Bioenergy Policy Roadmap until 2050 and Action Plan until 2025

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1. Introduction.

There are several important factors that necessitate the elaboration of a long-term strategy for the development of bioenergy in Ukraine and a Roadmap as its essential component.

First, current Ukraine's Energy Strategy sets an ambitious goal of achieving 11 Mtoe of biomass, biofuels and waste in the total supply of primary energy in 2035. However, the Energy Strategy has not been accompanied by a document (a roadmap or an action plan) showing due to what types of biomass/biofuels and technologies, and in which sectors these 11 Mtoe in TPES will be actually reached. It is necessary to understand what types of equipment (boilers, CHP plants, TPPs) of what capacity and in which sectors (heat production, power production, cogeneration, and transport sector) should be introduced to most effectively achieve the goals.

Second, Ukraine has the international commitment to reduce greenhouse gas emissions under the 2015 Paris Climate Agreement, which means to implement so-called nationally determined contributions. At present, this reduction commitment is 40% of 1990 GHG emissions level, which must be achieved by 2030; however, the reduction commitment may increase up to about 70% of 1990 GHG emissions level by 2050 in the coming years. To meet this new target, Ukraine needs to turn to a low-carbon economy, significantly reduce fossil fuels consumption, actively develop energy efficiency and introduce renewable energy sources. According to some preliminary estimates, the share of RES in the energy sector of Ukraine may reach 60% in 2050, of which more than a half will be the contribution of bioenergy. Thus, bioenergy plays a significant role in Ukraine's implementation of its international obligations to reduce greenhouse gas emissions, which also necessitates the elaboration of a long-term strategy for the bioenergy development.

The third factor is that the equipment of most coal-fired power plants in Ukraine is already on the verge of its physical depreciation because these power plants were put into operation as far back in the 1960s. In addition, all possible terms of the prolonged operation of Ukrainian NPPs will expire by 2050. The bioenergy development strategy until 2050 will show how biofuels, bioenergy plants and technologies will contribute to replacing the coal/natural gas plants and NPPs that will be decommissioned by 2050.

Thus, Ukraine needs a long-term strategy for the development of bioenergy, which will:

- outline *prospects* for the development of the bioenergy sector until 2050;
- provide an action plan for achieving *the existing goals* for the development of the sector by 2035;
- present the role of bioenergy in fulfilling Ukraine's international commitment *to reduce GHG emissions*;
- show the contribution of bioenergy installations and technologies to the *replacement* of fossil fuel plants capacities and NPPs capacities that will be decommissioned by 2050.

An important component and the first step towards the preparation of the Ukraine's bioenergy development strategy is the Roadmap, the description of which is the subject of this report. Materials of the Roadmap can be used for the elaboration of a new Energy Strategy of Ukraine with the extension of its coverage period until 2050.

The Roadmap until 2050 should be accompanied by an Action plan that includes legislation to be developed or amended within the next five years. That is necessary to ensure the implementation of the suggested Roadmap. The Action plan in question is included in the report.

2. Policy goals.

2.1. Goals for 2030 set by Vectors of Economic Development.

On November 6, 2020, the Government of Ukraine presented the document "Vectors of Economic Development until 2030"[1]. This document, together with the presented "Economic Audit of the country" will be the basis for the development of the "National Economic Strategy 2030"[2].

Vectors of Economic Development until 2030, among other things, determine the vision, strategic goal, indicators and priority steps in the field of energy. The following planned points seem to be especially important for the energy sector of Ukraine and, in particular, for renewable energy:

- Reducing the carbon footprint of the fuel and energy complex.
- Attracting $ 10 billion investment in renewable energy.
- Reducing the share of coal generation.
- **Ensuring an increase in the biomass share in heat production up to 30%.**

According to 2018 data, the share of biomass in heat production is about 7%, and in 2020 this figure may increase to 10%. We consider the 30% planned by the Government in 2030 to be a rather ambitious goal, which corresponds to the triple figure forecasted for 2020 and is well in line with the sector development plans set out in the Heat Supply Concept[3], namely, 30% of heat production from alternative energy sources in 2025 and 40% in 2035.

- Reaching the share of RES in the total electricity production at the level of 25%.

According to 2018 data, the share of RES in electricity production is about 9%, and in 2020 this figure may increase to 11%. The 25% planned by the Government in 2030 corresponds more than double figure expected in 2020.

- Considering the production of hydrogen using excess renewable electricity in the power system, in order to further export hydrogen to the EU.
- Creating competitive markets for gas, electricity, heat, coal, oil and petroleum products; to provide competitive conditions for their transportation through the territory of Ukraine.

2.2. Goals for 2035 set by the Energy Strategy of Ukraine.

Bioenergy targets beyond 2020 are set by the **Energy Strategy of Ukraine until 2035** (2017)[4]. According to the Strategy, the contribution of RES to the total primary energy supply must be **25%** in 2035 (which is equal to 24 Mtoe), including that of biomass, biofuels and waste **11.5%** (**11** Mtoe) (**Table 2.1**). In addition, the RES share in the power generation is expected to increase to **>25%**, RES share in the transport sector will rise to **20%**, and the share of alternative fuels[5] in the local fuel and energy balances will amount to **20%** by 2035.

[1] https://assets.documentcloud.org/documents/20402477/doc-vector.pdf
[2] https://www.kmu.gov.ua/news/predstavleno-ekonomichnij-audit-krayini-ta-vektori-ekonomichnogo-rozvitku-do-2030-roku
[3] https://zakon.rada.gov.ua/laws/show/569-2017-%D1%80#Text
[4] Energy Strategy of Ukraine until 2035. Approved by CMU Resolution No. 605-p of 18.08.2017 https://zakon.rada.gov.ua/laws/show/605-2017-%D1%80
[5] Alternative fuels include biomass, biogas, liquid biofuels and some other fuels which are alternative to fossil fuels according to the Law of Ukraine "On Alternative Fuel Types" https://zakon.rada.gov.ua/laws/show/555-15#Text.

Table 2.1. Structure of TPES of Ukraine according to the Energy Strategy until 2035[4], Mtoe.

Source of primary energy	2015	2020	2025	2030	2035
	fact	forecast	forecast	forecast	forecast
Coal	27.3	18	14	13	12
Natural gas	26.1	24.3	27	28	29
Oil products	10.5	9.5	8	7.5	7
Nuclear energy	23.0	24	28	27	24
Biomass, biofuels and waste	**2.1**	**4**	**6**	**8**	**11**
Solar and wind energy	0.1	1	2	5	10
Hydro power plants	0.5	1	1	1	1
Ambient and waste heat	0.5	0.5	1.0	1.5	2.0
Total, Mtoe	**90.1**	**82.3**	**87**	**91**	**96**
Share of RES, %	**4%**	**8%**	**12%**	**17%**	**25%**
incl. biomass, biofuels and waste	**2.3%**	**4.9%**	**6.9%**	**8.8%**	**11.5%**

It should be noted that the National Security and Defense Council of Ukraine decided to ensure the revision of the Energy Strategy of Ukraine until 2035 "Security, Efficiency, Competitiveness"[6]. To implement this decision, the Government of Ukraine has developed a draft Concept of Green Energy Transition of Ukraine until 2050 (Ukraine Green Deal)[7].

2.3. Goals for 2050 set by the draft Concept of Green Energy Transition of Ukraine.

In January 2020, the Ministry of Energy and Environmental Protection of Ukraine presented the draft ***Concept of Green Energy Transition of Ukraine until 2050 (Ukraine Green Deal)***[8]. The document is developed taking into account the goals and objectives of the ***European Green Deal***[9] presented by the European Commission in December 2019.

The concept is aimed at achieving a **climate-neutral economy** of the country by 2070. Some selected main directions of decarbonization of the economy, including the energy sector as its important component, are identified as the following:

- development of RES use in combination with energy efficiency increase;

- reduction to zero consumption of carbon-intensive energy resources and maximization of the use of RES so that the agricultural and forestry sector switched to complete self-provision with energy resources;

- increasing sustainable production of **biomass, biofuels** and other RES to support the implementation of the green transition in other sectors of the economy;

[6] Resolution of the National Security and Defense Council of Ukraine of 02.12.2019 put into force by Order of President of Ukraine N 874/2019 of 02.12.2019 https://www.president.gov.ua/documents/8742019-30769
[7] Concept of Green Energy Transition of Ukraine until 2050 https://menr.gov.ua/news/34424.html
[8] Concept of Green Energy Transition of Ukraine until 2050, Ministry of Energy and Environmental Protection of Ukraine, 2020. Presentation: https://bit.ly/3edeS9u; text: https://bit.ly/2tR0P7n; https://bit.ly/2wtr8BM
[9] European Green Deal https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

- complete replacement of coal-fired power plants by 2050 due to the development of solar and wind generation, **biomass** power plants in combination with new highly maneuverable generating capacity on gas (in the longer term, on synthetic gas produced using RES);

- orientation of new DH CHP plants primarily to the use of **biomass and biogas**;

- intensification of the large-scale use of RES (**biofuels and waste**, renewable heat and power) in industrial processes to replace carbon-intensive resources.

In addition to achieving a climate-neutral economy by 2070, the Concept of Green Energy Transition also includes such areas as an increase of energy efficiency, development of electric transport, circular economy (waste reduction), smart grids, demand management, as well as support for research and innovations (**Fig. 2.1**).

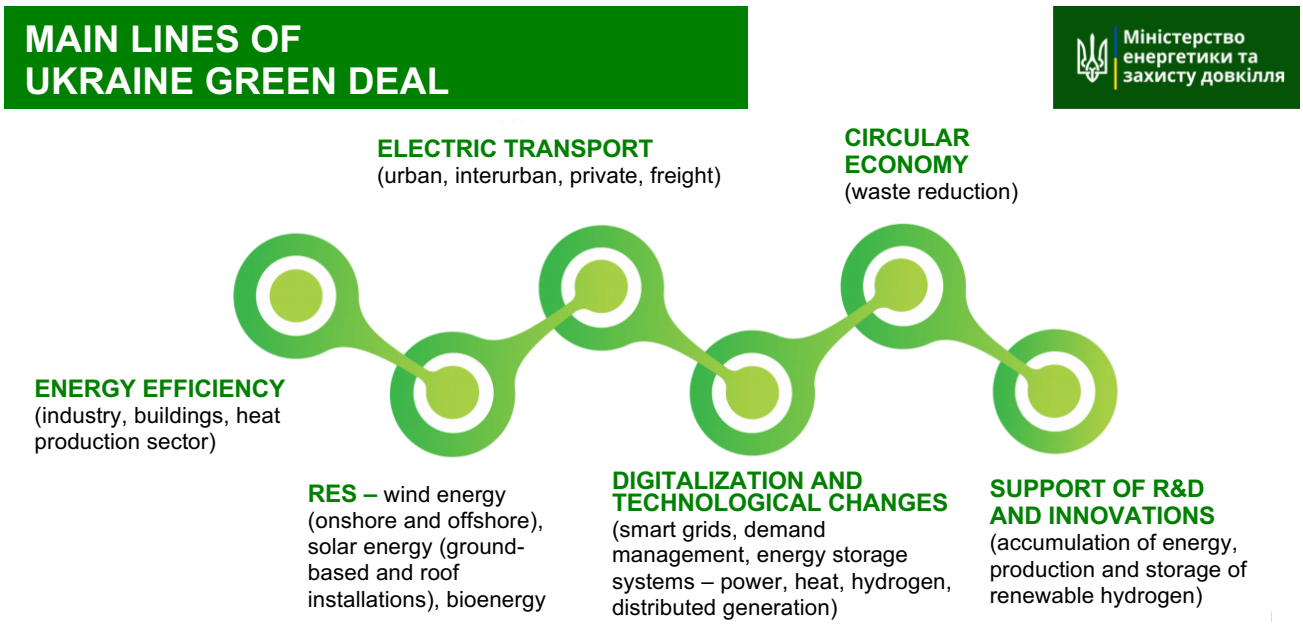


Fig. 2.1. Main directions of Ukraine Green Energy Transition until 2050[8].

3. Main advantages of bioenergy.

Biomass is a promising source of renewable energy both in the world and in Ukraine. Currently, biomass ranks fourth in the world in terms of its energy use. In recent years, Ukraine has seen a gradual increase in the number of facilities and installed capacity for the production of heat and power from biomass. Sustainable development of bioenergy makes it possible to reduce Ukraine's dependence on expensive imported energy carriers and ensure the efficient use of local biomass resources. The transition to the use of biomass for energy contributes to the development of the local economy of Ukraine's regions through the receipt of taxes and fees to local budgets. At the state level, bioenergy development is improving the country's trade and payment balance by reducing energy imports. Positive social impact is expected due to the creation of new jobs, lowered heat tariffs and improved reliability of heat supply. A large number of successful projects that have already been implemented, the economic feasibility of most bioenergy projects, state

support and assistance in the development of bioenergy encourage private investors and financial institutions to implement new bioenergy projects in Ukraine.

One of the main advantages of using biomass for energy is the availability of many options, both in terms of energy conversion technologies and in terms of end use. Biomass can be used for energy production by direct combustion (wood chips, straw bales, biomass pellets and briquettes), as well as consumed in processed form. Examples of the latter are liquid biofuels (biodiesel, bioethanol, pyrolysis oil) and gaseous biofuels (biogas, producer gas, pyrolysis gas). Biomass and biofuels can replace fossil fuels in the production of heat and electricity, as well as in the transport sector. The role of bioenergy is particularly considerable in the heat production as biomass can directly replace natural gas and coal, which is very important for Ukraine. Regarding the power sector, it should be noted that in contrast to solar and wind energy, the production of power from biomass/biogas is stable. Moreover, biomass/biogas power generation can participate in the balancing of the electricity market of Ukraine.

Due to CO_2-neutrality of biomass, bioenergy makes an important contribution to reducing greenhouse gas emissions, which is especially topical in the context of global warming and climate change. The full cycle of the production and preparation of biomass for energy is associated with certain GHG emissions caused by energy inputs; however, these emissions are much lower as compared to emissions from the consumption of fossil fuels (coal, oil and natural gas). This difference is especially noticeable in the production of heat and power. Thus, bioenergy plays a significant role in the decarbonization of energy and the reduction of GHG emissions.

4. Current state of bioenergy development in Ukraine.

Renewable energy sources are playing an increasing role in Ukraine's energy sector. According to the Energy Balance for 2018, the amount of renewable energy in the final energy consumption was **3582** ktoe, which was equivalent to **7.0%** of the total final energy consumption (**Fig. 4.1**). Of these, the largest contribution was made by bioenergy – **77.3%.**

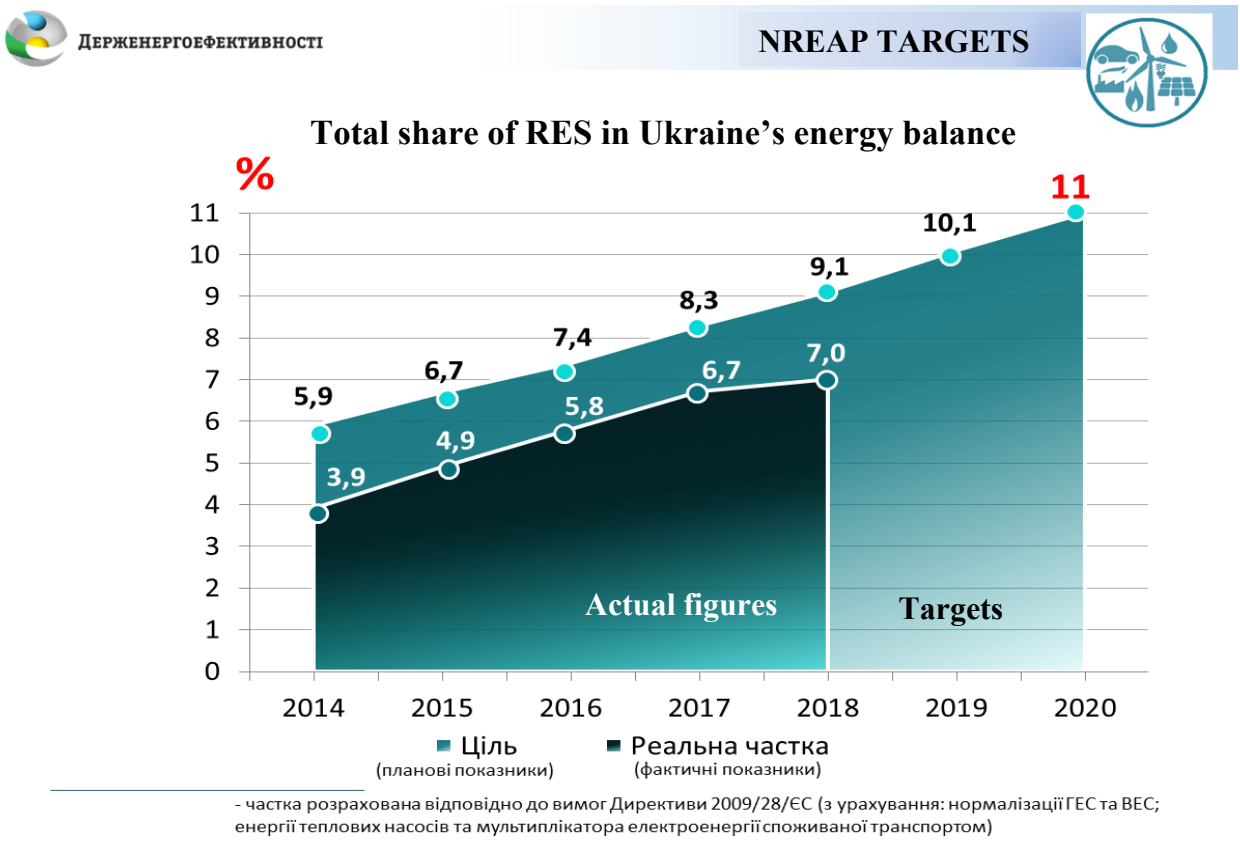


Fig. 4.1. RES share in Ukraine's final energy consumption (SAEE's data).

In Ukraine, there has been a steady trend of increasing energy production from alternative fuels, in particular, from biomass. According to the Energy Balance of Ukraine for 2018, the total supply of primary energy from biofuels and waste amounted to **3195** ktoe (**Fig. 4.2**), which is equivalent to the replacement of **4 bln m^3/yr** of natural gas. The share of biofuels in the total supply of primary energy is **3.4%** (over **70%** of the total supply of renewable energy). The growth of the sector in 2010-2018 averaged **31%** per year.

Traditionally, bioenergy has played the most important role in heat production and made there the largest contribution among all the renewables: up to 80-90%. In 2018, the share of RES in heating systems was **8%**, including **7%** of the total heat production covered at the expense of biomass.

Power production from biomass is underdeveloped in Ukraine as compared to solar and wind energy. Nevertheless, up to 20 CHPPs and TPPs running on wood chips and sunflower husk are in operation; projects of about 30 power plants are on different stages of development (from project idea to designing). In addition, there is a number of biogas cogeneration plants operating on manure, maize silage, sugar beet pulp as well as LFG power plants.

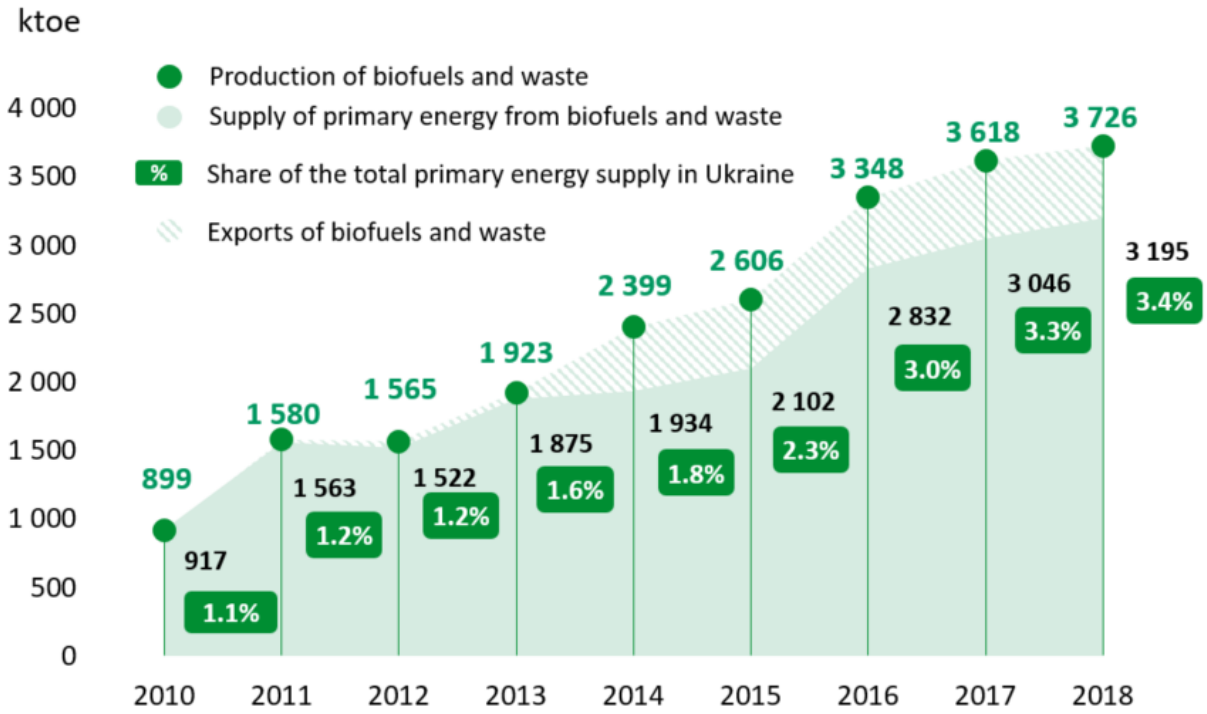


Fig. 4.2. Production and consumption of biofuels in Ukraine in 2010-2018 according to the Energy Balances prepared by the State Statistics Service of Ukraine.

Production of motor biofuels is the least developed sector of Ukraine's bioenergy. At the moment, the production of bioethanol is poorly developed; biodiesel seems not to be produced at all. One can expect the revival of the sector after the adoption of the draft Law of Ukraine On Amendments to certain legislative acts of Ukraine regarding the mandatory use of liquid biofuels (biocomponents) in the transport industry[10].

[10] Draft Law #3356 as of 17.04.2020 http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=68617

5. Basic approach and characteristics of the Roadmap for Ukraine's bioenergy development until 2050.

5.1. Goal, timeframe and benchmarks of the Roadmap.

The goal of the Roadmap is to present a realistic long-term scenario for the development of bioenergy, which corresponds to Ukraine's transition to 100% RES in 2070.

The proposed Roadmap covers the period of 2020-2050 and has several benchmarks. One of them is the year 2030 as the new NREAP is to be developed until 2030, in which at least **8** Mtoe of biomass, biofuels and waste should be consumed according to the current Ukraine's Energy Strategy. The second benchmark takes into account the goal of bioenergy development set by the Energy Strategy of Ukraine for 2035 – **11** Mtoe of biomass, biofuels and waste in the total supply of primary energy.

The Roadmap is in line with the scenario of achieving over **60%** of RES in the energy balance of Ukraine in 2050 (**Fig. 5.1**), including the individual sectors:

- power production – **70%** of RES (**Fig. 5.2**);
- heat production – **65%** of RES (**Fig. 5.3**);
- transport – **35%** of RES (**Fig. 5.4**).

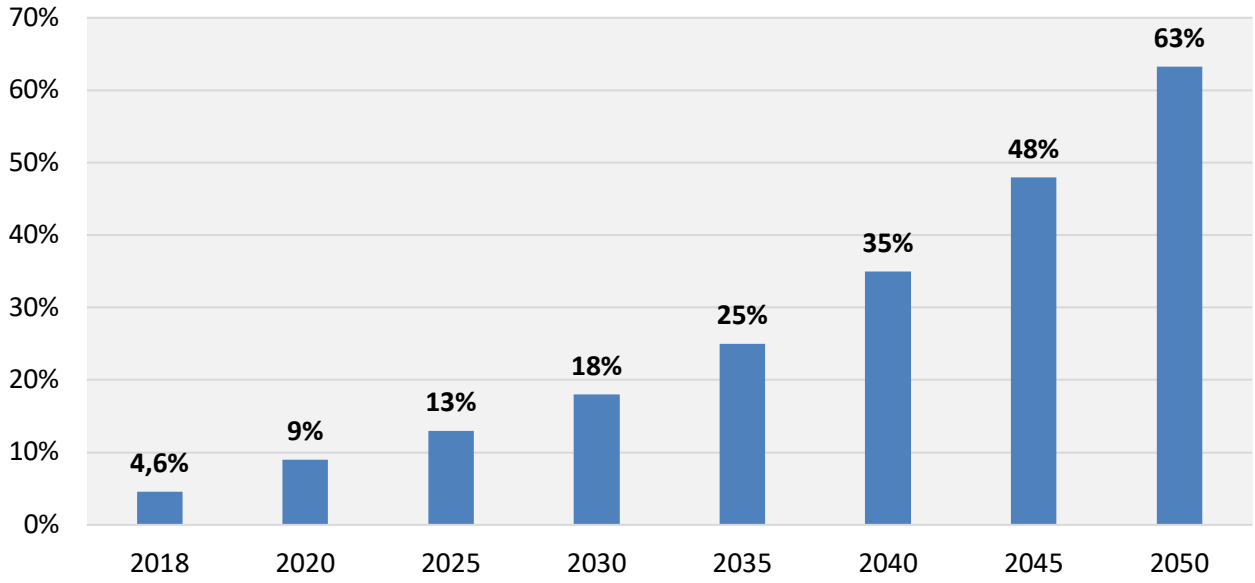


Fig. 5.1. Forecasted share of RES in Ukraine's total primary energy supply until 2050[11].

[11] The figure of 4.6% in TPES in 2018 is according to Ukraine's Energy Balance for 2018 prepared by the State Statistics Service of Ukraine. The figure of 25% in TPES in 2035 is according to the Energy Strategy of Ukraine until 2035.

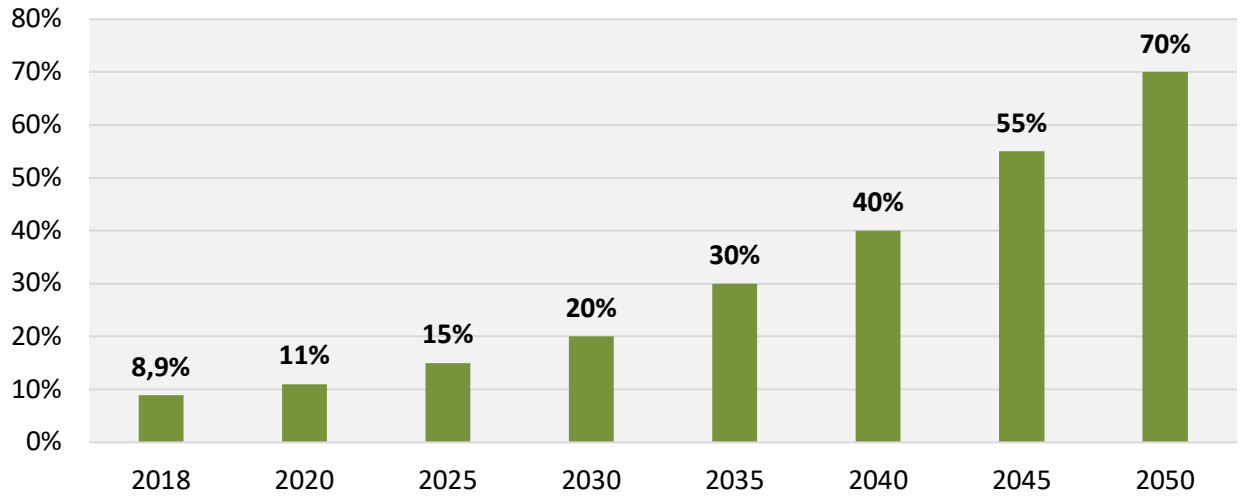


Fig. 5.2. Forecasted share of RES in the power production until 2050[12].

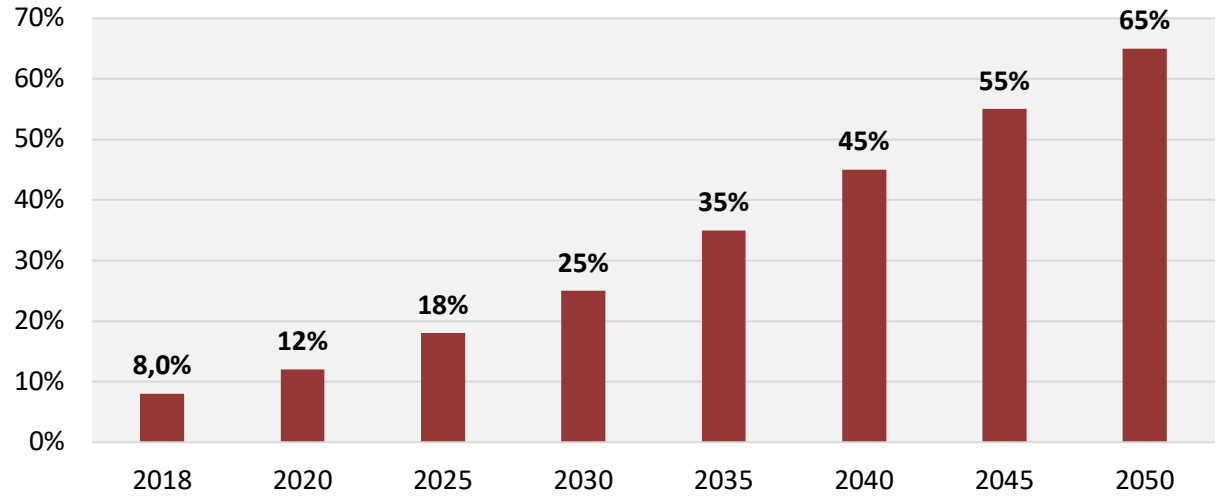


Fig. 5.3. Forecasted share of RES in the heat production until 2050[12].

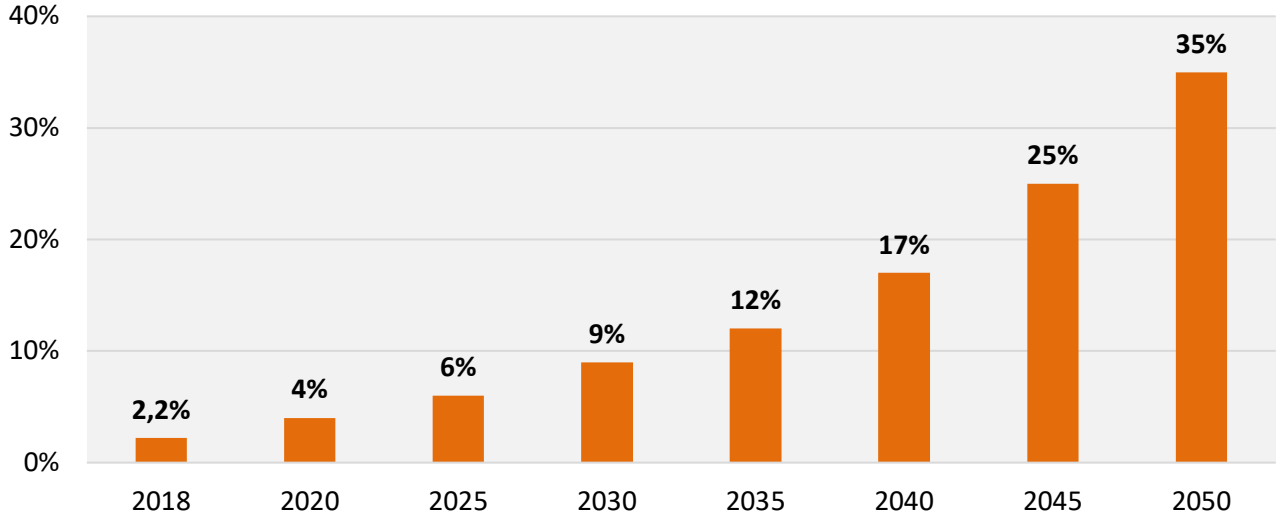


Fig. 5.4. Forecasted share of RES in the transport sector until 2050[12].

[12] The figures for 2018 correspond to SAEE's data on RES shares in power consumption, heat consumption and renewable energy in transport sector.

The realization of these goals is possible under the condition of reducing TPES in 2050 compared to 2018 (93.2 Mtoe) by 9% (up to 85 Mtoe). Regarding the production of heat from RES, it should be noted that up to 85-90% of the total amount is now provided by biomass. According to the forecast of the Bioenergy Association of Ukraine, in the future, the biggest share of heat production from RES will also fall to biomass. This approach runs counter to some "radical" predictions that Ukraine may completely move to electrical heating in the future.

The example of Lithuania, where the production of heat from biomass is actively developing with some ambitious plans for the future, seems to be demonstrative. According to Lithuania's National Energy Independence Strategy[13], by 2030, 90% of heat will be produced from RES, mainly through modern biomass CHP plants. By 2050, all heat consumed in Lithuania will be produced from RES and other clean energy sources. The Lithuanian District Heating Association notes that Lithuania has enough resources to provide 100% heating based on biofuels without causing a negative impact on the environment[14].

Taking into account the above considerations, the Roadmap for the development of Ukraine's bioenergy until 2050 provides for high biomass shares of all RES in heat production (**Fig. 5.5**). According to the dynamics of changes in TPES and its structure assumed in the Roadmap, this corresponds to the share of biomass in the total heat production in 2050 – 44% (**Fig. 5.6**).

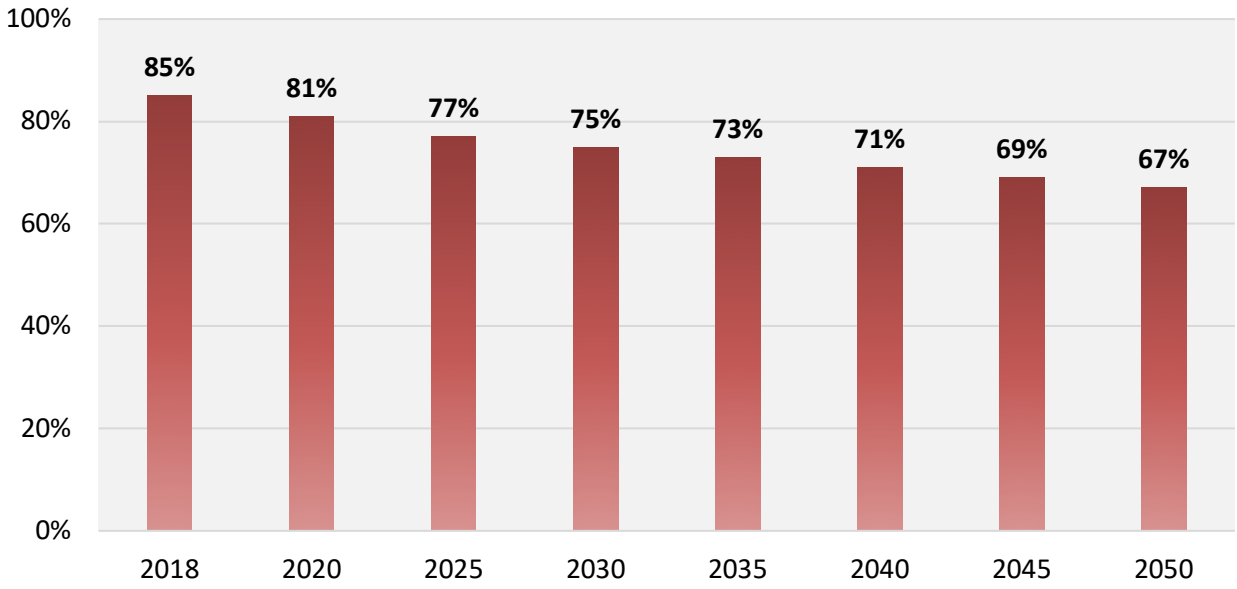


Fig. 5.5. Forecast for biomass shares of all RES in heat production[15].

[13] Lithuania's National Energy Independence Strategy
http://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018.pdf
[14] ABOUT DH SECTOR https://lsta.lt/en/about-dh-sector/
[15] The figure for 2018 is UABIO's estimation.

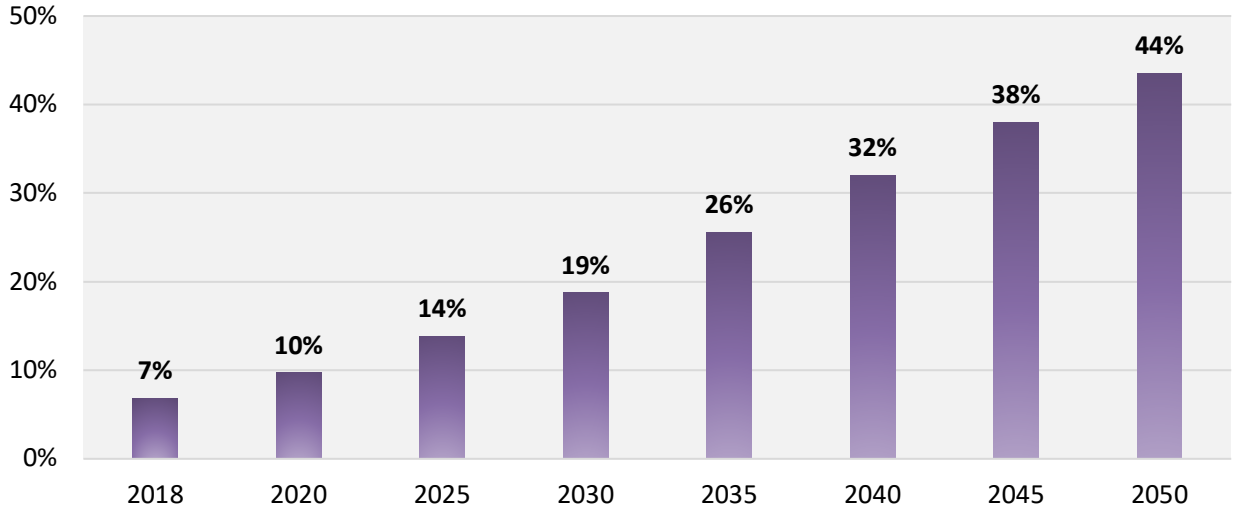


Fig. 5.6. Forecast for biomass shares in heat production[15].

Assumed in the Roadmap biomass shares of all RES in electricity production and obtained respective contribution of biomass to the total electricity production until 2050 are presented in **Fig. 5.7**, **5.8**.

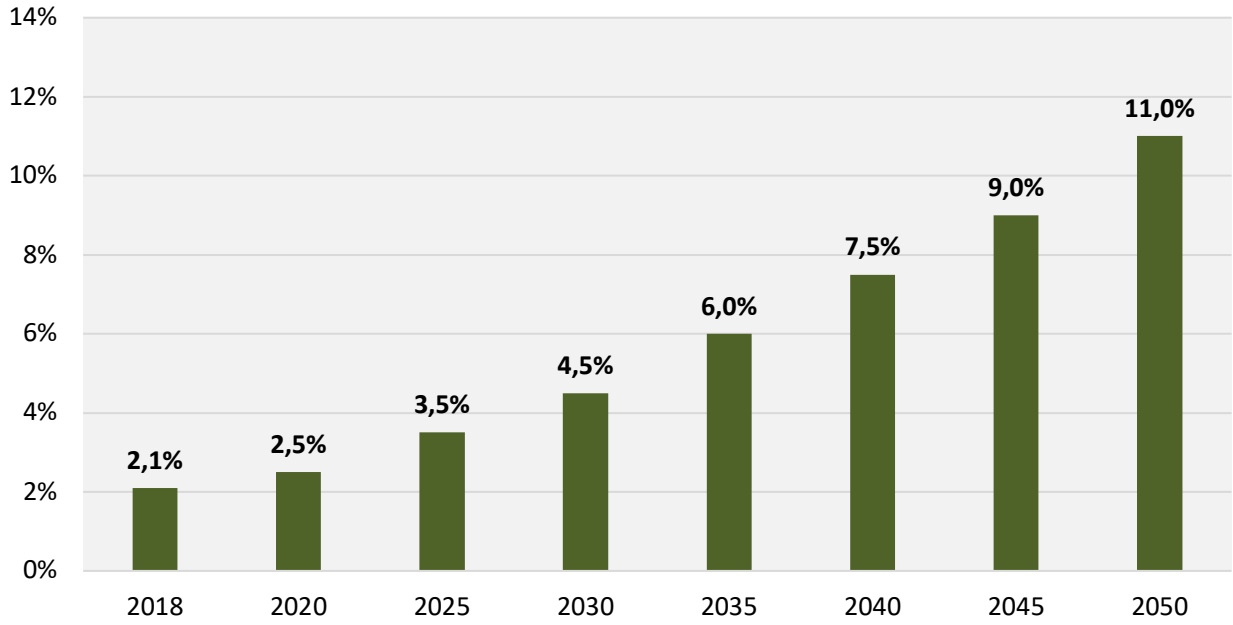


Fig. 5.7. Forecast for biomass shares of all RES in power production[16] [17].

[16] The figure for 2018 is according to the Energy Balance of Ukraine for 2018.
[17] When predicting, the authors took into account data of GLOBAL ENERGY TRANSFORMATION. A Roadmap to 2050, IRENA, 2018 (http://energytransition.in.ua/wp-content/uploads/2018/12/IRENA_Report_GET_2018.pdf) considering Ukraine's conditions (current and future bioenergy potential, state of the art and prospects for the development of other RES etc.).

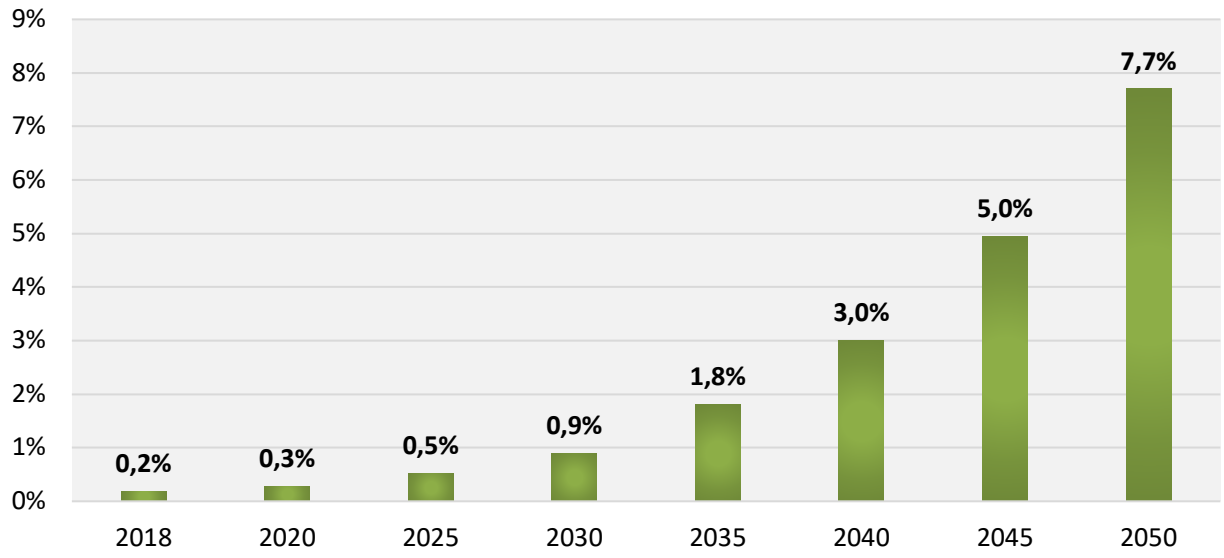


Fig. 5.8. Forecast for biomass shares in power production[18].

When modelling the development of the motor biofuels sector in Ukraine, we used some results of the project "Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties"[19] (**Fig. 5.9, 5.10**) and data of IRENA's Roadmap to 2050[20] for the global energy transformation (**Fig. 5.11**).

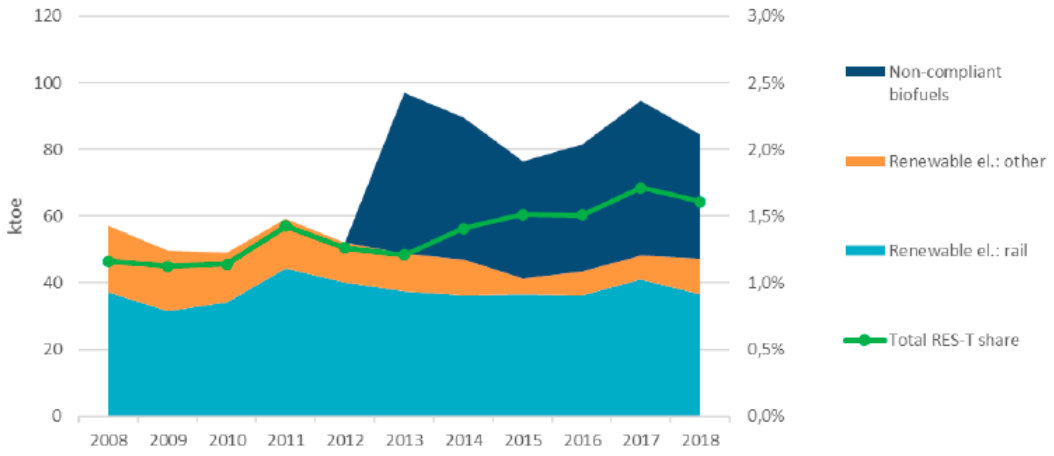


Fig. 5.9. Renewable energy consumption in transport sector in Ukraine[19].

[18] The figure for 2018 was calculated based on data of the Energy Balance of Ukraine for 2018 and SAEE.
[19] Project "Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties" (2019-2020) was carried out in cooperation with SAEE. Project results regarding Ukraine were presented at a webinar on 16.10.2020.
[20] GLOBAL ENERGY TRANSFORMATION. A Roadmap to 2050, IRENA, 2018 (http://energytransition.in.ua/wp-content/uploads/2018/12/IRENA_Report_GET_2018.pdf)

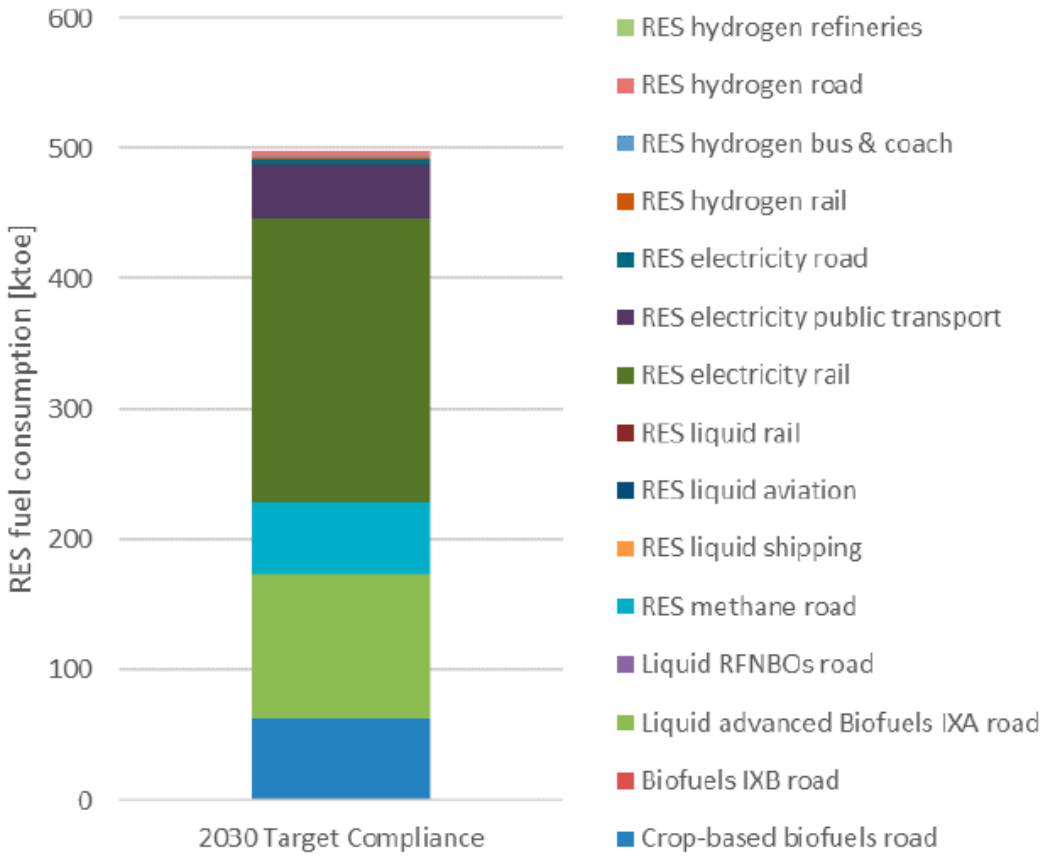


Fig. 5.10. Forecasted structure of renewable energy consumption in Ukraine's transport sector in 2030[19].

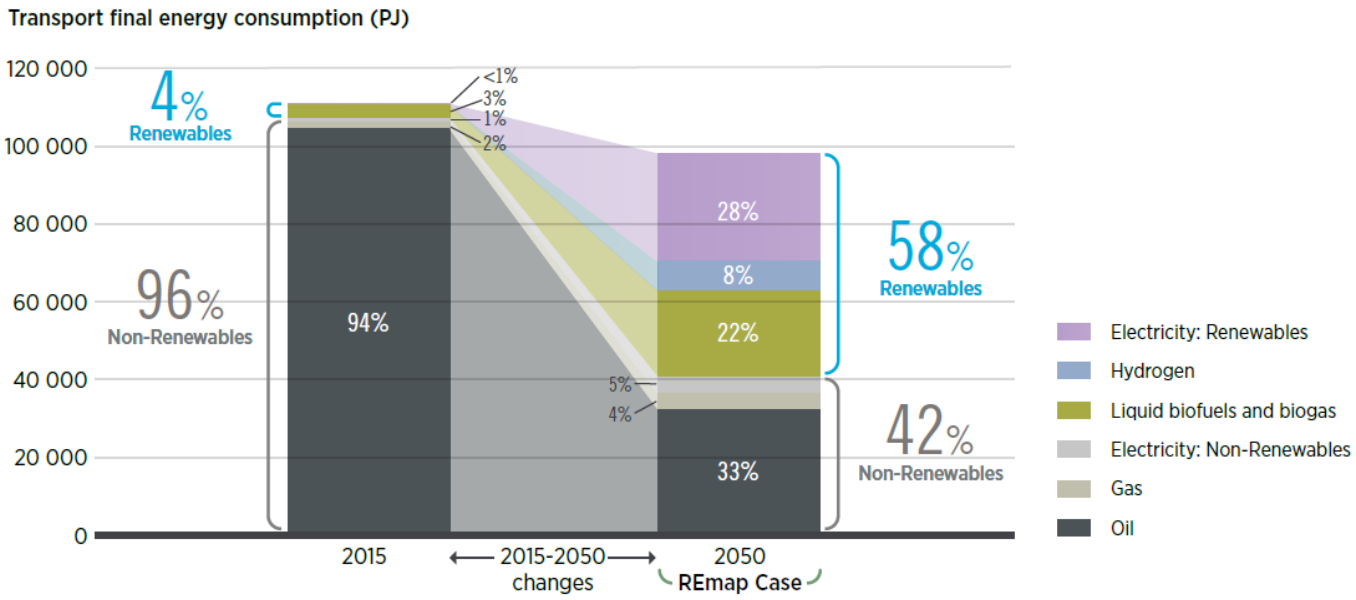


Fig. 5.11. Structure of the global transport final energy consumption until 2050[20].

Assumed in the Roadmap biomass shares of all RES in transport sector and obtained respective contribution of biomass to the energy consumption in transport until 2050 are presented in **Fig. 5.12**, **5.13**.

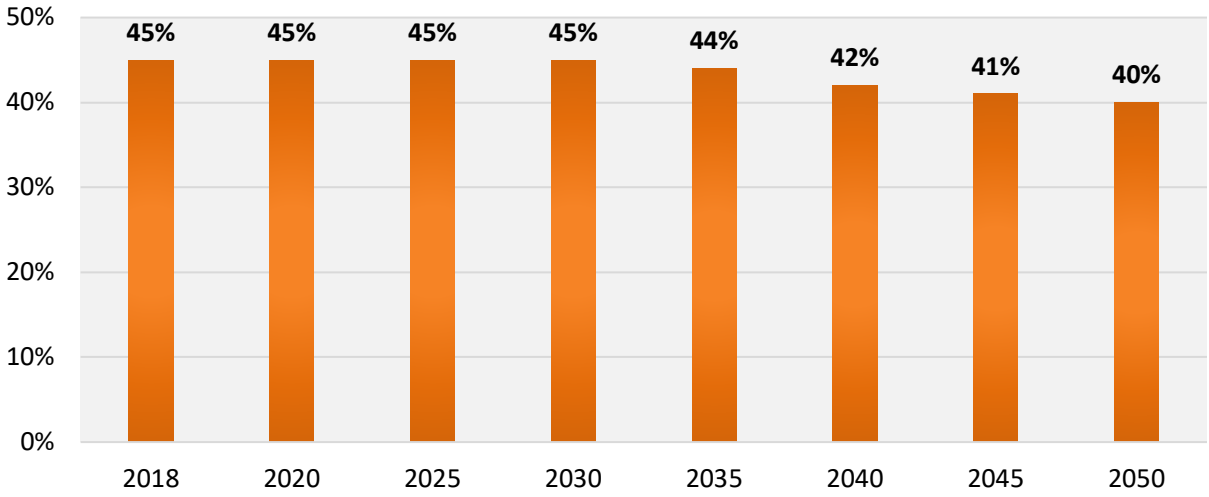


Fig. 5.12. Forecast for biomass shares of all RES in transport sector[21].

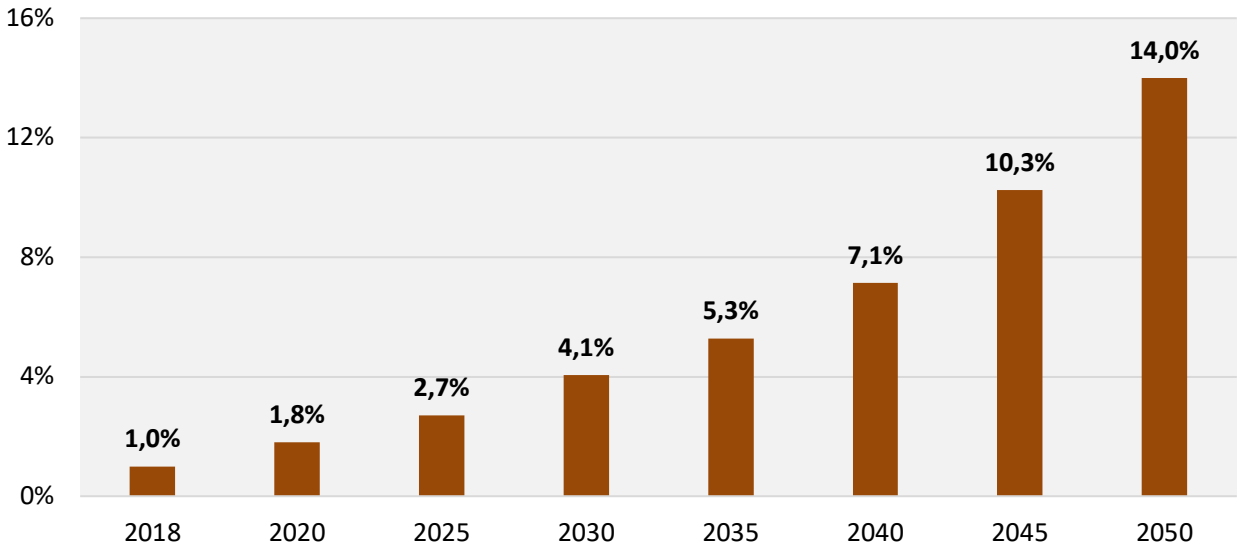


Рис. 5.13. Forecast for biomass shares in the total final energy consumption in transport[22].

Based on the forecasted bioenergy development in the heat, electricity and transport sectors, we have obtained data on the possible contribution of biomass/biofuels to renewable energy production and to the total primary energy supply in Ukraine by 2050: 38% and 24% in 2050, respectively (**Fig. 5.14, 5.15**).

[21] Figures for 2018 and 2030 are estimation of project "Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties" (2019-2020).
[22] Figure for 2018 is calculated based on data of project "Modalities to foster use of renewable energy sources in the transport sector by the Energy Community Contracting Parties" (2019-2020) and SAEE.

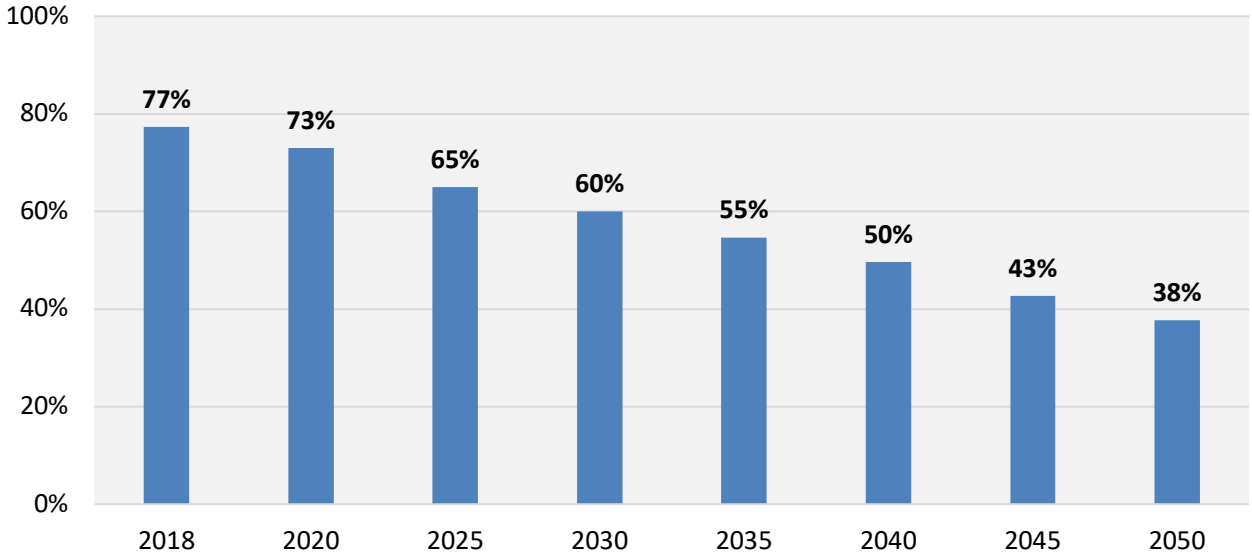


Fig. 5.14. Forecasted biomass shares of all RES in Ukraine's total primary energy supply[16].

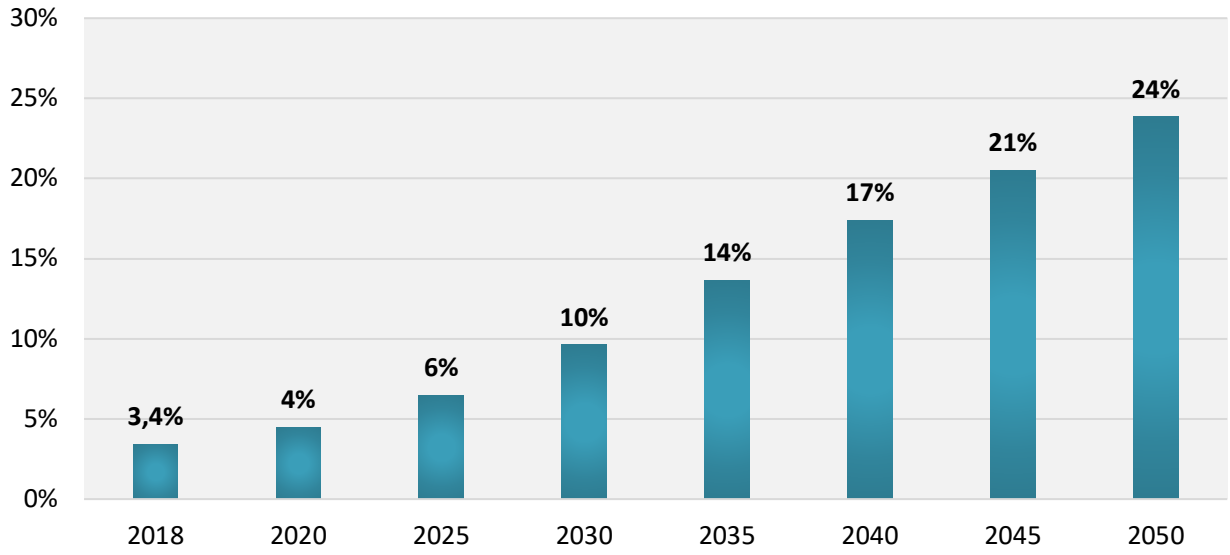


Fig. 5.15. Forecasted contribution of bioenergy to Ukraine's total primary energy supply[16].

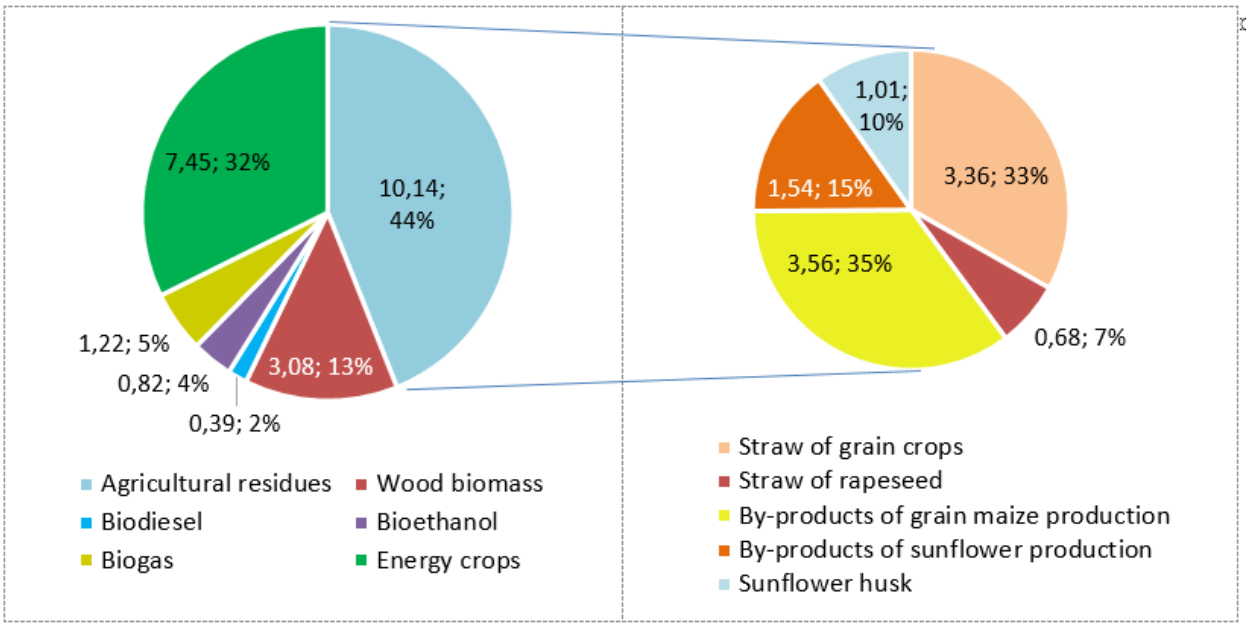
5.2. Biomass potential in Ukraine and its estimation until 2050.

According to 2018 data, the potential of biomass for energy in Ukraine is about **23** Mtoe, the biggest constituents being agricultural residues (44% of the total) and energy crops (32%) (**Table 5.1, Fig. 5.16**). Within the agricultural residues, the largest amounts fall to the shares of grain crops straw (33%) and by-products of grain maize production (35%).

Table 5.1. Bioenergy potential in Ukraine in 2018.

Type of biomass	Theoretical potential, million tons	Potential available for energy (economic potential)	
		Share of the theoretical potential, %	Mtoe
Straw of grain crops	32.8	30	3.36
Rapeseed straw	4.9	40	0.68
By-products of grain maize production (stalks, cobs)	46.5	40	3.56
By-products of sunflower production (stalks, heads)	26.9	40	1.54
Secondary agricultural residues (sunflower husk)	2.4	100	1.00
Wood biomass (fuel wood, felling residues, wood processing waste)	8.8	96	2.06
Wood biomass (deadwood, wood from shelterbelt forests, biomass from APPR)	8.8	45	1.02
Biodiesel (from rapeseed)	-	-	0.39
Bioethanol (from maize and sugar beet)	-	-	0.82
Biogas from waste and by-products of agro-industrial complex	2.8 bln m^3 CH_4	42	0.99
Landfill gas	0.6 bln m^3 CH_4	29	0.14
Sewage gas (industrial and municipal wastewater)	0.4 bln m^3 CH_4	28	0.09
Energy crops:			
- willow, poplar, miscanthus (1 mln ha*);	11.5	100	4.88
- maize for biogas (1 mln ha*).	3.0 bln m^3 CH_4	100	2.57
Total	**-**	**-**	**23.10**

** Provided that 1 million hectares of unused agricultural land is used for growing the energy crops.*



a) Total potential of biomass *b) Potential of agricultural residues*

Fig. 5.16. Structure of the biomass potential in Ukraine (2018), **Mtoe**.

Expert estimation shows that in 2050 this potential may increase to more than **47.5** Mtoe/yr that is practically double as compared with 2018 (**Table 5.2**). Thus, the level of biofuel consumption in 2050 (about **20** Mtoe) envisaged in the Roadmap will come to only **43%** of the biomass potential available at that time.

Table 5.2. Forecast for the energy potential of biomass in Ukraine in 2050.

Type of biomass	Theoretical potential, million tons	Potential available for energy (economic potential)	
		Share of theoretical potential, %	Mtoe
Straw of grain crops*	49.2	30	5.04
Rapeseed straw	4.9	40	0.68
By-products of grain maize production (stalks, cobs)*	58.1	40	4.45
By-products of sunflower production (stalks, heads)	26.9	40	1.54
Secondary agricultural residues (sunflower husk)	2.4	100	1.00
Wood biomass (fuel wood, felling residues, wood processing waste)*	12.3	96	2.88
Wood biomass (deadwood, wood from shelterbelt forests, biomass from APPR)	8.8	45	1.02
Biodiesel (I and II generation)*	-	-	1.10
Bioethanol (I and II generation)*	-	-	2.33
Biogas from waste and by-products of agro-industrial complex*	8.4 bln m^3 CH_4	83	5.92
Biogas from MSW*	0.7 bln m^3 CH_4	70	0.42
Sewage gas (industrial and municipal wastewater)*	0.4 bln m^3 CH_4	31	0.11
Energy crops*:			
- willow, poplar, miscanthus (2 mln ha**);	34.5	100	14.65
- maize for biogas (2 mln ha**).	7.5 bln m^3 CH_4	100	6.43
Total	**-**	**-**	**47.57**

** Components of the biomass potential, the growth of which is expected by 2050. Other components are left at their level estimated for 2018 according to the conservative approach.*
*** Provided that 2 million hectares of unused agricultural land are used for growing the energy crops.*

Main factors for the growth of energy potential of biomass until 2050 include:

- Increase in the yield of crops, first of all, cereals.

Analysis of the current state and current trends in agriculture of Ukraine, as well as data on grain crops yield in Ukraine and the EU countries (FAOSTAT statistics[23]) shows that the yield of wheat

[23] FAOSTAT. Crops http://www.fao.org/faostat/en/#data/QC

and maize in Ukraine may increase 1.5 and 1.4 times by 2050, respectively.

- *Significant increase in the economic potential of biogas obtained from different types of feedstock due to the following factors:*

- expansion of feedstock types for biogas production by including crop residues;
- growth of main products output by various industries;
- consolidation of livestock enterprises;
- switch from MSW landfilling to the mechanical and biological treatment technology.

- *Doubling of areas under energy crops and an increase in their yield.*

It is assumed that in 2050 the area under energy crops will be 2 million hectares for willow, poplar, miscanthus and another 2 million hectares for maize for biogas.

- *Growth of the level of the net annual forest increment fellings.*

Analysis of the current state and current trends in forestry in Ukraine, as well as data on the level of felling of the net annual forest increment in Ukraine and the EU countries (Bioenergy Europe Statistical Report on Biomass Supply 2019[24], fig. 13) shows that this figure may increase by1.4 times (from ~ 51% to ~ 71%) in Ukraine[25].

- *Switchover to II generation biofuels and new types of feedstock for I generation biofuels.*

Assessment of the potential of liquid biofuels for 2018 is based on I generation biodiesel (from rapeseed) and I generation bioethanol (from sugar beet molasses and maize grain). Estimation of the potential for 2050 considers the production of II generation biofuels (from lignocellulose feedstock) and the use of new types of feedstock (for example, waste cooking oil, animal fats) for the production of I generation biofuels.

5.3. Sustainability criteria for biomass.

In the EU, the RED II[26] defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with to be counted towards the overall 14% target of RES on transport by 2030 and to be eligible for financial support by public authorities. Some of these criteria are the same as in the original RED I[27], while others are new or reformulated. In particular, the RED II introduces sustainability for forestry feedstocks as well as GHG criteria for solid and gaseous biomass fuels (**Table 5.3**).

Default GHG emission values and calculation rules are provided in Annex V (for liquid biofuels) and Annex VI (for solid and gaseous biomass for power and heat production) of the RED II. The Commission can revise and update the default values of GHG emissions when technological developments make it necessary. Economic operators have the option to either use default GHG intensity values provided in RED II or to calculate actual values for their pathway.

[24] Bioenergy Europe Statistical Report on Biomass Supply 2019
https://bioenergyeurope.org/article/178-biomass-supply-report.html
[25] Justification can be found in UABIO's Position Paper N 19 (2018)
"Opportunities for wood fuel harvesting in forests of Ukraine"
https://uabio.org/wp-content/uploads/2018/01/position-paper-uabio-19-en.pdf
[26] DIRECTIVE (EU) 2018/2001
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN
[27] DIRECTIVE 2009/28/EC
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

Table 5.3. Greenhouse gas savings thresholds in RED II[28].

Plant operation start date	Transport biofuels	Transport renewable fuels of non-biological origin	Electricity, heating and cooling
Before October 2015	50%	-	-
After October 2015	60%	-	-
After January 2021	65%	70%	70%
After January 2026	65%	70%	80%

As for Ukraine, by becoming a full member of the Energy Community in 2011, the country has committed itself to implementing a number of regulations, including RED I. In accordance with the requirements of the Directive, Ukraine has developed and adopted the National Renewable Energy Action Plan for the period until 2020 (approved by the Order of the Cabinet of Ministers of Ukraine of October 1, 2014, No. 902-r). This document sets the national indicative target for achieving 11% of RES in the gross final energy consumption by 2020, as well as 10% of RES consumption in the transport sector. NREAP states that the quantitative assessment of the expected volume of RES consumption in transport takes into account biofuels that meet the sustainability criteria. However, these criteria are not detailed in this document, and the requirement that biofuels must meet the sustainability criteria for enrollment in the 2020 target is not explicitly included.

The Order of the Cabinet of Ministers of Ukraine of September 3, 2014, No. 791-r approved the Action Plan for the Implementation of RED I. Clause 12 of this Order provided for the development of sustainability criteria for biofuels and biofuel liquids in Ukraine by December 30, 2014. So far, these criteria have not been implemented into the national legislation. As a member of the Energy Community, Ukraine is also obliged to implement RED II. However, to date, there are no documents or legislative initiatives that regulate such implementation.

The draft Law #3356 "On Amendments to certain legislative acts of Ukraine regarding the mandatory use of liquid biofuels (biocomponents) in the transport industry" was registered in Ukrainian Parliament on 17/04/2020. The Law contains, among other, a declaration that liquid biofuel (biocomponents), which is taken into account to comply with the mandatory statutory share in the sales of motor gasoline in the customs territory of Ukraine from July 1, 2022, must meet the criteria of sustainability. The draft law states that the procedure for confirming compliance with the sustainability criteria for liquid biofuels (biocomponents) and biogas intended for the use in transport ***shall be approved by the Cabinet of Ministers of Ukraine*** taking into account Ukraine's obligations under the Energy Community and the Association Agreement between Ukraine on the one part, and the European Union, the European Atomic Energy Community and their Member States, on the other part. However, at the same time, it is noted that the verification of compliance should take place with the involvement of voluntary certification systems. Article 8-2 "Sustainability criteria for liquid biofuels (biocomponents) and biogas intended for the transport use" of the draft Law provides the list of the sustainability criteria for the protection of land plots with high biodiversity, high carbon reserves, peatlands and wetlands according to the RED. There are no GHG emission reduction requirements in the text of the draft Law. Technical requirements

[28] Renewable Energy – Recast to 2030 (RED II) https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

for the reduction of greenhouse gas emissions for the production and use of liquid biofuels (biocomponents) and biogas intended for the use in the field of transport shall be determined in accordance with the national standard according to the Law.

The first version of the national standard "Biofuels and bioliquids. Greenhouse gases. Technical requirements" has been developed by the Institute for Environment and Energy Conservation in cooperation with the USAID project "Municipal energy reform in Ukraine" and the State Agency of Energy Efficiency and Energy Saving of Ukraine. This normative document aims to identify and provide information to economic operators for the production and use of biofuels and bioliquids, namely on: Technical requirements for greenhouse gas emissions; Reference value of greenhouse gas emissions for fossil fuels; The use of default values for the calculation of greenhouse gas emissions reduction; Rules of calculation of actual greenhouse gas emissions and their reductions. Officially, this standard has not been adopted yet.

5.4. Suggested use of bioenergy potential by types of biomass and obtained energy carrier until 2050.

The structure and directions of using bioenergy potential envisaged in the Roadmap are presented in **Fig. 5.17, 5.18.** The covered types of biofuels include wood biomass, primary and secondary agricultural residues, energy crops, biogas/biomethane from different types of feedstock and liquid biofuels (biodiesel and bioethanol), the total amount of consumption in 2050 being over **20** Mtoe. Directions of biofuels use include the production of heat, power, biomethane and motor biofuels. Biomethane will be used for power and heat production, as gaseous motor fuel and also partly exported.

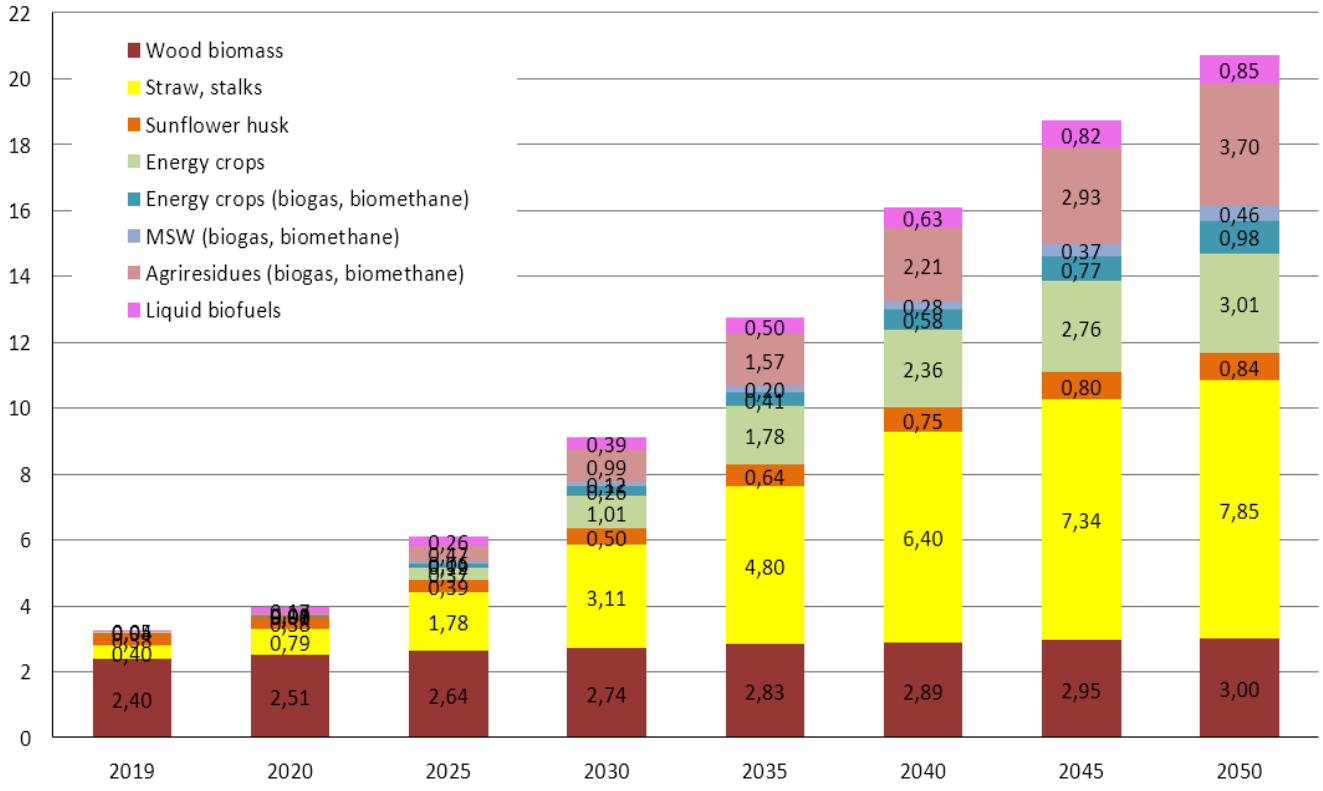


Fig. 5.17. Suggested structure of biofuels production in Ukraine until 2050, by type, **Mtoe**.

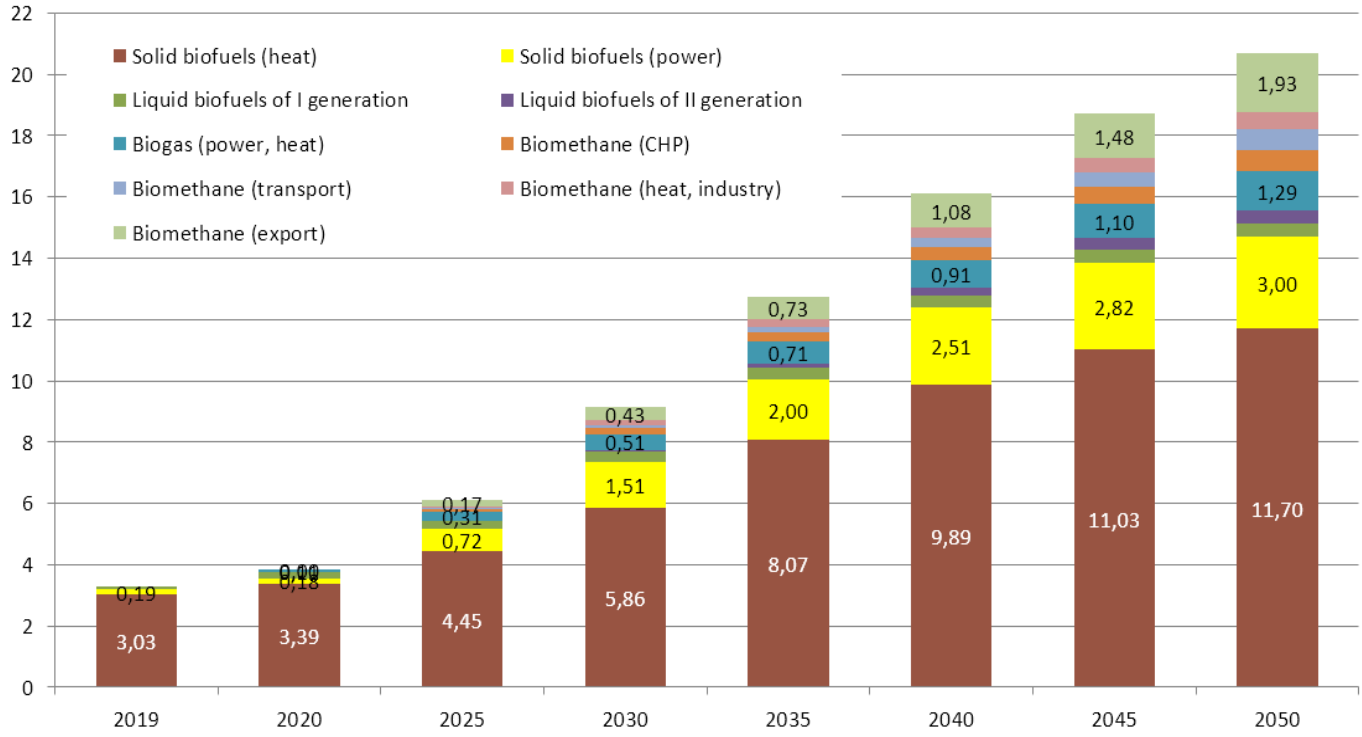


Fig. 5.18. Suggested structure of biofuels production in Ukraine until 2050, by type of the obtained energy carrier, **Mtoe**.

The suggested structure of production and consumption of biofuels takes into account and reflect ***the key trends*** that, according to the expert prediction, will take place in the bioenergy sector of Ukraine during 2020-2050:

- *Increase in the share of agrobiomass, namely agricultural residues and energy crops, in the structure of solid biofuels consumption up to 60% and 20% of the total in 2050, respectively.*

Currently, the main components of the energy potential of biomass in Ukraine are primary agricultural residues (straw of cereals and rapeseed, by-products of maize for grain and sunflower production) and energy crops (willow, poplar, miscanthus for solid biofuels and maize silage for biogas production). The share of primary agricultural residues is almost 40% of the total potential (hereinafter data for 2018), and that of energy crops is 32%. However, in the structure of energy production from biomass in Ukraine, the primary agricultural residues and energy crops rank last as their potential is used only by 0…3% depending on the type of biomass. The Roadmap envisages a significant increase in the energy production from agrobiomass, primarily stalks and other by-products of maize and sunflower production.

- *Minimal growth in the use of wood biofuels, namely 1.2 times in 2050 (against 8 times for agricultural residues during 2020-2050).*

The share of wood biomass in the structure of bioenergy potential in Ukraine is only about 13%; however, the utilization of the potential exceeds 80%. Based on the principles of sustainable development, the Roadmap envisages the minimum growth in the energy production from wood

biofuels required to meet the 2050 targets. This growth can be achieved through the involvement of felling residues, deadwood, wood from the reconstruction and renewal of shelterbelt forests, residues from pruning and removal of orchards and vineyards in energy production. It is also planned to increase the level of felling of the net annual forest increment from the current ~ 51% to ~ 71%[25], which is in line with European experience[24].

- *Increase in the production of biogas and liquid biofuels: up to 1.29 Mtoe/yr and 0.85 Mtoe/yr, respectively, in 2050.*

Ukraine has the necessary prerequisites and opportunities for a significant increase in the production of liquid and gaseous biofuels. Feedstock for biogas production can be agricultural residues (primary residues such as straw; secondary residues such as spent grain in beer production, sugar beet pulp; manure), energy crops (maize silage), as well as MSW and some other types of biomass. Liquid motor biofuels include bioethanol and biodiesel. In Ukraine, traditional feedstock for the production of liquid biofuels of the first generation is maize grain, sugar beet molasses for bioethanol and rapeseed for biodiesel.

- *The launch and considerable growth of the production of biomethane and motor biofuels of the second generation: up to 3.9 Mtoe/yr and 0.43 Mtoe/yr in 2050, respectively.*

Production and consumption of biomethane not only for power/heat production but also as motor fuel as well as production and consumption of second-generation motor biofuels are relatively new but very promising sectors of bioenergy.

In Ukraine, unlike in Europe, the production and consumption of biomethane for the production of electricity/heat and for use in transport, as well as the production of motor biofuels of the second generation have not begun to develop yet unfortunately. The Roadmap envisages the launch and growth of the production of these types of biofuels. This is in line with European trends and offers some clear benefits for the country's energy and transport sectors.

5.5. Biofuels in the sectors of heat production, power production and transport.

In Ukraine, more than half of the final energy consumption is accounted for heat (**Fig. 5.19**). Taking this into consideration, according to the Roadmap, about a half of the total consumption of biofuels will fall to solid biofuels used for heat production (11.7 Mtoe) in 2050 (see **Fig. 5.18**). The rest will be divided into relatively comparable proportions between solid biofuels for electricity production (3.0 Mtoe), biogas (2.36 Mtoe), and biomethane (2.36 Mtoe). The smallest share of the total biofuel consumption in 2050 falls to liquid biofuels (0.85 Mtoe); of them, the second generation biofuels (the production of which has not started yet in Ukraine at all) account for 0.43 Mtoe.

Forecast for the structure of the use of solid biofuels for the production of heat and power in different sectors in Ukraine is presented in **Fig. 5.20, 5.21**. These data show that the volume of heat production from solid biomass will be comparable in DH/public sector, industry and individual heating closer to 2050, while power production from biomass will be concentrated more in the industrial sector during the whole period until 2050.

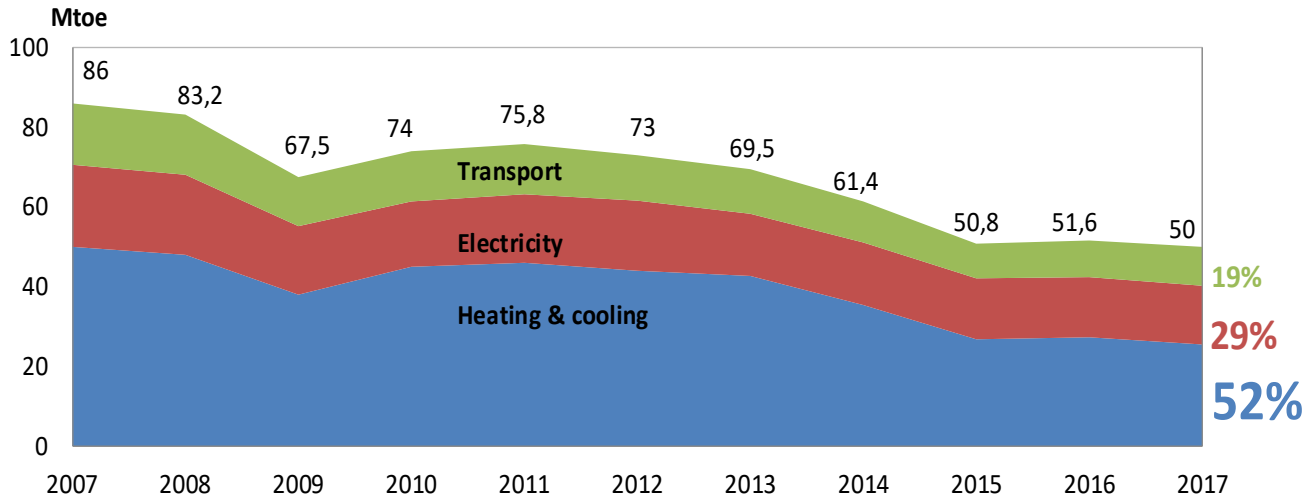
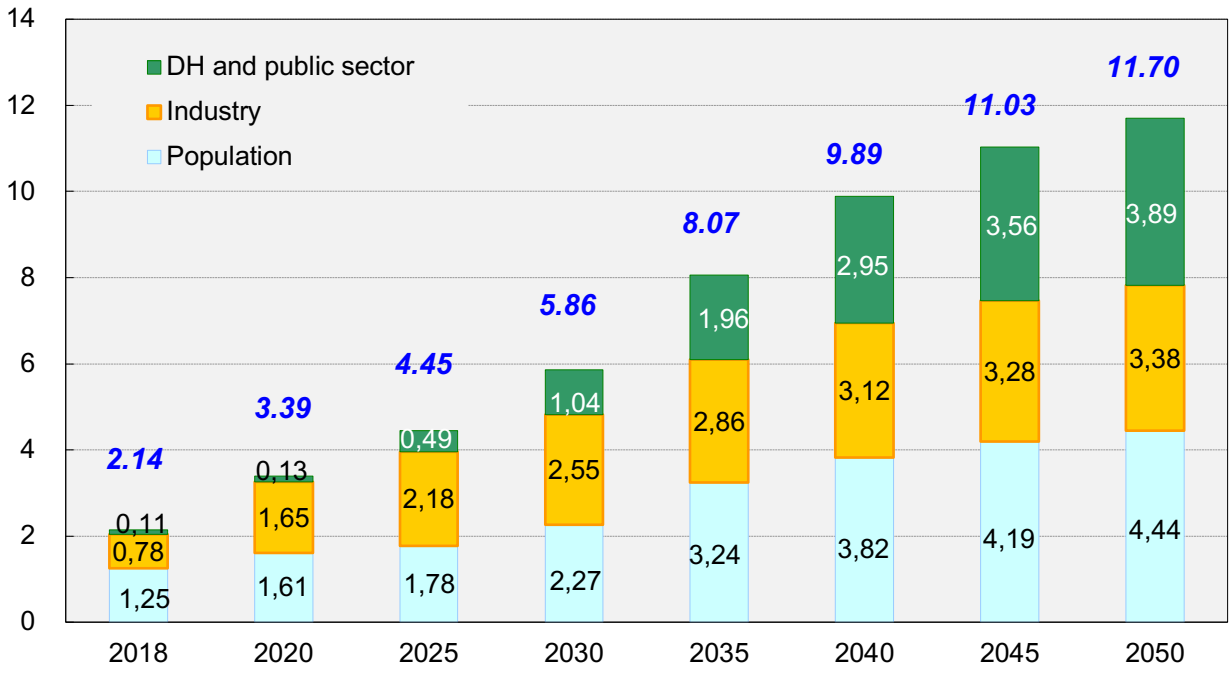


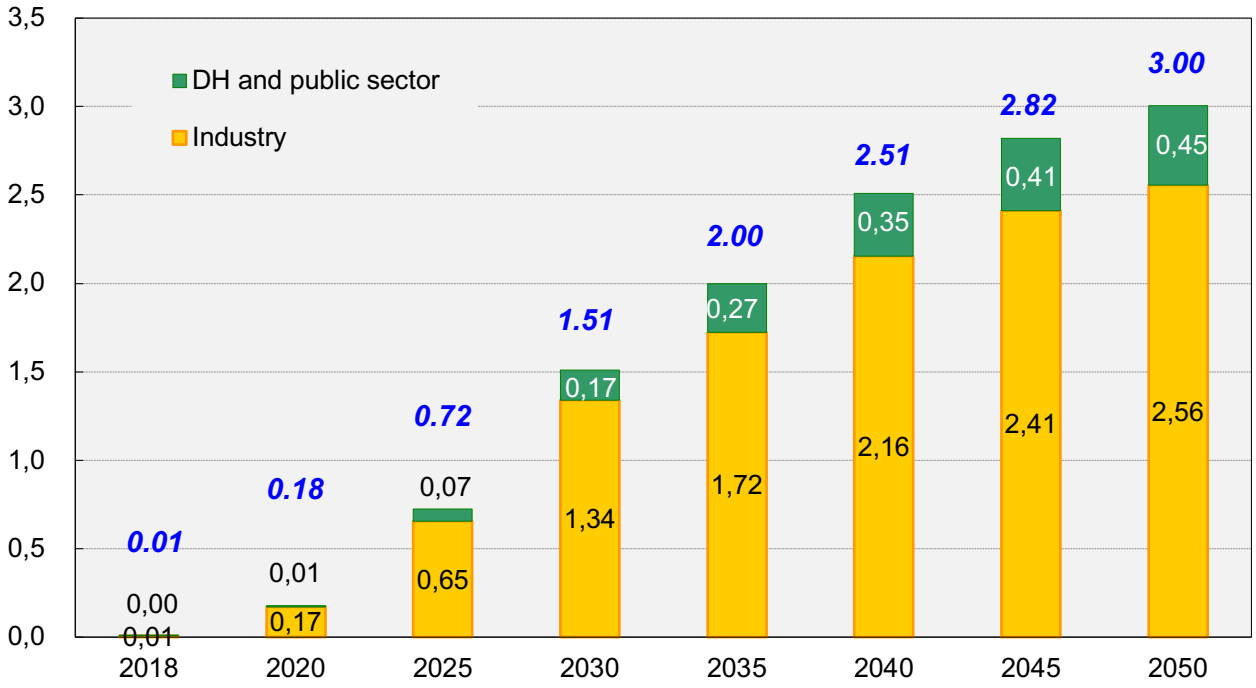
Fig. 5.19. Structure of Ukraine's final energy consumption by sectors, 2007-2017[29].



The upper figures are sums total by sectors

Fig. 5.20. Forecasted structure of using solid biofuels for heat production in different sectors in Ukraine, **Mtoe**.

[29] Calculated based on data of Ukraine's Energy Balances.



The upper figures are sums total by sectors

Fig. 5.21. Forecasted structure of using solid biofuels for power production in different sectors in Ukraine, **Mtoe**.

5.6. Envisaged bioenergy technologies and equipment to be introduced until 2050.

It is estimated that the total installed capacity of bioenergy equipment will be about **48** GW_{th} and **4** GW_{el} in 2050. The total consumption of biofuels will be over **20** Mtoe/yr, which actually corresponds to almost entire current potential of biomass in Ukraine (see **Table 5.1**).

Table 5.4 presents the distribution of equipment by sectors in 2050: household sector (domestic boilers and stoves on solid biofuels), DH/public sector (boilers and CHP plants on solid biofuels), and industry (boilers, CHP plants, TPPs, ORC TPPs on solid biofuels, CHP plants on biogas/biomethane).

Table 5.4. Envisaged installed capacity of bioenergy equipment in Ukraine in 2050.

Type of equipment	Total installed capacity in 2050	
	MW_{th}	**MW_{el}**
Household sector		
Domestic boilers and stoves on wood biomass (firewood, pellets, briquettes)	5285	
Domestic boilers on agrobiomass (pellets, briquettes, small bales)	7500	
Domestic boilers on energy crops (pellets, chips)	6000	
DH + public sector		
Boilers (wood biomass)	600	
Boilers (primary agricultural residues)	12750	
Boilers (secondary agricultural residues)	900	
Boilers (energy crops)	2750	
CHP plants (wood biomass)	225	75
CHP plants (primary agricultural residues)	1500	500
CHP plants (energy crops)	2250	750
Industry		
Boilers (wood biomass)	1400	
Boilers (primary agricultural residues)	3000	
Boilers (secondary agricultural residues)	300	
CHP plants (wood biomass)	240	80
CHP plants (primary agricultural residues)	1520	475
CHP plants (secondary agricultural residues)	300	100
CHP plants (biogas, biomethane)	1536	1151
TPPs (primary agricultural residues)		380
TPPs (secondary agricultural residues)		160
TPPs (wood)		55
TPPs (energy crops)		340
TPPs ORC (primary agricultural residues)		25
Total	**48056**	**4091**

5.7. Assessment of investments required for implementing Roadmap until 2050.

Preliminary expert estimates indicate that the implementation of the Roadmap requires investments in the range of **21…33.5** billion EUR, depending on the cost of the equipment to be installed. Approximate distribution of the investments by type of bioenergy equipment/technologies is given in **Table 5.5**.

Table 5.5. Assessment of investments required for the implementation of the Roadmap.

Types of bioenergy equipment/technology	Specific capital costs*	Expected investments, bln EUR
Individual boilers and stoves on solid biomass.	50…100 EUR/kW_{th}	0.9…1.9
Boilers on solid biomass.	200…300 EUR/kW_{th}	4.3…6.5
CHP plants/TPPs on solid biomass.	2500…4000 EUR/kW_{el}	7.4…11.8
CHP plants on biogas/biomethane (agricultural residues, landfill gas, mechanical and biological treatment of waste, wastewater).	2500…4000 EUR/kW_{el}	5.7…9.1
Production of biomethane (motor fuel).	10000…16000 EUR/(m^3 CH_4/hr)	1.1…1.8
Production of liquid biofuels of I generation.	837…1648 EUR/toe	0.4…0.7
Production of liquid biofuels of II generation.	2346…4246 EUR/toe	1.0…1.8
Total		**20.8…33.5**

** These are some average figures as the specific capital costs depend on type/capacity of an installation, type of applied technology and used biomass. They will be gradually decreasing during the period until 2050.*

Expected sources of funding include private investments, loans/grants from Ukrainian and international financial institutions and programs (Ukrgasbank, EBRD, GEF, IFC, USAID, GIZ, NEFCO, UNDP etc.) as well as state funds under the relevant support programs.

5.8. Supportive measures.

The current Ukrainian legislation related to the bioenergy sector includes a number of legal acts that regulate different areas of bioenergy. The legislation can be divided into two levels – law level that includes basic laws of Ukraine for bioenergy regulation and by-laws level with a number of important rules and procedures approved by resolutions of different state authorities.

Despite quite a big number of current normative and legal acts related to the bioenergy sector, supportive measures for the sector in fact include only two instruments: **"green" tariff** for electricity produced from RES (including biomass/biogas) and **stimulating tariff** for heat produced from alternative energy sources (including biomass/biogas). At one time, these incentive tools played a significant role, but now they need some improvement and revision.

Law of Ukraine "On alternative energy sources"[30] (No. 555-IV dated 20 February 2003) regulates economic, ecological and organizational principles of using alternative energy sources and promoting the expansion of their use as well as the order of "green" tariff calculation and application. The Law foresees the **"green" tariff** for electricity produced from biomass and biogas and possible premiums in case of Ukrainian equipment usage. The Law also defines the procedure of renewable energy auctions for state support obtaining.

The Law was amended several times and the last amendments negatively affect the bioenergy projects, whereas the right to obtain "green" tariff for them is limited by January 2023. The second problem is that the existing "green" tariff is too low to effectively stimulate the wide introduction of biogas and biomass power plants. In particular, biomethane under the current incentive mechanism system cannot compete with other renewable energy sources due to relatively high production cost. Up to now, there are no examples of biogas-to-biomethane upgrading facilities in Ukraine, as there is no sufficient legal and regulatory framework for its production and use. There are no even government strategic targets regarding biomethane in Ukraine.

Therefore, it is necessary to envisage legal grounds to encourage the production and consumption of biomethane, i.e., electricity production from biomethane, the establishment of the register of the biomethane production and consumption and support of biomethane use as motor fuel for public transport and agricultural machinery.

RES producers that produce electricity from biomass or biogas have the possibility to participate in auctions for the allocation of support quotas. Auction for the allocation of support quota is a way to determine the entities that acquire the right for state support in case of the electricity production from alternative energy sources.

Producers of electricity from biomass or biogas may participate in auctions voluntarily. At the same time, the auctions for solar power plants more than 1 MW and wind farms more than 5 MW are obligatory. The auctions shall be implemented starting with 1 July 2019 until 31 December 2029. Unfortunately, up to now, the first auction has not been held.

[30] Law of Ukraine "On alternative energy sources". https://zakon.rada.gov.ua/laws/show/555-15 .

Law of Ukraine "On heat supply"[31] (No. 2633-IV dated 2 June 2005) regulates relations related to the production, transportation and heat energy supply. In 2017, the Law was amended, and the **incentive tariff** for heat produced from biomass (and other AES) was introduced. Local self-government authorities (municipalities) have gained powers (previously owned by NEURC) to establish tariffs for heat from alternative energy sources, including biomass, as well as publish established tariffs and review them. The existing stimulating tariff for heat produced from biomass does not take into account the difference in capacities of biomass plants. As a result, this tariff is too low for small-scale biomass installations producing heat.

Law of Ukraine "On alternative fuel types"[32] (No. 1391-XIV dated 14 January 2000) is the framework law that defines main terms of bioenergy such as "biomass", "biofuels", "biogas", establishes basic principles of state policy in the field of alternative fuels, features and types of alternative fuels. The Law is under the amending process now regarding the introduction of the mandatory usage of liquid biofuels (biocomponents) on transport.

Law of Ukraine "On animal by-products not intended for human consumption"[33] (No. 287-VIII dated 7 April 2015) defines organizational and legal principles of activity related to the formation, collection, transportation, storage, treatment, processing, disposal, removal of animal by-products not intended or declared unfit for human consumption, products of animal by-products processing not intended for human consumption. In fact, the Law has a legal effect on the order of the usage of digestate from biogas plants. According to the Law, a digestate from manure can be considered as organic fertilizer. And residues formed from the conversion of animal by-products into biogas or compost can be placed on the market and used as organic fertilizers or soil improvers.

Tax Code of Ukraine[34] (No. 2755-VI dated 2 December 2010): on January 1, 2019, amendments to the Tax Code of Ukraine regarding the payments of the CO_2 emissions tax came into force. In particular, the tax rate for CO_2 emissions from stationary pollution sources was increased from UAH 0.41. per ton up to 10 UAH per ton, i.e. increased by 24 times. According to the Tax Code of Ukraine, biomass combustion plants are taxpayers of the CO_2 emissions tax. However, this state of affairs is not in line with world practice, as biomass is considered as CO_2-neutral fuel, because when biomass is burnt, carbon dioxide is formed as much as was absorbed by plants during the growth. In all EU member states, CO_2 emissions tax for biomass is also not applied.

It should be noted that today receipts from the CO_2 emission tax are directed to the general fund of the State budget and are used on general expenses without particular purposes. It does not correspond to the function of the CO_2 tax that should be aimed at the reduction of CO_2 emissions. Thus, the administration of the CO_2 emission tax should be improved to support projects that ensure CO_2 emissions reduction.

[31] Law of Ukraine "On heat supply". https://zakon.rada.gov.ua/laws/show/2633-15
[32] Law of Ukraine "On alternative fuel types". https://zakon.rada.gov.ua/laws/show/1391-14#Text
[33] Law of Ukraine "On animal by-products not intended for human consumption". https://zakon.rada.gov.ua/laws/show/287-19
[34] Tax Code of Ukraine. https://zakon.rada.gov.ua/laws/show/2755-17

5.9. Economic impacts.

Implementation of the Bioenergy Roadmap will have positive economic impacts such as reduced import of fossil fuels, GDP growth, development of national economy, creation of new jobs and some others.

Based on the Roadmap data for 2050 on the consumption of biofuels, the possible currency saving caused by the reduced imports of natural gas and petrol/diesel to Ukraine is estimated as **2.31** bln USD/yr and **0.77** bln USD/yr respectively[35], the total sum being **3.08** bln USD/yr.

The total number of created new jobs may be over 162,000 by 2050. They include direct jobs (connected with servicing bioenergy equipment) and indirect jobs (connected with harvesting and supply of biomass for energy).

Replacement of coal, heavy oil, petrol and diesel by biofuels in the energy sector and on transport leads to a reduction of pollutant emission, which makes a generally positive impact on people's health.

5.10. Roadmap summary.

Roadmap summary indices by benchmark years are presented in **Table 5.6**. According to the forecast presented in the Roadmap, by 2050, the development of bioenergy in Ukraine may lead to:

- replacement of **19** bln m^3/yr of natural gas and more than **1** Mt of petrol and diesel;
- reduction of GHG emissions by nearly **47** Mt $CO_{2\text{-eq}}$/yr;
- creation of over **150,000** jobs.

Table 5.6. Bioenergy Roadmap summary indices.

Year	Installed capacity of bioenergy equipment		Consumption of biofuels*, Mtoe	Replacement of NG, bln m^3	Replacement of petrol and diesel, Mt	Reduction of CO_2 emission Mt/yr	Required investments, bln EUR		Creation of new jobs, number
	MW_{th}	MW_{el}					min	max	
2020	8231	225	3.85	4.34	0.17	9.19	1.58	2.62	17342
2025	12385	918	6.09	6.39	0.26	14.35	4.32	7.0	33870
2030	19185	1886	9.13	9.19	0.43	21.20	8.08	13.1	57648
2035	29949	2618	12.74	12.66	0.60	29.37	12.04	19.5	87067
2040	38822	3265	16.10	15.72	0.82	36.91	15.87	25.6	115220
2045	44493	3740	18.73	17.71	1.11	42.62	19.02	30.7	136595
2050	48056	4091	20.70	19.00	1.24	46.71	21.35	34.5	150550

** Including liquid and gaseous biofuels for transport.*

[35] Data on the amount and cost of natural gas, petrol and diesel imported to Ukraine in 2019 are taken according to the Statistical Yearbook "Ukraine's Foreign Trade" issued by the State Statistics Service of Ukraine, 2020.

Of these, the solid biomass segment makes the biggest contribution accounting for 17.9 bln m^3/yr of natural gas, 35 Mt CO_2/yr and over 107,000 new jobs in 2050 (**Table 5.7**). Another 1.14 bln m^3/yr of natural gas and 0.41 Mt/yr of petrol and diesel will be replaced at the expense of the production and consumption of biogas/biomethane (**Tables 5.8-5.10**). The contribution of liquid biofuels to the Roadmap indexes in 2050 will lie in the replacement of 0.83 Mt/yr of petrol/diesel, reduction of almost 2 Mt CO_2/yr of GHG and creation of over 8,500 new jobs (**Table 5.11**).

Table 5.7. Forecast for the development of bioenergy until 2050 in terms of solid biofuels.

Year	Installed capacity		Consumption of biofuels, Mtoe	Replacement of NG, bln m^3	Reduction of CO_2 emission Mt/yr	Required investments, bln EUR		Creation of new jobs
	MW_{th}	MW_{el}				min	max	
2020	8103	105	3.57	4.33	8.49	1.14	1.85	13334
2025	11955	552	5.18	6.29	12.32	2.74	4.39	23284
2030	18465	1295	7.36	8.94	17.53	5.24	8.39	39853
2035	29173	1908	10.06	12.22	23.95	7.90	12.64	64023
2040	37854	2421	12.40	15.06	29.51	10.28	16.41	85987
2045	43307	2738	13.85	16.82	32.97	11.75	18.75	99755
2050	46520	2940	14.71	17.86	35.01	12.63	20.15	107543

Table 5.8. Forecast for the development of bioenergy until 2050 in terms of biogas.

Year	Installed capacity		Consumption of biofuels, Mtoe	Replacement of NG, bln m^3	Reduction of CO_2 emission, Mt/yr	Required investments, bln EUR		Creation of new jobs
	MW_{el}	MW_{th}				min	max	
2020	120	128	0.11	0.01	0.4	0.3	0.48	2 271
2025	317	340	0.31	0.04	1.15	0.79	1.27	6 021
2030	478	512	0.51	0.08	1.90	1.20	1.91	9 084
2035	530	568	0.71	0.12	2.63	1.32	2.12	10 068
2040	595	638	0.91	0.18	3.35	1.49	2.38	11 310
2045	681	729	1.10	0.23	4.05	1.7	2.72	12 932
2050	755	809	1.29	0.30	4.74	1.89	3.02	14 343

Table 5.9. Forecast for the development of bioenergy until 2050 in terms of biomethane.

Year	Installed capacity		Consumption of biofuels, Mtoe	Replacement of NG, bln m^3	Reduction of CO_2 emission, Mt/yr	Required investments, bln EUR		Creation of new jobs
	MW_{el}	MW_{th}				min	max	
2020	0	0	0	0	0	0	0	0
2025	49	90	0.08	0.05	0.31	0.12	0.20	936
2030	113	208	0.19	0.12	0.71	0.28	0.45	2 151
2035	180	208	0.31	0.20	1.13	0.45	0.72	3 419
2040	249	330	0.42	0.27	1.57	0.62	1.00	4 738
2045	321	457	0.55	0.35	2.02	0.80	1.29	6 108
2050	396	727	0.68	0.43	2.49	0.99	1.59	7 530

Table 5.10. Forecast for the development of bioenergy until 2050 in terms of gaseous biofuels (biomethane).

Year	Production		Replacement of motor fuels including:			Reduction of CO_2 emissions Mt/yr	Required investments, bln EUR		Creation of new jobs
	Mt	Mtoe	NG, bln m^3	Diesel and petrol, Mt	Total, Mtoe		min	max	
2020	0	0	0	0	0	0	0	0	0
2025	0.01	0.01	0.01	0.01	0	0.05	0.01	0.01	47
2030	0.06	0.06	0.05	0.05	0.02	0.24	0.03	0.05	241
2035	0.14	0.15	0.12	0.12	0.05	0.58	0.08	0.12	587
2040	0.25	0.28	0.21	0.21	0.11	1.07	0.14	0.23	1 084
2045	0.41	0.45	0.31	0.31	0.19	1.70	0.23	0.36	1 733
2050	0.59	0.65	0.41	0.41	0.32	2.49	0.33	0.53	2 533

Table 5.11. Forecast for the development of bioenergy until 2050 in terms of liquid biofuels.

Year	Production of biofuels				Replacement of petrol and diesel		Reduction of CO_2 emission Mt/yr	Required investments, mln EUR		Creation of new jobs
	Total, Mt	Including II-gen biofuels, Mt	Total, Mtoe	Including II-gen biofuels, Mtoe	Mt	Mtoe		min	max	
2020	0.27	0.00	0.17	0.00	0.17	0.17	0.29	145	286	1737
2025	0.39	0.04	0.26	0.03	0.25	0.26	0.52	257	496	2599
2030	0.58	0.11	0.39	0.08	0.38	0.39	0.82	447	851	3928
2035	0.70	0.20	0.50	0.15	0.48	0.50	1.08	640	1205	4965
2040	0.85	0.31	0.63	0.25	0.61	0.63	1.41	905	1687	6280
2045	1.09	0.49	0.82	0.39	0.80	0.82	1.88	1285	2382	8227
2050	1.12	0.53	0.85	0.43	0.83	0.85	1.98	1359	2516	8538

Estimation of natural gas substitution volumes in **Tables 5.8-5.9** takes into account NG substitution as a result of heat production from biogas and biomethane only.

Estimation of CO_2 emission reductions in **Tables 5.8-5.10** takes into account: avoided emissions from fossil fuel burning, avoided emissions from inorganic fertiliser manufacture, avoided landfill emissions from biodegradable waste digestion, avoided emissions from manure management and avoided emissions from burning of crops. The calculations take a specific indicator of CO_2 emissions reduction by 1 toe of primary energy from biogas produced from a mix of different sources, estimated when calculating the global potential for biogas energy production[36]. Thus, with an estimated biogas production potential of 12,065 TWh (equivalent to 1,037 Mtoe), the potential for CO_2 emission reductions estimated to 3,825 Mt of CO_{2eq}, and therefore the specific reduction potential is 3.687 tons of CO_{2eq} per 1 toe.

5.11. Biomethane production and hydrogen energy.

Biomethane along with hydrogen is one of the two main types of renewable gaseous fuel. Biomethane is direct analogue of natural gas with avaiable infrastructure for transportation and storage, in some countries there is developed fleet of vehicles for use of gaseous fuels. Biomethane has a higher physical and energy density compared to hydrogen (**Table 5.12**).

Table 5.12. Key physical properties of biomethane and hydrogen.

Parameter	Hydrogen H_2	Biomethane CH_4	Ratio H_2/CH_4
Density, kg/m^3*	0.0899	0.7168	8.0
NCV, MJ/kg*	141	47.5	0.33
NCV, MJ/m^3*	12.5	33.2	2.65
NCV compressed gas MJ/m^3**	725	2130	2.93
NCV ultra-compressed gas, MJ/m^3***	≈ 8000 (gas-liquid)	≈ 22 000 (liquid)	≈ 2.75
Energy density of practical transportation mix: 20%vol. H_2 + 80%vol. biomethane, MJ/m^3**	29.1		-

* *Normal conditions (0 ^{0}C temperature, 1 bar pressure).*

** *Natural gas pipeline conditions (0 ^{0}C temperature, 60 bar pressure).*

*** *Practical hydrogen transportation conditions (-196 ^{0}C temperature, 300 bar pressure).*

In addition, there are number of fuels that can be obtained from hydrogen using excess energy from renewable sources and which are combined under the common name Power-to-X (PtX). These are synthetic methane, methanol, kerosene, synthetic gasoline, diesel fuel and others.

Thus, the advantages of hydrogen include virtually unlimited raw material resources, the possibility of conversion into other renewable fuels, the possibility of decarbonization in sectors with low electrification capacity. However, hydrogen has a number of significant disadvantages.

[36] Global Potential of Biogas / World Biogas Association, 2019 (https://www.worldbiogasassociation.org/global-potential-of-biogas/)

These are high energy costs for its production, low energy density compared to biomethane, lack of infrastructure for transportation in undiluted state, difficulties with storage due to high permeability, wide explosive limits, the need to manufacture special hydrogen engines for cars and power plants.

In energy systems with large share of renewable energy sources, excess electricity could be used to produce hydrogen by electrolysis of water followed by the production of methane from hydrogen and carbon dioxide (Sabatier reaction). In this case, the source of carbon dioxide could be the process of biogas upgrading the biomethane (**Fig. 5.22**).

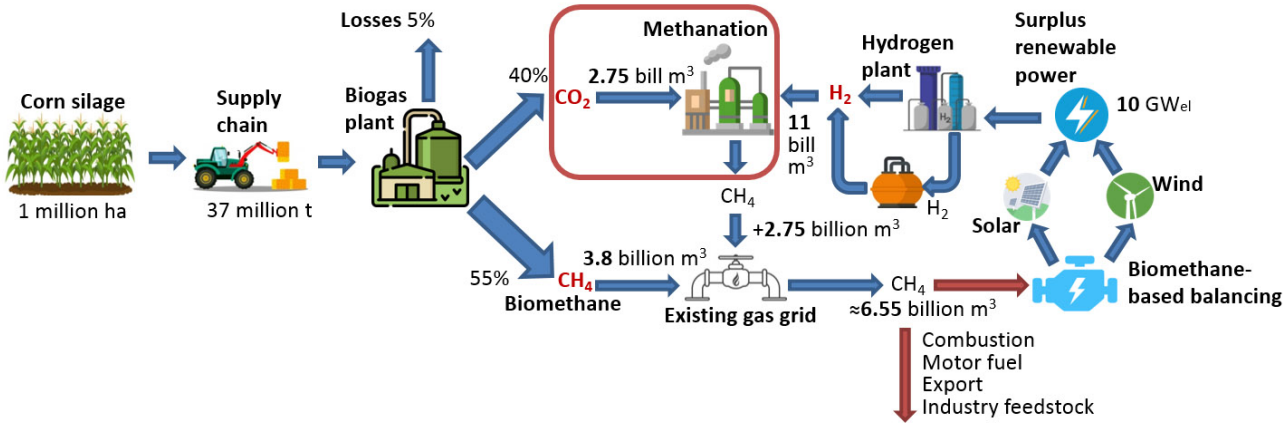


Fig. 5.22. Possible concept of conversion of green hydrogen to biomethane.

By combining of biogas upgrading to biomethane and hydrogen production by electrolysis (P2G process), additional benefits can be gained from reducing carbon emissions, as soon as CO_2 remaining after biogas upgrading can be used in hydrogen methanization process. This can significantly increase the overall efficiency of both processes, as well as the amount of biomethane produced. It should be noted that this amount of biomethane is additional to the values that can be obtained by anaerobic digestion and are given in **Tables 5.9** and **5.10**.

Wärtsilä Energy's simulation results[37] identify synthetic methane as more cost-effective among the various renewable gas technologies available. The company notes that it can already be used for most of the available natural gas facilities, and due to the higher density with better fuel efficiency (which is one of the main indicators for the operation of power plants), and therefore, for the same result less fuel is needed». According to the company, there are three main factors on which the economic feasibility of PtX fuel depends:

- availability of renewable electricity at low prices;
- rapid reduction of equipment costs for production processes (large state subsidies are currently required);

[37] Saara Kujala. On the threshold of a carbon-free future: are there competitors in "green" hydrogen (in Ukrainian). https://mind.ua/

- regulating demand for synthetic fuels through regulatory methods, primarily the commitment to use renewable fuels and increase fossil fuel prices by taxation and higher CO_2 emissions cost to reduce the difference in the cost of fossil and synthetic fuels.

It is expected that the use of biomethane and hydrogen will be developed in parallel. According to the Gas for Climate Consortium[38], the scenario of complete substitution of natural gas with biomethane and hydrogen is possible in Europe by 2050. The contribution of biomethane will be more important in the production of heat in buildings and for transport as motor fuel. The total potential for biomethane production in the EU is 1170 TWh. The value of hydrogen will be higher in the industry applications and power production. The total potential for hydrogen production in the EU is 1710 TWh.

6. Action Plan until 2025.

The Action Plan represents a detailed list of actions aimed to develop or amend Ukraine's laws and by-laws until 2025 (**Table 6.1**). These actions are required to ensure the implementation of Ukraine's bioenergy development Roadmap until 2050.

[38] Gas Decarbonisation Pathways 2020-2050, April 2020, Gas for Climate Consortium https://gasforclimate2050.eu/sdm_downloads/2020-gas-decarbonisation-pathways-study/

Table 6.1. Action Plan until 2025 for Ukraine's bioenergy development.

Name of action	Responsible bodies	Due date	Performance indicator	Expected results
Development of biomethane production				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Law of Ukraine "On Alternative energy sources" to stimulate production of biomethane.	SAEE Ministry of Energy	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Establishment of facilities that produce biomethane.
Development and submission to the Cabinet of Ministers of Ukraine the draft Procedure of the functioning of the Register of biomethane production and consumption.	SAEE Ministry of Energy	2nd quarter of 2022	The Procedure is adopted by the Resolution of the Cabinet of Ministers of Ukraine	Launch of the Register of biomethane production and consumption.
Development of solid biomass trade				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the certain legislative acts of Ukraine regarding the development of solid biofuels trading.	SAEE Ministry of Energy	3rd quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Introduction of the electronic system for solid biomass trading through electronic auctions.
Development and submission to the Cabinet of Ministers of Ukraine of the draft Rules of the electronic trading for solid biofuels	SAEE Ministry of Energy	1st quarter of 2022	The Rules are adopted by the Resolution of the Cabinet of Ministers of Ukraine	Establishing the order for electronic trading with solid biofuels.

Development of the draft Procedure of the competitive operator selection	SAEE Ministry of Energy	1st quarter of 2022	The Procedure is adopted by the Ministry of Energy	Introduction of the procedure for operator selection.
Development of the draft Methodology for operator's services threshold price formation.	Ministry for Development of Economy, Trade and Agriculture Ministry of Energy SAEE	1st quarter of 2022	The Methodology is adopted by the Ministry for Development of Economy, Trade and Agriculture	Operator's services threshold price establishment.
Development of the draft Procedure for the consideration of operator and participants reports and approval of their forms.	SAEE Ministry of Energy	1st quarter of 2022	The Procedure is adopted by the Ministry of Energy	Introduction of the consideration of operator and participants reports and approval of their forms.
Development the draft of quality requirements for solid biofuels traded via electronic trading for solid biofuels.	SAEE Ministry of Energy	1st quarter of 2022	The requirements are adopted by the Ministry of Energy	Ensuring biomass quality within the electronic system for solid biofuels trading.
Improvement of Carbon Tax levying and administration				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Tax Code of Ukraine on exemption from CO_2 emissions tax of biofuel combustion plants.	SAEE Ministry of Energy Ministry of Finance	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Biofuel combustion plants are exempted from the CO_2 emissions tax.
Adoption of the draft Law of Ukraine on amending the Budget Code of Ukraine as for introducing the state decarbonization fund	Verkhovna Rada of Ukraine SAEE	4th quarter of 2020	The draft Law adopted by the Verkhovna Rada of Ukraine	Creation of the decarbonization fund.

(draft Law # 4347 as of 09.11.2020).	Ministry of Energy			
Development of Procedure for using funds of the state decarbonization fund and procedure for monitoring the influence of projects (measures) of the state decarbonization fund on CO_2 emission reduction.	SAEE Ministry of Energy	1st quarter of 2021	The Procedure is adopted by the Resolution of the Cabinet of Ministers of Ukraine	The use of funds of the state decarbonization fund.
Support for producers of biomass and biofuels				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Tax Code of Ukraine and other legislative acts of Ukraine on encouraging energy crops growing.	SAEE Ministry of Energy	3rd quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Introduction of legal basis for the support for energy crops growing. Simplified access for leasing of the state and communal lands with the purpose of energy crops growing.
Development and submission to the Cabinet of Ministers of Ukraine of the draft Procedure for using the funds provided in the state budget to support the cultivation of energy crops.	SAEE Ministry of Energy Ministry for Development of Economy, Trade and Agriculture	1st quarter of 2022	The Procedure is adopted by the Resolution of the Cabinet of Ministers of Ukraine	Allocation of the funds provided in the state budget to support the cultivation of energy crops.
Development and submission to the Cabinet of Ministers of Ukraine of amendments to procedures of using state budget funds set aside for granting state support to agricultural producers and farmers in case of	Ministry for Development of Economy, Trade and Agriculture SAEE Ministry of Energy	4th quarter of 2021	The Procedure is adopted by the Resolution of the Cabinet of Ministers of Ukraine	Providing state support to agricultural producers and farmers in case of production of biomass and biofuels, implementation of bioenergy projects.

production of biomass and biofuels, implementation of bioenergy projects.				
Development of power production from RES				
Development and submission to the Cabinet of Ministers of Ukraine the draft Law on granting the right to RES electricity producers, including biomass and biogas, to leave the balancing group of the guaranteed buyer and freely sell electricity on the market with the possibility of receiving compensation in the form of the difference between the established "green" tariff or auction price and the market price.	Ministry of Energy	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Contribution to solving the problem of payments for electricity produced from alternative energy sources.
Development of heat production from RES				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Law of Ukraine "On heat supply" as for improving formation and setting of tariffs for heat, including heat produced from RES.	Ministry of development of communities and territories of Ukraine SAEE Ministry of Energy	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Improving the mechanism of formation and establishment of tariffs for heat energy produced from RES by the introduction of the possibility to choose the procedure for the heat tariffs formation and for heat sale to the communal DH companies.
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Law	Ministry of Energy SAEE	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of	Introduction of the competitive heat market.

of Ukraine “On heat supply” and to certain laws of Ukraine on competition introduction in district heating systems.	Ministry of development of communities and territories of Ukraine		Ukraine to the Verkhovna Rada of Ukraine	
Development of the draft Procedure of heat producers connection to heat networks and connection fee calculation	NEURC Ministry of Energy SAEE Ministry of development of communities and territories of Ukraine	2nd quarter of 2022	The Procedure is adopted by the NEURC	Ensuring non-discriminatory access to heat networks.
Development of the draft Procedure of bidding for heat energy purchase and form of a model heat energy purchase contract in the competitive DH system.	NEURC Ministry of development of communities and territories of Ukraine Ministry of Energy SAEE	2nd quarter of 2022	The Procedure is adopted by the NEURC	Introduction of bidding for the purchase of heat energy from independent heat energy producers.
Development of the draft Methodology for the formation of threshold tariffs for operators’ heat production in the competitive DH systems.	NEURC Ministry of development of communities and territories of Ukraine Ministry of Energy SAEE	2nd quarter of 2022	The Methodology is adopted by the NEURC	Establishment of threshold tariffs for operators’ heat production in the competitive DH systems.

Development of the draft Methodology of heat supply tariff formation for heat suppliers that are simultaneously operators in the competitive DH systems.	NEURC Ministry of development of communities and territories of Ukraine Ministry of Energy SAEE	2nd quarter of 2022	The Methodology is adopted by the NEURC	Establishment of the heat supply tariffs for heat suppliers that are simultaneously operators in the competitive DH systems.
Development of the draft Procedure for balancing, dispatching control, reserving of heat generating installations and the reservation fee calculation in the competitive DH system.	NEURC Ministry of development of communities and territories of Ukraine Ministry of Energy SAEE	2nd quarter of 2022	The Procedure is adopted by the NEURC	Ensuring balancing, dispatching control and reserving of heat generating installations in the competitive DH systems.
Development of the production and consumption of biofuels in the transport sector				
Adoption of the draft Law of Ukraine on amendments to certain legislative acts of Ukraine regarding the mandatory use of liquid biofuels (biocomponents) in the transport (draft Law #3356 as of 17.04.2020).	Verkhovna Rada of Ukraine SAEE Ministry of Energy	2nd quarter of 2021	The draft Law adopted by the Verkhovna Rada of Ukraine	Increased use of liquid biofuels in transport, introduction of sustainability criteria for liquid biofuels.
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the certain legislative acts on support of biomethane use as motor fuel,	SAEE Ministry of Energy	4th quarter of 2022	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Launch of using biomethane as motor fuel, including for public transport and agricultural machinery.

including for public transport and agricultural machinery.				
Encouraging of using digestate of biogas plants in the market				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Law of Ukraine "On pesticides and agrochemicals" to ensure the possibility to use digestate of biogas plants in Ukrainian market.	Ministry for Development of Economy, Trade and Agriculture Ministry of Energy	4th quarter of 2021	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Removal of legislative barriers for using digestate of biogas plants as organic fertilizer. Increased use of digestate of biogas plants as organic fertilizer.
Development of the State Standard of Ukraine for digestate when using it as an organic fertilizer or soil improver	Ministry for Development of Economy, Trade and Agriculture Ukrainian Research and Training Center of Standardization, Certification and Quality (SE "UkrNDNC")	4th quarter of 2022	Adopted and entered into force by the Order of the Ministry for Development of Economy, Trade and Agriculture	Laying down the regulatory requirements for the digestate of biogas plants when using it as organic fertilizer or soil improver. Increasing consumers' confidence in the quality of the digestate.
Adaptation of EU Regulation (EU) 2019/1009 into Ukrainian legislation by developing on its basis a new Law of Ukraine laying down rules on making fertilising products available on the market	Ministry for Development of Economy, Trade and Agriculture	After adoption of Ukraine's commitment to implement EU Regulation	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Laying down the regulatory requirements for the production and sale on the market of fertilizer products from the digestate of biogas plants.

		(EU) 2019/1009		
Introduction of sustainability criteria for solid biofuels				
Development and submission to the Cabinet of Ministers of Ukraine of the draft Law on amendments to the Law of Ukraine “On Alternative fuel types” regarding the introduction of sustainability criteria for solid biofuels.	SAEE Ministry of Energy	After adoption of Ukraine's commitment to implement Directive (EU) 2018/2001	Approved and submitted by the Cabinet of Ministers of Ukraine to the Verkhovna Rada of Ukraine	Application of sustainability criteria to solid biofuels.

Abbreviations

AES – alternative energy sources
APPR – agrarian plantations pruning and removal
CHP – combined heat and power
CHPP – combined heat and power plant
CMU – Cabinet of Ministers of Ukraine
DH – district heating
GDP – gross domestic product
GHG – greenhouse gas
LFG – landfill gas
MSW – municipal solid waste
NEURC – National Energy and Utilities Regulation Commission
NG – natural gas
NPP – nuclear power plant
NREAP – National Renewable Energy Action Plan
ORC – organic Rankine cycle
RES – renewable energy sources
SAEE – State Agency on Energy Efficiency and Energy Saving
TPES – total primary energy supply
TPP – thermal power plant
UABIO – Bioenergy Association of Ukraine
Mtoe – million tons of oil equivalent
ktoe – thousand tons of oil equivalent
bln – billion
mln – million