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Prospects for Bioenergy Development in Ukraine: Roadmap until 2050

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ABSTRACT

Ukraine has expressed its intention to follow basic principles of the European Green Deal. Most probably, Ukraine will set the goal to achieve climate neutrality of its economy by 2060. Effective reduction of GHG emission and successful implementation of the green energy transition is possible only on condition that the bioenergy sector is developing intensively. The same applies to fulfilling Ukraine's commitments within the Paris Agreement and the Energy Community. It is obvious that Ukraine urgently needs a long-term strategic document for the bioenergy sector and the Roadmap until 2050 could be such a document. The Roadmap is in line with the scenario of achieving over 60% renewable energy sources (RES) in the energy balance of Ukraine by 2050 and 100% RES by 2070. Biomass shares of all RES in 2050 assumed in the Roadmap, which are 38% in the total primary energy supply (TPES), 67% in heat production, 11% in power production and 40% in the transport sector, result in 24% of bioenergy in TPES in 2050. This corresponds to using about 20 Mtoe of biomass for energy. The obtained bioenergy benchmark figures can be used for the elaboration of a new energy strategy of Ukraine until 2050, the current strategy being only until 2035.

Keywords: renewable energy, bioenergy, biomass, biofuel, biogas, agrobiomass, biomass potential.

INTRODUCTION

Decarbonization of economy and energy, implementation of green energy transition and mitigation of climate change are current global trends and challenges. Ukraine has announced its commitment to the European Green Deal; in 2021, a respective interagency task force started its work on implementing the Green Deal in the country. Earlier, at the beginning of 2020, the Ministry of Energy and Environmental Protection presented a draft Concept of Ukraine's Green Energy Transition until 2050 (Ukraine Green Deal). The document aimed at achieving the climate-neutral economy of the country by 2070 was elaborated taking into consideration the goals and objectives of the European Green Deal. Though the draft Concept has not been further elaborated and officially adopted, it shows the main suggested directions for decarbonization of the economy, including the energy sector as its important component. Among others, these directions are:

- development of renewable energy along with the increase in energy efficiency;
- reduction to zero the consumption of carbon-intensive energy resources and maximum use of renewable energy sources (RES) so that agriculture and forestry could be completely self-provided with energy resources;
- increase in the sustainable production of biomass, biofuels and other RES to support the implementation of green transition in other sectors of economy;
- complete replacement of coal-fired power plants by 2050 due to the development of solar, wind and biomass power generation combined with new highly maneuverable generating capacity on natural gas and, in the long term, on synthetic gas produced using RES;

- priority use of biomass and biogas at new district heating (DH) combined heat and power (CHP) plants;
- large-scale use of biofuels and waste as well as renewable heat and power in industrial processes to replace carbon-intensive resources.

Successful implementation of the green energy transition is possible only on condition that the bioenergy sector is developing intensively. The same applies to fulfilling Ukraine's commitments within the Paris Agreement and the Energy Community. At present, the only strategic national document in force in the energy sector is the Energy Strategy of Ukraine until 2035. The Strategy sets the goal to achieve 25% of RES in the total primary energy supply (TPES) by 2035, of which 11.5% (11 Mtoe) should be covered at the expense biomass and waste. At that, no national goals regarding energy are set beyond 2035 and no document specifies what types of biomass will provide 11 Mtoe in TPES by 2035 and what bioenergy technologies will be used. Thus, it is obvious that Ukraine urgently needs a long-term strategic document for the bioenergy sector and the Roadmap for bioenergy development until 2050 could be such a document.

During the last ten years, the average annual growth rate of bioenergy in Ukraine has been 16%. The current contribution of biomass/biofuels to the total primary energy supply comes to almost 3.4 Mtoe (Fig. 1). This makes up the biggest share of all renewable energy sources – 77% (Fig. 2). The current use of biofuels provides the annual replacement of about 4.2 bln m^3 of natural gas. Biomass and solid biofuels are mostly used for heat production. The installed capacity of power plants that produce electricity by feed-in tariff is 109 MW for biomass and 103 MW for biogas.

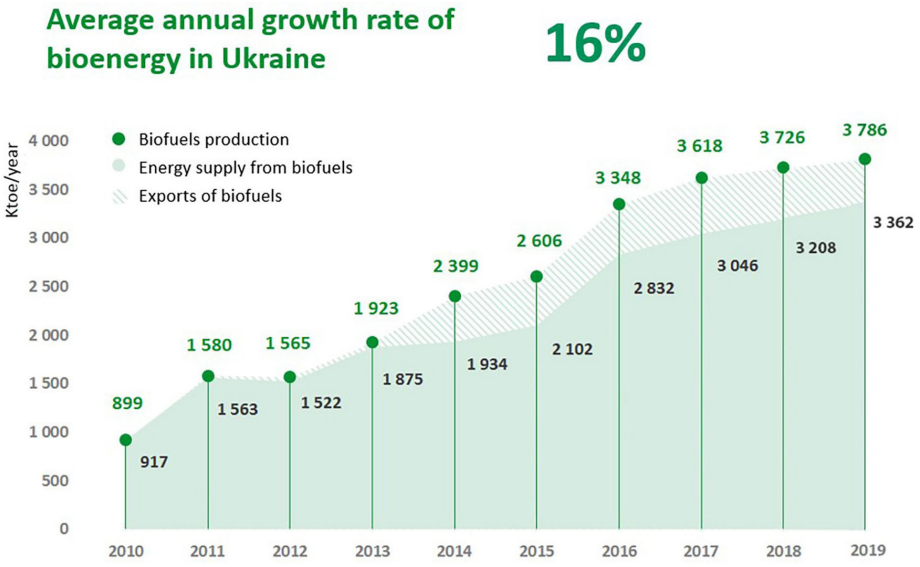

Figure 1. Dynamics of bioenergy development in Ukraine

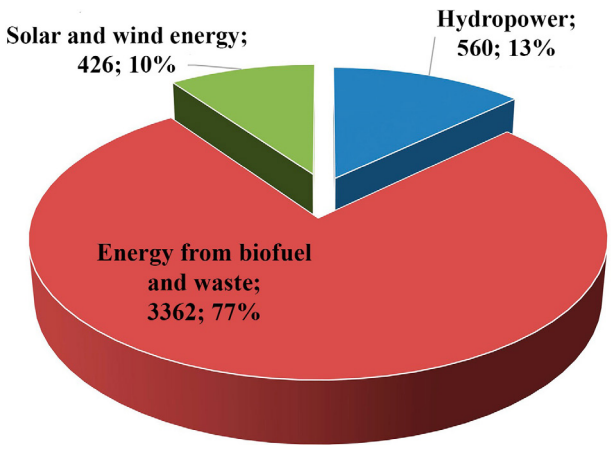

Figure 2. Contribution of RES to the total primary energy supply in Ukraine (2019)

MATERIALS AND METHODS

The purpose 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 suggested Roadmap covers the period of 2020-2050 with several benchmarks. One of them is 2030 as a new National Renewable Energy Action Plan until 2030 (NREAP) is to be elaborated presently. It is expected that according to the new NREAP, at least 8 Mtoe of biomass, biofuels and waste should be consumed in 2030 as it complies with targets of the current Ukraine's Energy Strategy. The second benchmark takes into account the goal of 11 Mtoe of bioenergy contribution to TPES set by the Energy Strategy of Ukraine for 2035.

The Roadmap is in line with the scenario of achieving over 60% of RES in the energy balance of Ukraine in 2050 (Fig. 3), which includes renewable energy targets fixed for individual sectors such as power production (70%), heat production (65%) and transport (35%). In the figure, the value for 2019 is according to Ukraine's actual Energy Balance for 2019, and the value for 2035 is according to the Energy Strategy of Ukraine until 2035.

Achievement of the assumed renewable energy goals is possible on the assumption of reducing TPES by 9% in 2050 compared to 2018, which means the decrease from 93 Mtoe (2018) to 85 Mtoe (2050). At that, distribution of the primary energy supply between sectors in 2050 is assessed as follows: 31 Mtoe for heat production, 42 Mtoe for power production, and 12 Mtoe for transport.

Biomass shares of all RES in 2050 assumed in the Roadmap, which are 38% in TPES, 67% in heat production, 11% in power production and 40% in the transport sector, result in 24% of bioenergy contribution to TPES in 2050 with the dynamics presented in Figure 4. In the figure, the value for 2019 complies with Ukraine's actual Energy Balance for 2019.

Based on all the above, it follows that about 20 Mtoe/yr of biomass will be consumed for energy production in 2050. The potential of biomass available for energy is a crucial precondition for the successful development of bioenergy and attaining of the set targets. Estimation for the year

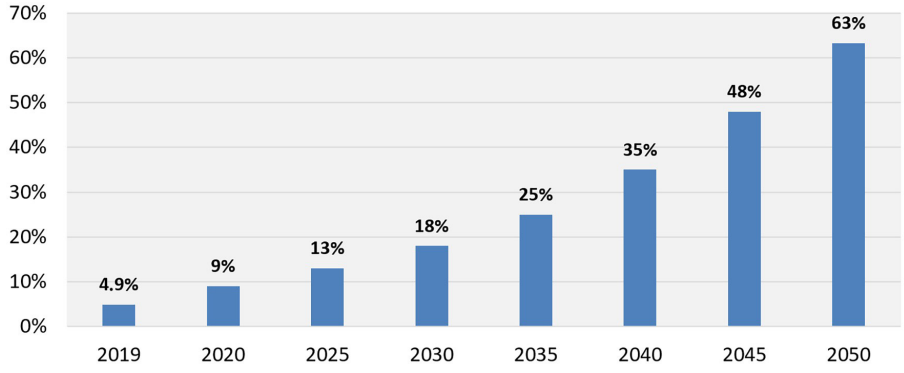

Figure 3. Forecasted share of RES in Ukraine's total primary energy supply until 2050

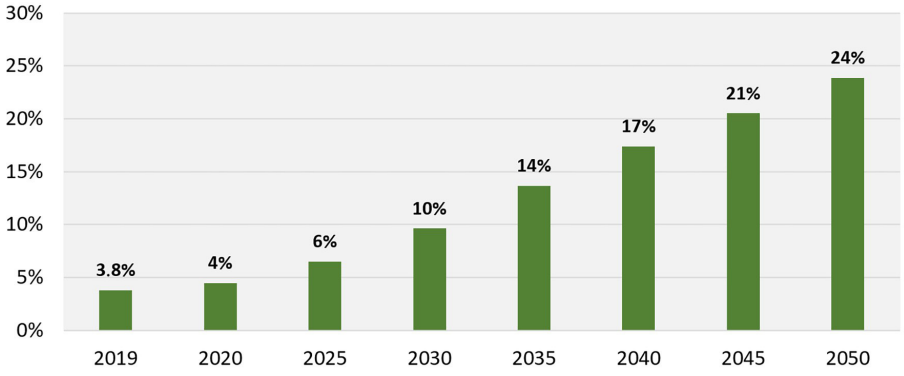

Figure 4. Forecasted contribution of bioenergy to Ukraine's total primary energy supply

Table 1. Bioenergy potential in Ukraine in 2019

Type of biomass	Theoretical potential, Mt	Economic potential	
		% of the theoretical potential	Mtoe
Primary agricultural residues:			
straw of grain crops	37.5	30	3.84
straw of rapeseed	5.9	40	0.81
byproducts of grain maize production (stalks, cobs)	46.6	40	3.57
byproducts of sunflower production (stalks, heads)	29.0	40	1.66
Secondary agricultural residues: sunflower husk	2.6	100	1.08
Wood biomass such as fuel wood, logging residues, wood working waste	7.4	95	1.73
Wood biomass such as deadwood, wood from shelterbelt forests, biomass from agrarian plantation pruning and removal	8.8	45	1.02
Biodiesel (from rapeseed)	-	-	0.46
Bioethanol (from maize and sugar beet)	-	-	0.79
Biogas from waste and byproducts 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	0.4 bln m^3 CH_4	28	0.09
Energy crops:			
maize for biogas (1 mln ha*)	3.0 bln m^3 CH_4	100	2.57
miscanthus, poplar, willow (1 mln ha*)	11.5	100	4.88
TOTAL	-	-	23.63

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

2019 shows that the potential of biomass available for energy in Ukraine (the economic potential) is almost 24 Mtoe. The biggest parts of the potential are primary and secondary agricultural residues (46% of the total) and energy crops (32%) (Table 1). Within the agricultural residues, the largest amounts fall to the shares of grain crops straw (35%) and by-products of grain maize production (33%). The estimation of biomass potential has been carried out according to methodologies provided in (Geletukha 2011, Lakida 2010, Geletukha 2014a, Geletukha 2014b, Zheliezna 2016) for different types of biomass.

It should be noted that current structures of the available biomass resources and their utilization for energy are opposed. The biggest parts of the potential (primary agricultural residues and energy crops) are scarcely used while wood biomass is used most of all, though the potential of wood biomass available for energy is rather limited. This situation needs remedying, which has been taken into consideration in the Roadmap.

Assessment of a possible biomass potential in 2050 is based on a number of assumptions, the main of which are the following (Zheliezna 2020, Tryboi 2018):

- increase in the yield of crops, first of all, cereals;
- significant increase in the economic potential of biogas obtained from different types of feedstock;
- doubling of areas under energy crops and increase in their yield;
- growth of felling of the net annual forest increment;
- switchover to the production of II-generation biofuels and new types of feedstock for I-generation biofuels.

Preliminary expert estimation shows that the bioenergy potential may rise to almost 48 Mtoe/yr in 2050, which is actually double as compared to 2019. That means that the forecasted amount of biomass for energy production by 2050 (about 20 Mtoe) is comparable with the present bioenergy potential, but will make up only 42% of the biomass potential assessed for 2050. This ensures the availability of the required amount of biomass for energy until 2050.

RESULTS AND DISCUSSION

Main results of the elaborated Roadmap for Ukraine's bioenergy development until 2050 are presented in Figures 5 and 6. Figure 5 shows the

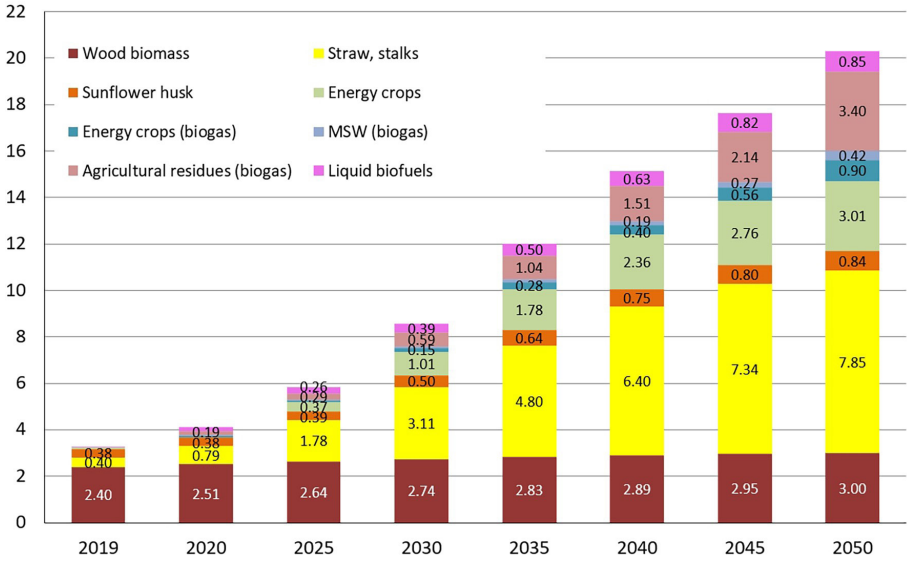

Figure 5. Suggested structure of biofuels consumption in Ukraine until 2050, by biomass type, Mtoe

suggested structure of biofuels consumption until 2050 by biomass type; Figure 6 presents the structure by type of the produced energy carrier. The covered types of biomass and biofuels include wood biomass, primary and secondary agricultural residues, energy crops, biogas from different types of feedstock such as municipal solid waste (MSW), agricultural residues, maze silage, and liquid biofuels such as biodiesel and bioethanol. The total consumption of biomass/biofuels in 2050 is estimated as 20.3 Mtoe, of which the lion share is agricultural residues: 8.69 Mtoe for direct heat and power generation, 3.4 Mtoe for biogas production. Directions of biomass usage comprise the production of heat, power, biogas, biomethane and motor biofuels. Biomethane is supposed to be used for power and heat production and as gaseous motor fuel.

The production of biomethane and II-generation biofuels, which is not now the case, is expected to begin in 2025. A considerable increase in the production of energy crops is envisaged in 2030. Since 2030, agricultural residues for energy will prevail over wood biomass. On the whole, the suggested structure of the production and consumption of biofuels takes into consideration and reflects some key trends, which are expected to occur in the bioenergy sector of Ukraine by 2050:

- Considerable increase in the share of agricultural residues and energy crops in the structure of solid biofuels consumption: up to 60% and 20%, respectively.

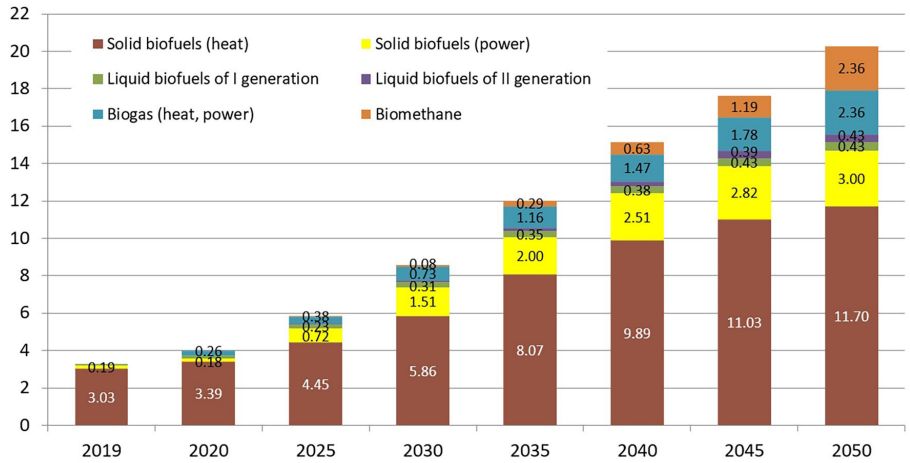

Figure 6. Suggested structure of biofuels consumption in Ukraine until 2050, by the type of produced energy carrier, Mtoe

- Minimum growth in the use of wood biofuels during the period of 2020-2050: 1.2 times against 8 times for the agricultural residues during the same period.
- Considerable increase in the production of biogas and liquid biofuels: up to 4.7 Mtoe/yr and 0.85 Mtoe/yr, respectively.
- Beginning and rise of the production of biomethane and motor biofuels of II generation: up to 2.4 Mtoe/yr and 0.43 Mtoe/yr, respectively.

In Ukraine, over 50% of the final energy consumption is accounted for heat. Based on this, it is predicted that about a half of biofuels consumed in 2050 (11.7 Mtoe) will fall on solid biofuels for heat production (see Figure 4). The rest will be divided into relatively comparable proportions between the solid biofuels for power production (3.0 Mtoe), biogas (2.36 Mtoe), and biomethane (2.36 Mtoe). The smallest share of the total biofuel consumption in 2050 falls on liquid biofuels: 0.85 Mtoe, of which II-generation biofuels account for 0.43 Mtoe.

Forecasted structure of using solid biofuels for heat production in different sectors in Ukraine is presented in Figure 7. At present, biomass is mostly used in industry for heat and power generation and utilized by the population for heating. The district heating (DH) sector hardly utilizes any biofuels with one or two examples ever known. One can see from the figure that the volume of heat production will be comparable in the DH/public sector, industry and individual heating in the period closer to 2050. At that, most power production will remain in the industry during the whole period until 2050.

The required installed capacity of bioenergy equipment is assessed to be nearly 50000 MW_{th} and about 5200 MW_{el} in 2050. Table 2 shows types of the envisaged bioenergy equipment by sectors: population, DH/public sector and industry.

According to expert estimation, the implementation of the Roadmap will require investments in the range of 21…34 billion EUR, depending on the actual cost of the equipment to be installed. The approximate distribution of the investments by type of bioenergy equipment/technologies is given in Table 3. The most capital costs are needed for the introduction of the planned number of CHP plants/TPPs on solid biomass (7.4…11.8 bln EUR) and CHP plants on biogas/biomethane (5.7…9.1 bln EUR).

Summary data of the Roadmap are presented in Table 4. It is expected that the introduction of bioenergy technologies in Ukraine by 2050 may lead to:

- replacement of nearly 20 bln m^3/yr of natural gas (NG);
- replacement of more than 1 Mt of petrol and diesel;
- reduction of greenhouse gases (GHG) emissions by over 54 Mt $CO_{2\text{-eq}}$/yr;
- creation of over 162,000 direct and indirect jobs;
- saving of currency due to reduced imports of natural gas and petrol/diesel to Ukraine by 2.31 bln USD/yr and 0.77 bln USD/yr respectively.

Of these, the segment of solid biomass makes the biggest contribution accounting for 17.9 bln m^3/yr of NG replacement, 35 Mt CO_2/yr of GHG reduction and creation of over 107000 new jobs in 2050 (Table 5). Another 2.1 bln m^3/yr of NG and 0.4 Mt/yr of petrol and diesel will be replaced at the expense of the production and consumption of biogas/biomethane (Tables 6, 7). 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 8).

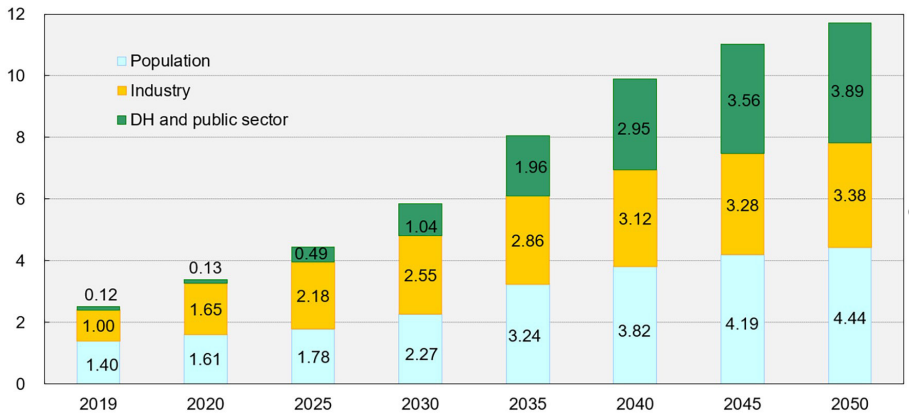

Figure 7. Forecasted structure of heat production from solid biofuels in different sectors in Ukraine, Mtoe

It should be underlined that in the light of increasing interest in Europe in renewable gases, the production, consumption and export of biomethane is considered a very promising area of bioenergy development in Ukraine. The country has quite good preconditions for the production and transportation of biomethane, which includes the availability of a big potential of the feedstock, as well as main and

Table 2. 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 agricultural residues (pellets, briquettes, small bales)	7500	
Domestic boilers on energy crops (pellets, chips)	6000	
DH and public sector		
Boilers (wood biomass)	600	
Boilers (primary agricultural residues)	12750	
Boilers (secondary agricultural residues)	900	
Boilers (energy crops)	2750	
Combined heat and power (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)	2870	2040
Thermal power plants (TPPs) (primary agricultural residues)		380
TPPs (secondary agricultural residues)		160
TPPs (wood biomass)		55
TPPs (energy crops)		340
TPPs ORC (primary agricultural residues)		25
CHP plants on biogas obtained from waste (landfills, mechanical and biological treatment of waste, wastewater)	265	250
TOTAL	49655	5230

Table 3. Assessment of investments required for the implementation of the Roadmap

Types of bioenergy equipment/technology	Specific capital costs*	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	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/ktoe	0.4…0.7
Production of liquid biofuels of II generation	2346…4246 EUR/ktoe	1.0…1.8
TOTAL		20.8…33.5

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

Table 4. 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	Investments, bln EUR		Creation of new jobs
	MW_{th}	MW_{el}					min	max	
2020	8206	202	3.8	4.3	0.17	8.9	1.5	2.5	16914
2025	12276	844	5.8	6.3	0.25	14.3	3.7	6.1	31438
2030	19087	1846	8.6	9.1	0.39	21.3	7.1	11.4	54302
2035	30237	2804	12.0	12.6	0.50	30.4	10.8	17.4	86237
2040	39338	3609	15.1	15.8	0.67	38.7	14.1	22.8	115439
2045	45351	4299	17.6	18.0	0.96	45.8	16.9	27.4	139013
2050	49655	5230	20.3	19.9	1.23	54.4	19.7	31.8	162710

* Including liquid and gaseous biofuels for transport.

Table 5. Forecast for the development of bioenergy until 2050 in terms of solid biofuels for heat and power production

Year	Installed capacity		Consumption of biofuels, Mtoe	Replacement of NG, bln m^3	Reduction of CO_2 emission, Mt/yr	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 6. Forecast for the development of bioenergy until 2050 in terms of biogas and biomethane for heat and power production

Year	Installed capacity		Consumption of gaseous biofuels, Mtoe	Replacement of NG, bln m^3	Reduction of CO_2 emission, Mt/yr	Investments, bln EUR		Creation of new jobs
	MW_{el}	MW_{th}				min	max	
2020	97	104	0.03	0.00	0.11	0.24	0.39	1843
2025	292	321	0.40	0.06	1.46	0.73	1.17	5547
2030	551	622	0.80	0.16	2.96	1.38	2.21	10474
2035	896	1064	1.39	0.35	5.13	2.24	3.58	17026
2040	1188	1484	1.94	0.59	7.16	2.97	4.75	22564
2045	1561	2044	2.61	0.91	9.63	3.90	6.24	29655
2050	2286	3135	3.89	1.54	14.36	5.72	9.14	43434

Table 7. Forecast for the development of bioenergy until 2050 in terms of biomethane as motor fuel

Year	Production	Replacement of motor fuels including:		Reduction of CO_2 emissions, Mt/yr min	Investments, bln EUR		Creation of new jobs
	Mtoe	NG, bln m^3	Diesel and petrol, Mt		min	max	
2020	0.00	0.00	0.00	0.00	0.00	0.00	–
2025	0.00	0.00	0.00	0.01	0.00	0.00	8
2030	0.01	0.01	0.00	0.05	0.02	0.03	47
2035	0.06	0.05	0.02	0.21	0.08	0.12	224
2040	0.16	0.12	0.06	0.58	0.21	0.34	609
2045	0.36	0.24	0.15	1.31	0.47	0.76	1377
2050	0.83	0.52	0.40	3.05	1.10	1.76	3195

Table 8. Forecast for the development of bioenergy until 2050 in terms of liquid biofuels

Year	Production of biofuels		Replacement of petrol and diesel, Mtoe	Reduction of CO_2 emission, Mt/yr	Investments, mln EUR		Creation of new jobs
	Total, Mtoe	Including II-gen. biofuels, Mtoe			min	max	
2020	0.17	0.00	0.17	0.29	–	–	1737
2025	0.26	0.03	0.26	0.52	257	496	2599
2030	0.39	0.08	0.39	0.82	447	851	3928
2035	0.50	0.15	0.50	1.08	640	1205	4965
2040	0.63	0.25	0.63	1.41	905	1687	6280
2045	0.82	0.39	0.82	1.88	1285	2382	8227
2050	0.85	0.43	0.85	1.98	1359	2516	8538

distribution gas pipelines. Ukraine can produce the amount of biomethane that is enough to cover its domestic demand and export to Europe. At that, according to expert estimation, for the EU biomethane imported from Ukraine may be cheaper than that supplied by other neighboring countries.

CONCLUSIONS

The elaborated Roadmap for Ukraine's bioenergy development until 2050 is a long-term strategic document, which plays several important parts. First, it specifies the way to attain the bioenergy target set by Ukraine's Energy Strategy until 2035. Second, it ensures a considerable contribution of bioenergy to fulfilling Ukraine's obligations within the Paris Agreement and Energy Community. Third, the Roadmap shows the possible role of bioenergy in Ukraine's green energy transition. In addition, the obtained bioenergy benchmark figures can be used for the elaboration of a new energy strategy of Ukraine until 2050. We consider it necessary to bring the suggested Roadmap to the level of an official document.

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