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Prospects and Potential for Biomethane Production in Ukraine

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ABSTRACT

Prospects and potential for the development of biomethane production in Ukraine are presented. The biomethane potential due to anaerobic digestion from the most prospective feedstock types is estimated as 9.7 billion m^3CH_4/year in 2020. At the level of regions of Ukraine, 60% of the potential for biomethane production is concentrated in all regions of the central part of country (Vinnytsia, Cherkasy, Dnipropetrovsk, Poltava and Kirovohrad regions), two regions of the northern part of Ukraine (Kyiv and Chernihiv regions), one region of the western part of Ukraine (Khmelnytsky region) and one region of the eastern part of Ukraine (Kharkiv region). Comparative analysis of two main renewable gases - biomethane and green hydrogen - has been carried out. It is shown that greatest prospects are associated with combination of biomethane and green hydrogen advantages, which involves the conversion of hydrogen into methane with subsequent supply to distribution or main gas networks. The use of such a scheme will allow in addition to AD potential of biomethane to add 6.8 billion m^3/year of synthetic methane, which can be obtained from methanation of CO_2 from biomethane plants and green hydrogen.The total biomethane production in Ukraine could reach 1.0 billion m^3/year in 2030. It is expected that biomethane could partly be exported to the EU. The rest could be utilized locally for combined heat and electricity generation in CHP units, heating and industry applications and for transportation purpose. In such a way biogas sector could serve the growing demand in sustainable and clean energy from the transport and industry sectors.

Keywords: bioenergy, biomass, biogas, biomethane, green hydrogen.

INTRODUCTION

Biomethane as a close analogue of natural gas can be used for the production of heat and electricity, as a fuel for transport as well as raw materials for the chemical industry. In addition, the production of biomethane is in line with the idea of circular economy as it converts agricultural by-products or household waste into energy ensuring the recycling of nutrients to agricultural land. The common opinion of experts in biogas sector is that upgrading biogas to biomethane could be a major source of future growth (IEA, 2020).

Current status of biomethane production

The International Energy Agency (IEA) estimates that the world´s biomethane production potential is 730 billion m^3/year (about 20% of current total natural gas consumption) (IEA, 2020). In 2019, world biomethane production reached almost 5 billion m^3/year (Cedigaz, 2019). Today, the EU is the leader in biomethane production, while biomethane production in Europe already exists in 18 countries. The EU biogas sector currently produces 15.8 billion m^3/year of biogas and 2.43 billion m^3/year of biomethane. There were 18,774 biogas and 880 biomethane plants in the EU in 2020 (EBA, 2021). Biomethane production in 2020 increased by 25% compared to the previous year (EBA, 2020). The leader of the European biomethane market remains Germany, where 242 plants produce about 40% of European biomethane. In recent years, countries such as France, the Netherlands, Denmark and Italy have been leading in terms of development. There is also a clear trend in the change of raw materials for biomethane production. In 2016, the transition from energy crops (corn silage) to agricultural residues, municipal waste and sewage sludge began. Since 2017, almost no new plants have been established to work on energy crops as main feedstock. In 2019, 60% of raw materials were covered by agricultural residues, 13% by sewage sludge, 10% by municipal waste, and only 4% by corn silage (EBA, 2020).

Prospects for biomethane production and consumption

According to the forecast of the European Biogas Association, the biogas and biomethane sector may almost double production by 2030, potential production of biogas and biomethane in the EU in 2030 may reach 44 billion m^3/year. By 2050, production could more than quadruple. According to Danish government plans, in 2025 the production of biomethane and natural gas in the country should equalize, and in 2035 natural gas will be completely replaced by biomethane (Eyl-Mazzega, 2019).

A potential European leader in the biomethane market is Italy, where the state uses various methods to stimulate consumption of compressed and liquefied biomethane as a motor fuel for transportation purpose. At the beginning of 2019, 900 applications were submitted in the country for the connection of biomethane plants to gas networks with a total capacity of 2.2 billion m^3/year. It is expected that in 2023 in Italy the transport sector will consume 2 billion m^3 of gas per year of which 25% will be provided with biomethane (bio-CNG).

According to IEA estimates, the annual production of biomethane in the world could reach 200 billion m^3/year in 2040 if the sustainable development strategy is implemented (IEA, 2020). At the same time, the EU will lose its role as a world leader, as more than 50% of biomethane will be produced and used in China and India.

Prerequisites and advantages of biomethane production in Ukraine

Ukraine has the largest area of agricultural land in Europe, and, accordingly, one of the world´s best potentials of agricultural raw materials for biomethane production. Highly developed existing natural gas supply network in Ukraine (both main pipelines (GTS) and distribution networks (GDS)) with all necessary infrastructure compatible for biomethane transmission as technically close analogue of natural gas. That includes storage facilities, pipelines, valves, regimes of operation, operator instructions, automatics, and personnel qualification. Connection of existing main gas pipelines of Ukraine to the European hubs creates possibility for biomethane export to the EU.

Biomethane is ready for injection into the gas network today unlike hydrogen. No investment is required in the modernization of gas networks (GTS and GDS) and gas equipment (gas burners, engines, turbines, valves etc.). Biomethane can help to load the Ukrainian GTS after the termination of the contracts with Russia. Biomethane plants, in addition to biomethane, generate digestate, which can become the main organic fertilizer needed for the revival of Ukrainian soils. Investments in biomethane plants are close to investments in biogas plants with electricity generation (approximately 2.5–3.0 thousand EUR/kW_{el}). The approximate calculations are as follows: a biomethane plant with a capacity of 10 million m^3/year of biomethane, is an analogue of a biogas plant with a capacity of 4 MW_{el}, and it will cost about 10 million Euros. Accordingly, to deliver one billion m^3 of biomethane into the natural gas network, Ukraine needs 100 plants of 10 million m^3/year. Accordingly they will cost one billion Euros in total. The roadmap for the development of bioenergy in Ukraine until 2050 provides for the introduction and growth of biomethane production in Ukraine to 1.7 billion m^3/year in 2035 and up to 3 billion m^3/year in 2050 (Geletukha et al. 2021).

By recent author's estimates (Geletukha et al. 2022) the total biogas production could reach 1.6 billion m^3/year CH_4 already in 2030. The significant part of that biogas could be upgraded to biomethane. Total biomethane production could be 1.0 billion m^3/year in 2030. It is expected that biomethane could partly (0.2 billion m^3/year`) be exported to the EU. The rest could be utilized locally for combined heat and electricity generation in CHP units (0.5 billion m^3/year), heating and industry applications (0.23 billion m^3/year) and for transportation purpose (0.08 billion m^3/year). In such a way biogas sector could serve the growing demand in sustainable and clean energy from the transport and industry sectors.

MATERIALS AND METHODS

Feedstock for biomethane production

A variety of organic materials can potentially be used for biogas production, including specially grown crops, by-products and wastes from plant and animal products, animal husbandry wastes, and other anthropogenic wastes. Due to the limited statistical data available to serve as input data for further estimation of waste volumes only main types of wastes and by-products are covered by this assessment including the following organic materials:

- Animal husbandry wastes, including cattle manure, pig manure, poultry litter, sheep and goat manure formed during animal keeping at the enterprises;
- Maize silage, specially grown;
- Crop residues of major crops, including wheat, rye, barley, maize, sunflower, soybean, rapeseed and sugar beet;
- Food & beverage industry by-products and wastes;
- Sewage sludge from municipal treatment facilities;
- Organic fraction of solid waste.

Animal husbandry wastes

The basic approach in estimation the availability of animal husbandry wastes (manure, litter) is using the data of State statistic service of Ukraine (SSSU) on the number of agricultural animals as of January 01, 2021. The reported livestock number on the date assumed to be the average livestock number within a year. Since 2015, statistics on the number of animals for both temporarily occupied territories in Donetsk and Luhansk regions (as on February 23, 2022) and the Autonomous Republic of Crimea (TOT) are not available. To take into account these territories of Ukraine in the total potential of biomethane production, an approximate estimate of the livestock that can be kept there until has been made.

The latest relevant data of the SSSU on the number of animals for the entire territory of Ukraine are given on January 1, 2014. With some assumption, it is estimated that the difference in livestock between 2015 and 2014 for Donetsk and Luhansk regions shows the number of animals remaining on the uncontrolled territory of Ukraine. Livestock at the level of 2014 is taken as the basic value for the AR of Crimea. The number of livestock estimated in this way for temporarily occupied territories of Ukraine has been adjusted as of 2021 for the growth / decline rate of livestock, which occurred in Ukraine in general from 2014 to 2021. Subsequently, the formation of manure given as the average number for mixed age groups of animals in the breeding cycles. To account biodegradable part of livestock wastes only the data on the specific formation of volatile solids (VS) (VNTP-APK-09.06, 2006, Kuznetsova, 2006) for each type of animal wastes were used. Methane yield potentials were taken according to methods of generalized assessment of technically achievable energy potential of biomass (Dubrovin et al. 2013).

Further, the technical availability for manure collection is basically defined by current practices of livestock keeping at the enterprises. The national data on the current livestock manure/litter handling practices were taken into account. Uncertainty reduction factor of 0.93 chosen for all types of animals waste (Table 1).

Maize silage

Potentially, maize silage can be grown in large quantities, which will be limited only by available land area and crop yield. From the point of view of sustainability of agricultural practices and the trend towards the production of second-generation biofuels from by-products and waste, such an approach can be justified only by the expediency of significantly increasing biogas production in

Table 1. Parameters used for manure and litter

Feedstock type	Specific VS formation, kgVS/head/day	Technical availability for collection, %	Uncertainty factor, %	Methane yield potential, Nm^3CH_4/kgVS
Cattle manure	4.04	53	93	0.193
Pig manure	0.46	100	93	0.45
Poultry litter	0.0356	100	93	0.32
Sheep and goats litter	0.88	27	93	0.19

the short term. However we estimate that maize silage will be used by existing or planned Ukrainian biogas plants in significant amounts in the foreseeable future, as huge amount of NG should be replaced, including biomethane, in short period since dramatic changes expected in natural gas market. Biogas from maize silage is widely proven and reliable technology that could satisfy short term needs in NG replacement, without a significant affect on food security in Ukraine. For example, the use of 5% of arable land (1.63 mln hectares) in Ukraine for maize cultivation for biogas production with an average yield of 40 t/ha in potential could give up to 7 billion CH_4 per year what will be enough to replace the whole volume of imported NG as in 2021.

In this study the potential of maize silage cultivation for biogas production tied to the potential of manure and litter formation. The unified approach is accounting maize silage raw mass potential as 1.5 times to raw mass of either manure or litter. Both specific VS formation for maize silage 0.285 tVS/t raw mass and specific CH_4 yield 0.365 Nm^3CH_4/kgVS assumed according to (FNR 2006).

Crop residues

Estimation of crop residues value is based on the data of SSSU on production of the main crops in 2019. To take into account the potential use of crop residues generated in the TOT of Ukraine, the data of the interactive online map EOS (Earth Observing System) and the data of SSSU on the cultivation of major crops as for 2013 and for 2019 were used. The data of the interactive map show the total area of the fields under different crops, with the distribution by regions of Ukraine, taking into account the TOT of Ukraine. The difference between the total area of land under a separate crop for Donetsk and Luhansk regions from EOS maps and the total area of land under a similar crop from official data of SSSU for 2019 roughly shows the total area of fields under a single crop in the occupied territories. Accordingly, for the AR of Crimea the data of EOS maps as of 2019 were taken as a basis. To estimate the area of land serviced by agricultural enterprises in the occupied territories, their shares in the total area of land under individual crops, which correspond to the data of SSSU for Donetsk and Luhansk regions for 2019, were accepted. The shares of fields served by agricultural enterprises for the AR of Crimea were accepted according to SSSU as for 2013.

To assess the harvesting potential of the main crops in the occupied territories and, accordingly, the formation of crop residues, data on the yield of individual crops in the relevant regions of Ukraine as of 2019 were used. For the AR of Crimea, the yield is accepted at the level of 2013. The yields of biomass tied to commodity crops production via corresponding rates given in the Table 2. The theoretical crop residue yields and technically available parts were used from (Geletukha et al. 2014, Kolchina 2012) and methane yield potentials used from (Kucheruk et al. 2018, Moset et al. 2015, Kaldis et al 2020). The crop residue yield indicator shows the specific theoretical mass of the plant, which is generated at the time of harvest per unit mass of the target product (grains, roots). The technical potential of the collection takes into account only the part of

Table 2. Parameters used for crop residues

Feedstock type	Theoretical crop residue yield, ton raw mass per ton of commodity crop	Technically available for collection crop residue yield, % to theoretical crop residue yield	Share accounted for biogas production, % to technically available for collection crop residue yield	Methane yield potential, Nm^3CH_4/t raw mass
Wheat straw	1	60	50	230
Rye straw	1	60	50	230
Barley straw	0.8	60	50	230
Maize stalks	1.3	70	43	140
Sunflower stalks and cobs	1.9	67	40	53
Soy straw	1	70	43	191
Rape straw	2	70	43	135
Sugar beet tops	0.45	90	100	38

the plant that can be collected by traditional technical means of collection. The rest of the unharvested mass of the plant actually remains in the field and is plowed. The assessment of the potential use of crop residues for biogas production takes into account the part of collected biomass as given in the Table 2. This approach is conservative and takes into account the potential alternative consumption of crop residues (as bedding for livestock farms, substrate for mushrooms growing, building or industrial material, solid renewable fuel, etc.) or their direct application to the fields to replenish humus balance.

However, ultimately the whole mass of collected crop residues can be used for biogas production without any substantial influence for the crop cultivation. It is well known that organic matter is converted via anaerobic digestion process resulting in biogas release composed mainly from methane and carbon dioxide. So, almost whole mass of nutrients and approximately a half of an organic carbon in raw matter is contained in digestate and, as a rule, is returned to the fields in the converted forms ready to use by plants. Using this approach will give even higher biomethane production potential from crop residues – up to 10.5 billion m^3 CH_4 per year.

Food industry by-products

The most significant branches of food and beverage industries in Ukraine are analyzed for potential use of by-products for biomethane production as following:

- sugar production;
- flour and cereals production;
- distilleries;
- breweries;
- sunflower oil production;
- dairies.

Sugar production

The main types of by-products originated from sugar production are sugar beet press (SBP) and molasses. Estimation of SBP formation tied to sugar beet production (for processing) in all the categories of agricultural enterprises, according to the data of SSSU on harvesting of industrial crops in 2019. Sugar beet production in temporarily occupied territories of Ukraine was estimated based on the data on land area under sugar beet according to the maps of EOS and yield of sugar beet in AR of Crimea as of 2013.

Residues output from processing 1 ton of sugar beet were used according to the data on production indicators of a typical sugar factory in Ukraine. Methane yield potentials were used according to Kucheruk (2016) and Kucheruk et al. (2017) (Table 3).

Flour & cereals production

With flour and cereals production, the different types of by-products and wastes are generated including grain shorts, bran, husks, unconditioned grains, flour powder, etc.

In this study, the data on production of bran, sharps and other residues according to the data of SSSU on output industrial products by type and regions in 2019 were used to estimate biomethane production potential. These residues formed from the sifting, milling or other treatment of different cereals including maize, wheat, rice and other. The accounted mass of bran, sharps and other residues is 752.15 thousand ton in 2019. The production of flour&cereals residues in TOT of Ukraine were estimated in proportion to the field areas under the main grain crops. There is lack of specific data on each type of flour and cereals by-products and methane yields. The average specific VS formation for flour & cereal by-products is assumed 0.8 tVS/t raw mass. Specific CH_4 yield conservatively assumed on average 0.15 $Nm^3CH_4/kgVS$. Biogas potential from flour&cereal by-products estimated for 50% of theoretically generated mass.

Distilleries

In distilleries, the main waste types are formed by potato, stillage, grain stillage and

Table 3. Parameters used for sugar production residues

Residue type	Residue output per 1 ton sugar beet processed		Methane yield potential	Share accounted for biogas production
	Tons of RM	Tons of VS	Nm^3CH_4/tVS	% to residue output
SBP	0.806	0.0627	450	75
Molasses	0.044	0.0318	315	25

molasses stillage. The first two types of stillage used mainly as a fodder because of its high nutritive value, however it needs drying and granulating as additional processing. Molasses stillage is the final residual what is reasonable for entirely utilization for biogas production.

As there are no available statistical data on the volumes and types of spirit production in Ukraine, stillage production rate considered as unique value for different types of stillage, with methane yield potential 360 Nm^3CH_4/tVS (Table 4). The overall production of spirit in Ukraine in 2019 estimated by Pro-Consulting company as 149.1 thousand ton. No data are available on the regional distribution of spirit production as well. By that reason the data on spirit production in temporarily occupied territories of Ukraine were also not taken into the account.

Stillage output per 1 ton of spirit produced was used according to (Tovazhnyansky et al. 2008) and methane yield potential – according to (Dubrovskis et al. 2017).

Breweries

The main by-product resulted from beer production is spent grain. Brewery`s spent grain (BSG) is mostly used as a fodder, for bakery macaroni foods, confectionery production etc. Besides, it is can be used as raw material for biogas production.

The data of SSSU on beer produced from malt in 2019 used as a base for calculating biomethane potential from BSG. To account potential from BSG in TOT of Ukraine additional 5% to general beer production in Ukraine was used for Donetsk region (Efes brewery in Donetsk), 0.5% - for Luhansk region (Luhansk brewery in Luhansk) and 0.5% - for AR Crimea (Crimea brewery in Simferopil).

BSG output per 1 m^3 of spirit produced was used according to Tovazhnyansky et al. (2008) and methane yield potential – according to Szaja et al. (2020) (Table 5).

Sunflower oil production

Sunflower oil production accompanied by-products generation including husks, oil extraction cake (meal), sludge, formed during storage of unrefined oil, and soap stock. Extraction cake generated in the processes of the primary and the secondary seed wringing, and meal and soapstock created in the processes of oil extraction from primary wringing cake.

Consumption of raw materials for production of 1 ton of sunflower oil ranges from 2 tons (extraction method) to 2.1–2.2 tons (press method) of sunflower seeds. According to VNTP 20-91 (departmental norms for technological design of enterprises for the production of vegetable oils from oilseeds (sunflower, soybeans)) specific husk generation is about 18% by weight of sunflower seeds received for processing. After the first pressing 42% of the materials formed cake, which subsequently sent to the extraction. The total estimated oil yield is 44% by weight of the processed seeds. Overall yield of residuals after extraction is some 35%. If the technology involves only pressing (first pressing), the main residual will be pressing cake, while its yield would be 0.96 tons per 1 t of sunflower oil.

The data of SSSU on production of unrefined and refined sunflower-seed oil used for calculation biomethane potential from by-products using parameters in Table 6. Oil production in temporarily occupied territories of Ukraine was estimated using the specific rates of by-products formation per 1 ton of sunflower seeds (commodity crop production). Methane yield potentials from

Table 4. Parameters used for distilleries by-products

Residue type	Residue output per 1 ton spirit produced		Methane yield potential	Share accounted for biogas production
	Tons of RM	Tons of VS	Nm^3CH_4/tVS	% to residue output
Stillage	13.650	0.960	360	75

Table 5. Parameters used for BSG

Residue type	Residue output per 1 m^3 beer produced		Methane yield potential	Share accounted for biogas production
	Tons of RM	Tons of VS	Nm^3CH_4/tVS	% to residue output
BSG	0.328	0.0444	330	50

Table 6. Parameters used for sunflower oil production by-products

Residue type	Residue output per 1 ton crude sunflower oil produced		Methane yield potential	Share accounted for biogas production
	Tons of RM	Tons of VS	Nm^3CH_4/tVS	% to residue output
Husk	0.398	0.3290	125	25
Extraction cake	0.773	0.6683	200	25
Unrefined oil sludge	0.008	0.0078	900	75
Soapstock*	0.055	0.0535	700	75

Note: * - per 1 ton of refined oil

sunflower oil production by-products were used according to (Mohanty et al. 2021) and the authors` experimental data.

Dairies

The main type of by-products in dairies, specifically in cheese production, is whey. Whey is a valuable product in different food industries. Whey processing requires high-technology equipment installation and due to particular circumstances is not always reasonable. Thereby the treatment in biogas plants might considered as alternative form of its utilization. Whey generation in the production of curd, cheese and casein lies in the range of factor 1.86…5.25 per ton of product depending on the type of manufactured products (Vasilyeva, 2006). The average level 3.5 t/t cheese assumed as shown in Table 7.

The data of SSSU on production of hard, soft and brine cheeses in 2019 used for calculation biomethane potential from whey. For temporarily occupied territories of Ukraine level of production was estimated based on proportion of cattle livestock. Methane yield potential from whey was used according to (Escalante H. et al. 2018).

Wastewater sludge

The assessment of biogas production potential from sewage sludge covers only municipal wastewater treatment plants. The data of the State Water Agency of Ukraine on the performance of public utilities in the field of sewerage in 2019 used as a basis. The overall wastewater volumes that are biologically treated at WWTPs in Donetsk and Luhansk regions, including temporarily occupied territories of Ukraine, were used from National report on the state of drinking water supply in Ukraine on 2019 and in AR Crimea – the corresponding report on 2012. In calculating the potential for biogas generation the average level of sewage sludge formation at the level of 1% to the volume of biologically treated wastewater taken. Specific CH_4 yield assumed 5.7 Nm^3CH_4/t of raw sludge according to the authors` experimental data.

Organic fraction of municipal solid waste

To assess biogas production potential from municipal solid waste (MSW) the data of the Ministry of Communities and Territories Development of Ukraine regarding amount of MSW collected and landfilled in 2019 were used. MSW volumes in temporarily occupied territories of Ukraine were accounted by using proportion in population numbers. The estimated current population in AR Crimea, taking into account the data on population in Ukraine, is 2.144 million. Specific CH_4 yield from average Ukrainian MSW assumed 65.83 Nm^3CH_4/t of raw MSW based on the data of Ukraine's Greenhouse Gas Inventory 1990–2018. It is assumed that availability of MSW for biogas production based on mechanical biological treatment is 75%.

RESULTS AND DISCUSSION

The estimated biomethane potential from the most prospective feedstock types described above amounts to 9.73 billion m^3CH_4 a year, as on 2020 (Figure 1). Half of this potential is

Table 7. Parameters used for dairies by-products

Residue type	Residue output per 1 ton cheese produced		Methane yield potential	Share accounted for biogas production
	tons of RM	tons of VS	Nm^3CH_4/tVS	% to residue output
Whey	3.5	0.2148	440	75

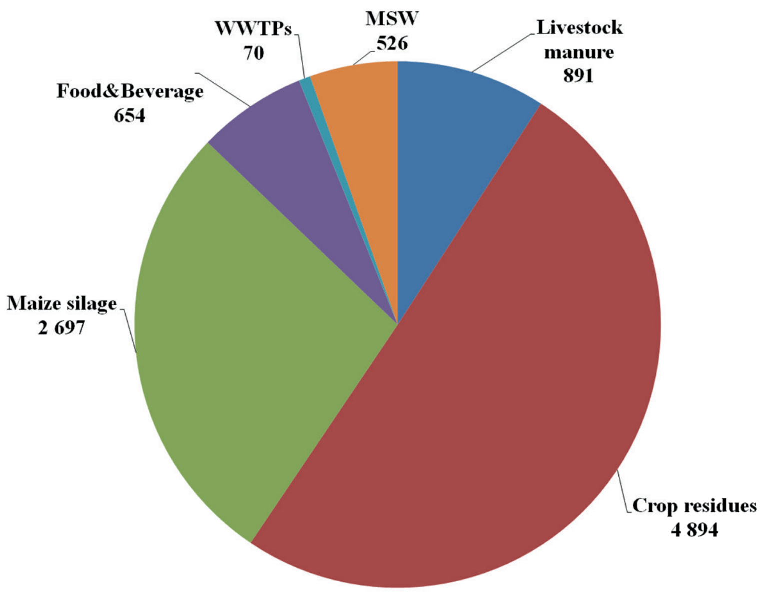

Figure 1. Biomethane potential in Ukraine by feedstock type as on 2020, mln m^3CH_4 a year (2020)

related to crop residues and one third to maize silage production. Animal husbandry wastes can contribute by 9.2%. Food & beverage industry can contribute by 6.7%. Organic fraction of MSW and wastewater sludge could contribute together by additional 6.1%. The potential of biogas production from municipal sewage sludge amounts to only 69.6 mln m^3CH_4 per year. The overall potential related to temporarily occupied territories of Ukraine amounts to 467 mln m^3CH_4 per year or 4.8%. In animal husbandry, the biggest share (53.5%) of biomethane production potential related to poultry litter and 30% to pig manure (Figure 2). Some 7.6% of this potential situated in TOT. The biggest biomethane potential among the crop residues could be obtained from wheat straw (34.7%) and maize stalks (34.7%) – all together 69.4% (Figure 3). Some 4.4% of this potential situated in TOT.

The most valuable potential among food&beverage by-products belongs to sunflower oil industry and sugar production. The overall potential that oil by-products could contribute amounts to 0.32 billion m^3CH_4 a year, whereas oil press cake only can give 203 mln m^3CH_4 a year. Sugar beet press can contribute 205 mln m^3CH_4 a year. The rest accounted types of by-products amounts to the little shares, however in total can

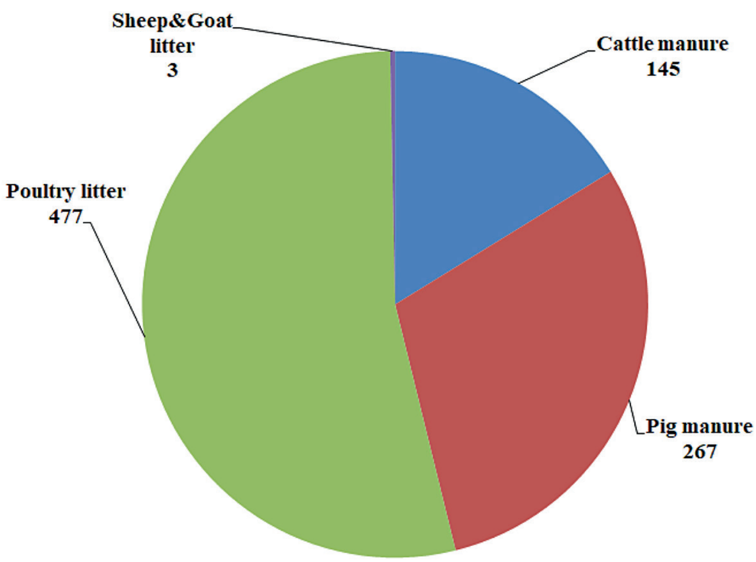

Figure 2. Biomethane potential by animal husbandry type, mln m^3CH_4 a year (2020)

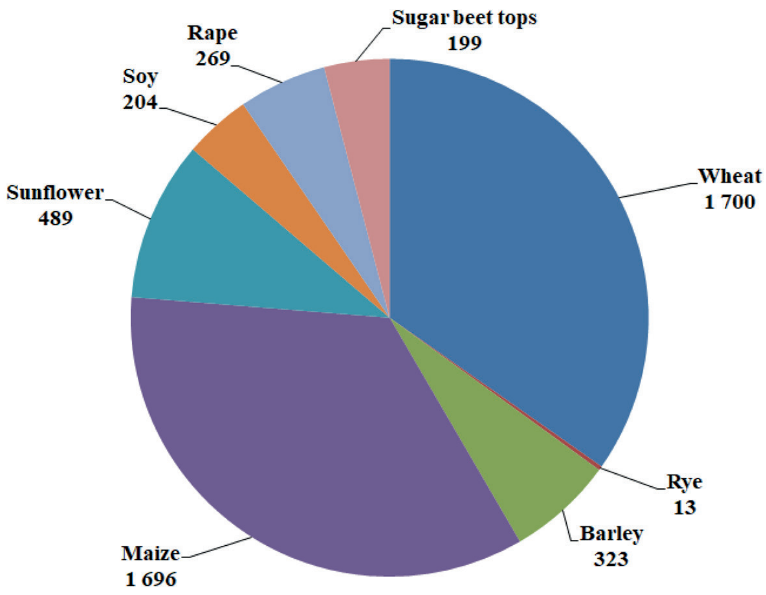

Figure 3. Biomethane potential by crop residues type, mln m^3CH_4 a year (2020)

contribute up to 35% to food & beverage biomethane potential. Estimated biomethane potential from food&beverage by-products related to TOT contribute only 0.4%. Figure 4 shows estimated potential from different types of food & beverage by-products in more detail. Sunflower oil press cake, SBP, sunflower seed husks, stillage and cereal processing by-products are among the most contributing raw materials. Growing the required amount of maize silage with an average yield in Ukraine of 21.8 tons of green mass per 1 hectare, the required total land area is 1.221 mln hectares or 3.7% of the total arable land in Ukraine.

In 2050, the total production potential of biogas/biomethane may increase to 17 billion m^3/year. A significant increase in capacity is projected due to the growth of industrial production, expansion of the raw material base for biogas/biomethane production, consolidation of livestock enterprises and the transition from solid waste disposal to the use of mechanical and biological treatment technology.

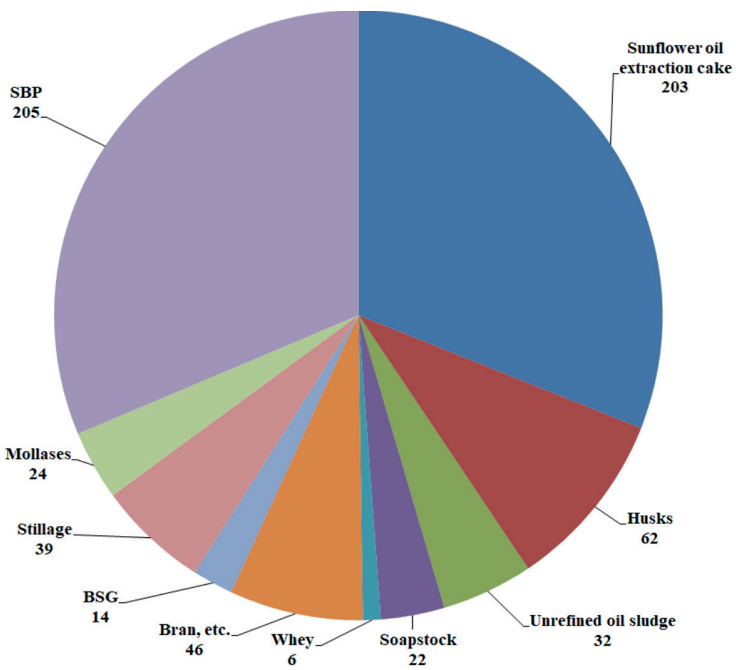

Figure 4. Biomethane potential by food & beverage by-product type, mln m^3CH_4 a year (2020)

Regional level

At the level of regions of Ukraine, almost a half of the potential for biomethane production is concentrated in 6 regions of Ukraine (Vinnytsia, Kyiv, Cherkasy, Poltava, Dnipropetrovsk and Donetsk) (Table 8, Figure 5). The highest potential estimated in Vinnytsya region, while the lowest in Zakarpattya region. Biomethane potential by regions ranges from 38 to 846 mln m^3CH_4/year, averaged at 385 mln m^3CH_4/year by region (Figure 6). The estimated area needed for cultivation of demanded maize volumes for biogas production by regions given in Table 9.

Biomethane or green hydrogen

There is a boom in information about the prospects for green hydrogen. The authors support the need for the development of hydrogen technologies as one of the way of production and use of renewable gases. However, the lower calorific value of biomethane [MJ/m^3] is 3.3 times higher than that for hydrogen at a pressure of one atmosphere, and 4.1 times higher at a pressure of 60 atmospheres (Table 10). This means that transporting one cubic meter of biomethane through a gas pipeline at a pressure

Table 8. Biomethane production potential by regions of Ukraine

Region	Biomethane potential, mln m^3CH_4/year						
	TOTAL	Livestock manure	Crop residues	Maize silage	Food& Beverage	WWTPs	MSW
Ukraine	9731.99	891.22	4893.57	2697.32	654.32	69.60	525.96
AR Crimea	193.55	24.92	72.97	60.80	2.93	6.14	25.79
Vinnytsya	846.15	117.98	391.94	253.41	67.71	1.32	13.79
Volyn	216.72	30.28	75.97	87.01	7.42	0.36	15.68
Dnipropetrovsk	567.16	83.44	231.98	185.02	20.95	5.90	39.87
Donetsk	560.48	70.99	243.97	202.38	13.25	4.23	25.66
Zhytomyr	300.06	13.77	182.58	71.65	15.79	1.52	14.75
Zakarpattya	37.68	2.78	8.79	8.85	0.01	1.43	15.82
Zaporizhzhya	332.18	18.53	191.32	57.15	33.38	2.36	29.45
Ivano-Frankivsk	144.83	21.90	39.09	71.40	1.13	2.03	9.28
Kyiv	792.24	100.57	272.31	281.56	34.51	17.09	86.20
Kirovohrad	410.45	14.76	261.24	60.71	54.69	0.01	19.05
Luhansk	320.22	19.49	235.15	48.36	9.40	0.23	7.59
Lviv	302.94	36.38	112.04	99.11	17.52	4.81	33.09
Mikolayiv	256.65	5.65	175.07	25.32	39.98	0.11	10.52
Odesa	336.64	8.08	199.99	34.79	49.12	4.11	40.55
Poltava	640.34	40.39	349.04	193.75	40.25	2.12	14.79
Rivne	166.05	13.27	88.85	38.24	14.22	0.60	10.86
Sumy	389.28	17.62	272.58	86.58	3.80	0.03	8.66
Ternopil	350.90	26.72	187.94	93.13	28.38	0.93	13.81
Kharkiv	477.13	27.84	246.57	125.36	31.18	10.13	36.05
Kherson	250.91	20.53	156.61	52.82	11.27	1.19	8.49
Khmelnytskiy	510.43	36.86	290.30	130.40	34.70	1.61	16.55
Cherkasy	680.67	106.37	274.13	272.37	18.34	0.17	9.29
Chernivtsi	67.07	8.46	22.35	25.84	0.00	0.88	9.55
Chernihiv	483.65	23.65	310.78	131.30	6.79	0.30	10.82

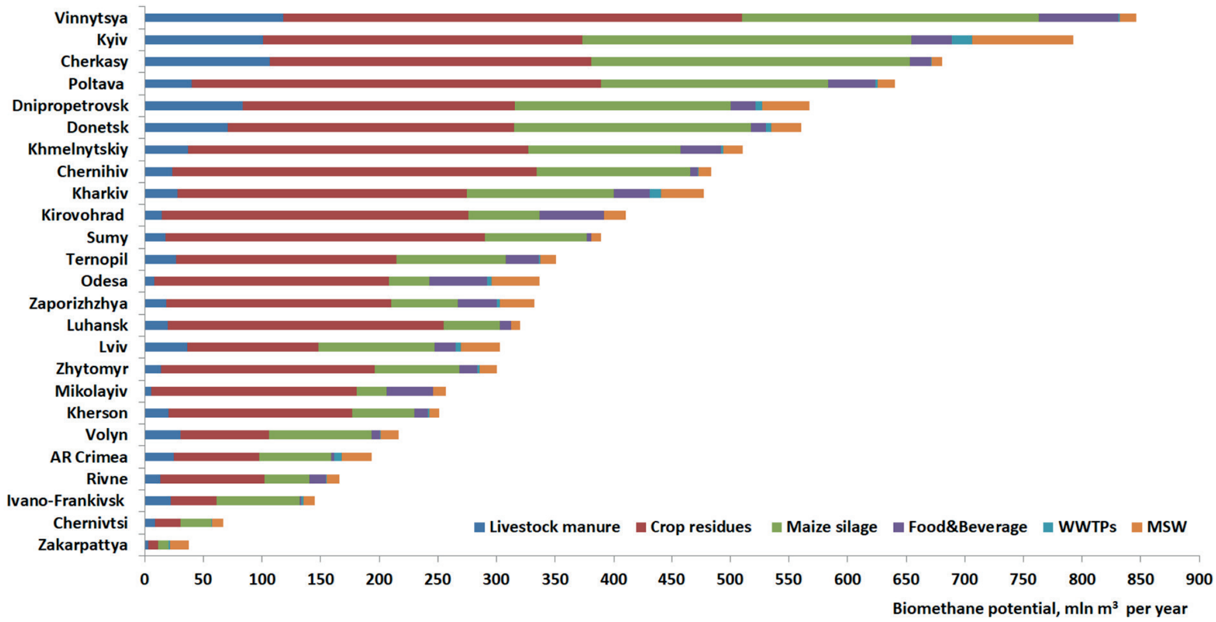

Figure 5. Biomethane potential by regions and by feedstock type (2020)

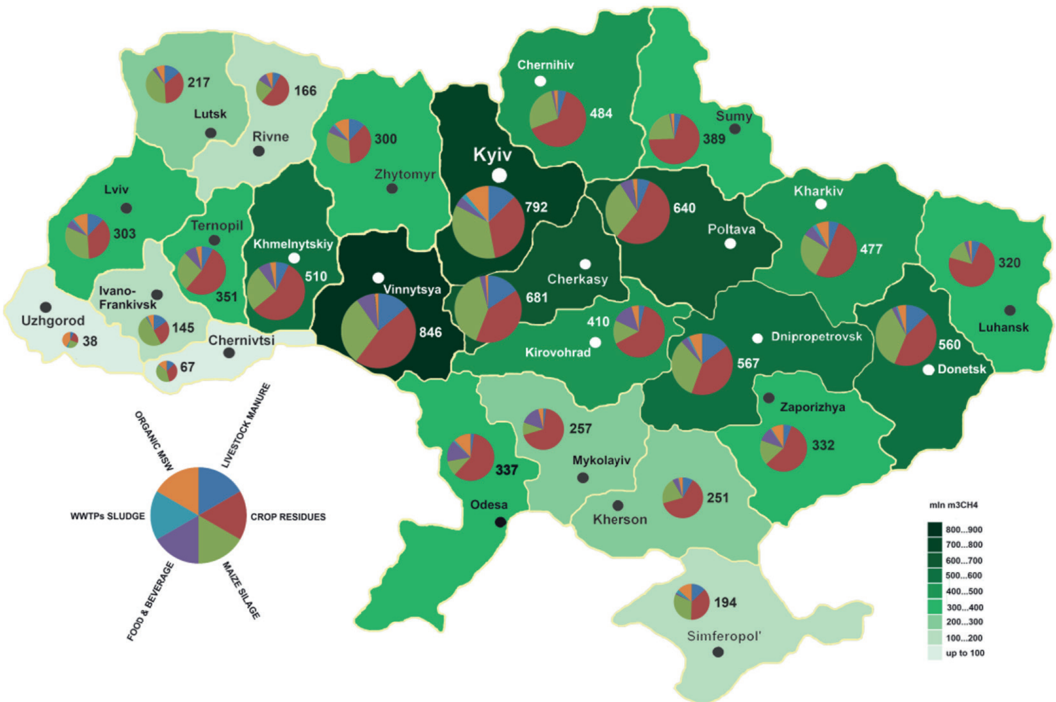

Figure 6. Mapping biomethane potential by regions and by feedstock type, mln m^3CH_4 a year (2020)

of 60 atmospheres transmits almost four times more energy than transporting one cubic meter of hydrogen. This is a fundamental advantage of biomethane. Other advantages of biomethane are the readiness of the gas infrastructure for its transportation and energy use, as biomethane is a close analogue of natural gas. Gas pipelines, gas boilers and engines, gas power plants, and other power equipment designed for the use of natural gas remain unchanged. In the case of large-scale use of green hydrogen, high investments will be needed in the modernization of gas networks and gas equipment. There are estimates by the Finnish company Wärtsilä Corporation, which show that given the cost of upgrading gas infrastructure to use hydrogen, it is more cost-effective to convert green hydrogen to synthetic methane using existing gas infrastructure (Wärtsilä, 2020).

Table 9. Estimated area needed for cultivation of maize for biogas production

Region	Average maize (as animal fodder) yield capacity in 2013–2016	Maize demand for biogas production	Area need for maize cultivation
	Tons per hectare	Ths tons per year	Ths hectares
Ukraine	21.8	25929.5	1192.1
AR Crimea	10.0	584.5	58.5
Vinnytsya	25.4	2436.1	95.9
Volyn	27.1	836.5	30.9
Dnipropetrovsk	17.3	1778.6	102.5
Donetsk	16.3	1945.5	119.2
Zhytomyr	20.9	688.7	32.9
Zakarpattya	9.6	85.1	8.9
Zaporizhzhya	14.9	549.4	36.8
Ivano-Frankivsk	26.1	686.3	26.3
Kyiv	26.0	2706.7	104.0
Kirovohrad	20.4	583.6	28.6
Luhansk	15.1	464.9	30.8
Lviv	24.6	952.7	38.7
Mikolayiv	13.1	243.4	18.5
Odesa	10.3	334.5	32.4
Poltava	26.2	1862.5	71.0
Rivne	24.2	367.6	15.2
Sumy	31.2	832.3	26.6
Ternopil	31.3	895.3	28.6
Kharkiv	19.5	1205.1	61.9
Kherson	19.5	507.7	26.0
Khmelnytskiy	27.1	1253.6	46.2
Cherkasy	28.0	2618.4	93.4
Chernivtsi	23.3	248.4	10.7
Chernihiv	26.5	1262.2	47.7

The cost of biomethane is competitive with the cost of green hydrogen in the near future. Today, the average cost of green hydrogen is about 7 USD per Kg with the prospect of reducing it to 3 USD per Kg by 2030, 2 USD per Kg by 2050 and in the future to 1 USD per Kg. The average cost of biomethane today is 700 USD per 1,000 m^3 with the prospect of reducing it to 650 USD per 1,000 m^3 by 2030, 600 USD per 1,000 m^3 by 2050 and in the future to 500 USD per 1,000 m^3. Table 11 shows the estimated unit cost of energy in biomethane and green hydrogen and their comparison. It can be seen that biomethane is now about three times cheaper than green hydrogen, in 2050 the cost of the two renewable gases is expected to equalize, and only a further reduction in the cost of green hydrogen below 2 USD per kg will make green hydrogen cheaper than biomethane. The greatest prospects can be seen in the combination of the advantages of both renewable gases - biomethane and green hydrogen (Figure 7).

Table 10. Basic physical properties of biomethane and hydrogen

Parameter	Hydrogen (H_2)	Methane (CH_4)	Ratio: CH_4/H_2
Density, kg/m^3	0.087	0.716	8.2
Lower calorific value, MJ/m^3 for normal conditions (0 ºC, 1 bar)	10.8	35.8	3.3
Lower calorific value of compressed gases, MJ/m^3 in the conditions of main gas pipeline (0 ºC, 60 bar)	604	2484	4.1

Table 11. Comparison of energy cost of biomethane and green hydrogen (Geletukha, Matveev, 2021)

Years	Units	2021	2030	2050	After 2050
Assumed hydrogen costs	USD / Kg	7	3	2	1
Cost of energy in hydrogen	USD / MJ	0.058	0.025	0.017	0.008
Assumed biomethane costs	USD / 1000 Nm^3	700	650	600	500
Cost of energy in biomethane	USD / MJ	0.020	0.018	0.017	0.014
Ratio: Cost of energy in hydrogen/ Cost of energy in biomethane	-	3.0	1.4	1.0	0.6

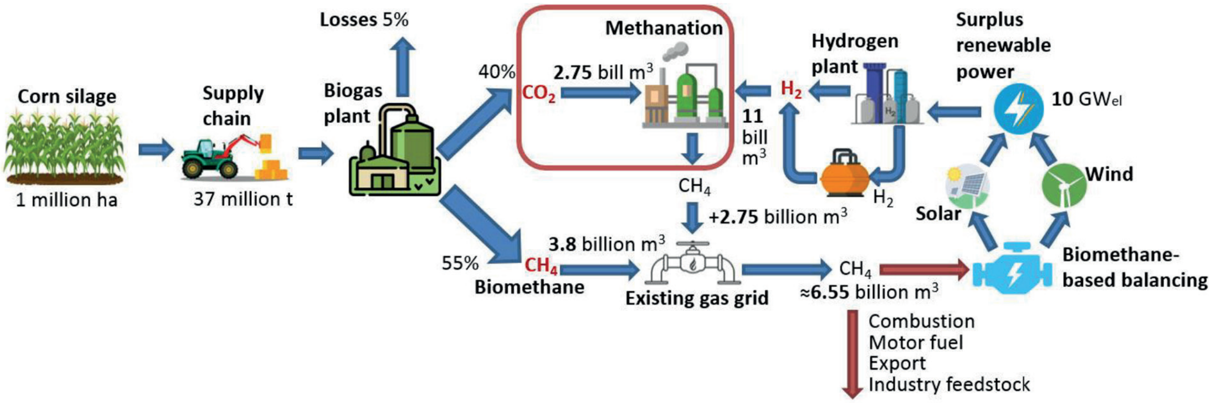

Figure 7. Concept of conversion of green hydrogen to synthetic methane

Implementation of the concept of conversion of green hydrogen into synthetic methane requires:

1. Installation of the equipment for the production of green hydrogen and biomethane in close location;
2. Convertion of green hydrogen into synthetic biomethane with use of CO_2 released during the production of biomethane;
3. Injection of both biomethane and synthetic methane into the pipeline.

Large agro biomass potential of Ukraine concentrated in the areas with potentially large power excess from wind/solar PV (Central/Southern Ukraine). Total biomethane potential is assessed as 9.7 billion Nm^3/year. Additionally 6.8 billion Nm^3/year of synthetic methane could be produced through methanation reaction using H_2 from excess electricity and CO_2 from the biogas-to-biomethane upgrading combining within one installation; large-scale concentrated agriculture (large farms) and large-scale solar PV and/or wind power facilities results in large scale methanation installations reducing overall CAPEX/OPEX for potential projects. The process is already used on fossil-fuel-based industrial level installations (on existing oil-refineries, steel mills, chemical industries).

CONCLUSIONS

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. It corresponds to 11.5% of the total primary energy supply. Biogas and especially biomethane will play important role in this development. Production of biomethane with biogas upgrading to the quality of natural gas can significantly increase the energy efficiency of biogas utilisation. The main advantage of biomethane compared to green hydrogen is the possibility of its transportation using the existing gas infrastructure without modernisation. The total biomethane production in Ukraine could reach 1.0 billion m^3/year in 2030. It is expected that biomethane could partly (0.2 billion m^3/year) be exported to the EU. The rest could be utilized locally for combined heat and electricity generation in CHP units (0.5 billion m^3/year), heating and industry applications (0.23

billion m^3/year) and for transportation purpose (0.08 billion m^3/year). In such a way biogas sector could serve the growing demand in sustainable and clean energy from the transport and industry sectors.

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