actual data were obtained from [23], and the forecast ones—from [21], for Poland—from [22], for Ukraine the actual values were obtained from [24], and the forecast values—from [8].

The Integrated National Energy and Climate Plan of France [21] provides data on the annual final energy consumption for all sectors of the economy. Therefore, the data of the annual gross final energy consumption, necessary for the calculations of the share of energy consumption of each renewable energy source (RES) for the corresponding year, were determined by multiplying the annual final energy consumption in this year by 1.08 (the arithmetic mean of the ratio of the annual gross final energy consumption to the annual final energy consumption of all sectors of the economy in 2023 and 2028, respectively [21]).

4 Presentation and Discussion of the Research Results

To achieve these goals, for the first time, a methodology was developed to analyze the energy and climate plans of European countries, which allows determining the share of renewable energy consumption in a selected sector of the economy.

The share of the source (or technology) of renewable energy in gross final energy consumption for each year was determined as the ratio of the annual final energy consumption from this renewable energy source to gross final energy consumption of all sectors of economy:

$$k_{tRES} = \frac{E_{tRES}}{E} \cdot 100, \%, \tag{1}$$

where E_{tRES} is the final energy consumption by the renewable energy source, PJ, TWh h or ktoe; E is the gross final energy consumption of the economy, PJ, TWh h or ktoe.

Since Table B10, and Table B28 in [20] contain the shares of renewable energy sources (technologies) in the energy consumption of the relevant sectors of economy—electric power, heating and cooling, and transport sector, then we propose to determine the total shares of RES energy consumption in the gross final energy consumption k_{tRES} as described below.

The share of final energy consumption from the renewable energy source in the sector of the economy equals to:

$$k^s_{tRES} = \frac{E^s_{tRES}}{E^s} \cdot 100, \%, \tag{2}$$

where E^s_{tRES} is the final energy consumption from the renewable energy source in the sector of economy, PJ; E^s is the final energy consumption of the sector of the economy, PJ.

Since $E_{tRES} = E^s_{tRES}$ for a renewable energy source, from which all produced energy is consumed only by one sector of the economy, and $E_{tRES} = \sum E^s_{tRES}$—by several economy sectors, then the share of the renewable energy source in gross final energy consumption k'_{tRES}, related to the consumption of all energy produced by one economy sector can be written as:

$$k'_{tRES} = k^s_{tRES} \cdot \frac{E^s}{E} \tag{3}$$

The share of RES final energy consumption in the corresponding total sectoral energy consumption:

$$k^s_{tRES} = \frac{E^s_{RES}}{E^s} \cdot 100, \%, \tag{4}$$

where E^s_{RES} is the final energy consumption from RES in the relevant sector of the economy [20, Table C2.7.1], PJ.

So, we obtain:

$$k'_{tRES} = k^s_{tRES} \cdot \frac{E^s_{RES}}{k^s_{tRES} \cdot E} = \frac{k^s_{tRES}}{k^s_{RES}} \cdot \frac{E^s_{tRES}}{E}. \tag{5}$$

Considering (1), the share of the RES in gross final energy consumption, related to the consumption of all energy produced by one economy sector equals

$$k'_{tRES} = \frac{k^s_{tRES} \cdot k_{RES}}{k^s_{RES}} \cdot \frac{E^s_{RES}}{E_{RES}}. \tag{6}$$

The share of the renewable energy source in gross final energy consumption, related to the consumption of all energy produced by several sectors of the economy is determined as:

$$k_{tRES} = \frac{\sum E^s_{RES}}{E^s} \cdot 100 = \sum k'_{tRES} \tag{7}$$

Using the proposed technique for the analysis of energy and climate plans, the actual and forecast shares of energy from biomass, biofuel, and waste (%) in gross final energy consumption were analyzed in Fig. 1.

The actual values of the share are the values of the share recorded by the state monitoring services in the past years, which are represented by solid lines in the graphs, and by straight, normal font saturation—in the tables.

The predicted values of the share are the present and future values of the share based on the adopted model of the development of the state energy policy. They are shown by dotted lines in the graphs, and by semi-rough font saturation—in the tables.

We can see from Fig. 1, that Ukraine plans to triple energy consumption from biomass by 2030 compared to 2020 and double it compared to 2023, reaching a share of 19.5%

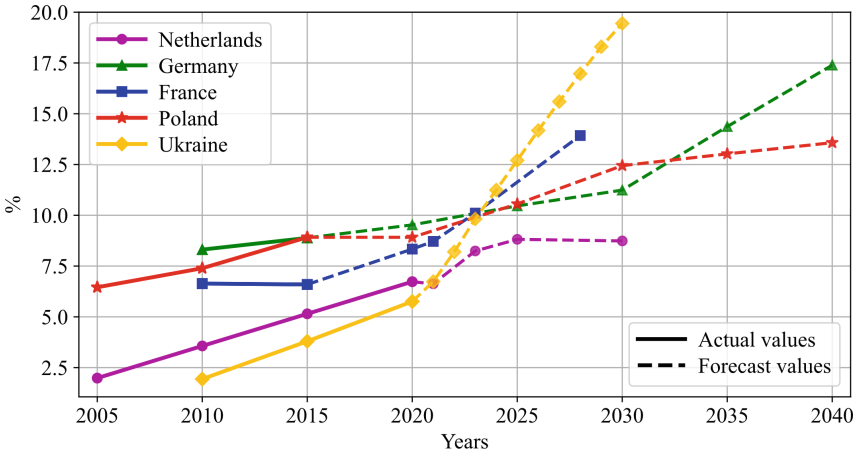

Fig. 1. Shares of energy from biomass, biofuel and waste in gross final energy consumption in Ukraine and the EU countries

in the country's gross final energy consumption. Germany is going to reach a 10.5% share of energy consumption in 2025, 11.2% in 2030, 14.4% in 2035, and 17.4% in 2040, almost doubling it from 2015. France plans 10.1% of biomass energy in gross final energy consumption in 2023 and 13.9% in 2028, i.e., to increase the share by 2.6 times and 3.7 times, respectively, compared to 2015. Poland plans to consume 10.6% in 2025, 12.4% in 2030, 13.0% in 2035, and 13.6% in 2040. The Netherlands is not going to increase energy consumption from biomass significantly, planning to increase the share only by 2% from 2020 to 2030.

Then the actual and forecast shares of wind energy (%) in the gross final energy consumption were analyzed (see Fig. 2).

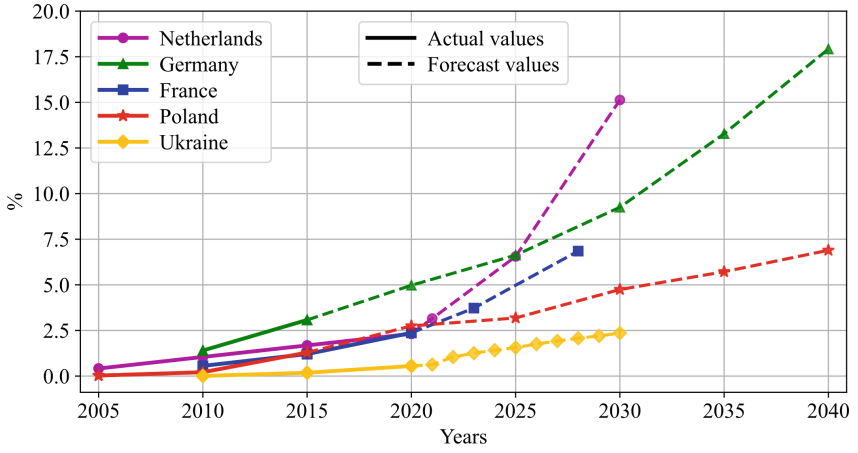

Fig. 2. Shares of wind energy in gross final energy consumption in Ukraine and the EU countries

Shares of renewable sources of solar energy in gross final energy consumption in Ukraine and EU countries are presented in Table 1, where the actual values are shown by straight, normal font saturation, predicted values—by semi-rough font saturation, and missing values—with a dash. Based on the data in Table 1, an analysis of the actual and forecast shares of solar energy in gross final energy consumption was carried out.

Table 1. Shares of solar energy (%) in gross final energy consumption of Ukraine and the EU countries

Country	2005	2010	2015	2020	2021	2022	2023	2025	2028	2030	2035	2040
Netherlands	0	0.5	1.0	1.5	1.9	2.3	**2.6**	3.5	**3.9**	4.2	–	–
Germany	–	0.6	1.7	2.4	2.7	2.9	**3.2**	**3.7**	**4.5**	**5.1**	**6.8**	**8.7**
France	–	0	0.4	0.9	1.1	1.3	**1.6**	**2.4**	**3.7**	–	–	–
Poland	0	0	0.1	0.4	0.5	0.6	**0.7**	**0.9**	**1.3**	**1.5**	**2.2**	**2.7**
Ukraine	–	0	0.1	1.0	1.3	1.5	**1.7**	**2.1**	**2.6**	**2.9**	–	–

Then an analysis of the actual and forecast shares of energy produced from heat pumps in gross final energy consumption was carried out (see Fig. 3).

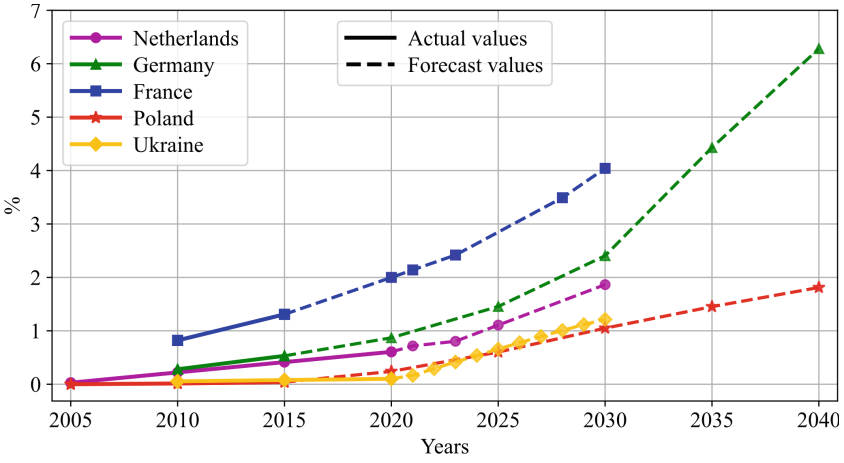

Fig. 3. Shares of energy from heat pumps in gross final energy consumption in Ukraine and the EU countries

Table B10, and Table B28 in [20] contain the total shares of solar thermal energy, geothermal energy, and heat pumps in the total energy consumption of Germany without dividing them into separate technologies. Therefore, the data for heat pumps were determined by subtracting the shares of solar thermal energy [20, Table. C2.1.1] and geothermal energy [24, 25] from the total shares.

According to Fig. 3, the low-temperature heat from heat pumps is most used in France, where its share in gross final energy consumption in 2010 and 2015 was more than 2.5 times higher than in Germany and was 0.8% and 1.3%, respectively. In the future, a 2.3% share of consumption is forecast in 2023, 3.5%—in 2028, and 4%—in 2030 [21].

The next step was the analysis of the actual and forecast shares of geothermal energy (%) in gross final energy consumption carried out in Fig. 4.

Figure 4 shows that geothermal energy does not take a significant share in gross final energy consumption of all investigated countries, but it is best developed in the Netherlands, where it provided 0.3% of all energy in 2020. In the future [19], a gradual increase in obtaining heat from this technology is predicted and it will reach a share in energy consumption of 0.8% in 2028. This type of thermal energy is somewhat worse developed in France, which plans to double heat production in 2023, reaching a share of 0.2% and triple in 2028, providing 0.3% of gross final energy consumption.

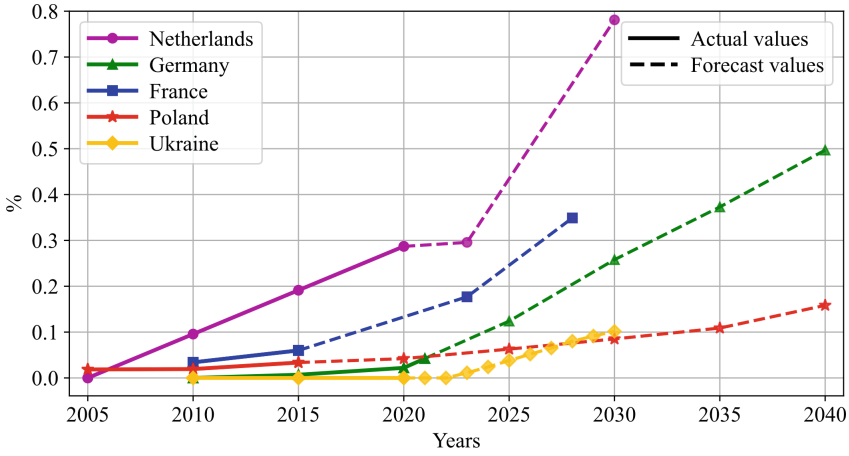

Fig. 4. Shares of geothermal energy in gross final energy consumption in Ukraine and the EU countries

Finally, the authors have analyzed the actual and forecast shares of hydropower (%) in gross final energy consumption (see Fig. 5).

Figure 5 shows that hydropower is best developed in France, where its actual share in gross final energy consumption during 2010–2020 fluctuated within 3.5%. In the future, the French government plans to refuse fossil fuels in the production of electrical and thermal energy, and to continue developing hydropower, reaching 4.2% of gross final energy consumption in 2028.

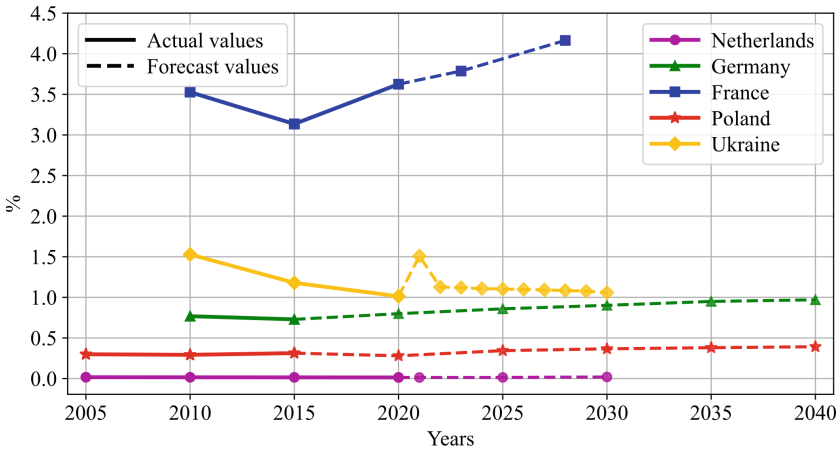

Fig. 5. Shares of hydropower in gross final energy consumption in Ukraine and the EU countries

5 Conclusion

In the paper, a new methodology was proposed for analyzing the shares of final energy consumption from the renewable energy source in the respective total sectoral energy consumption. Based on the developed methodology the authors have analyzed the current and forecast use of different renewable energy sources for some European countries. The research results show that the Netherlands and Germany are the leaders in the implementation of various renewable energy sources. The Netherlands prefers using wind energy (5% now and 15% till 2030) and solar energy (2.6% now and 4.2% till 2030). Germany uses 6% of wind energy now and approximately 18% till 2040, 3.2% of solar energy now and 8.7% till 2040 as well as 10% energy from biomass now and 17.5% till 2040. Poland leads in the use of biomass—10% now and 13% till 2040, however, according to forecasts, Ukraine is going to occupy a leading position in this sector (11% now and approximately 20% till 2030). France also prefers the use of biomass—10% now and 14% till 2028, heat pumps (2.5% now and 4% till 2030) and hydropower (3.5% now and 4.2% till 2028). The shares of geothermal energy in gross final energy consumption are the least for all investigated EU countries, for example, 0.3% now and 0.8% till 2030 for the Netherlands.

Now the European Union countries are working on the improvement of their national energy and climate plans to achieve the Union's main goals. Implementation of REPowerEU for energy saving will help the EU countries to increase the share of energy from renewable sources to 40–45% in gross final energy consumption by 2030 due to more active development of wind and solar power plants, use of biomethane and low-carbon hydrogen energy.

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