LOCAL UKRAINIAN BIOMASS – POTENTIAL, COLLECTION, AND TREATMENT PROCESSES

Contents

1. Introduction

The purpose of this document is to provide comprehensive information on the potential for utilization of local solid biomass[1] in Ukraine for electricity and combined heat and electricity production, and to support a larger utilization of this potential. Information is included on how to collect, treat, and prepare local biomass, transforming it into manageable bioenergy suitable for power and combined heat and power (CHP) production.

During the evaluation of the Urgent Technology Catalogue for Ukraine (UTC) 2023, it was pointed out that Ukraine has a strong agriculture sector with great potential for bioenergy supply, but for now this local bioenergy potential is underutilized due to lack of awareness of the potential and lack of experience in utilization of solid biomass agricultural waste. Additionally, Ukraine has a large forestry production and thereby a large potential for production of woody biomass energy as wood pellets, woodchips, and firewood. Furthermore, due to low population density (UA: 67 people/km^2, EU: 109 people/km^2)[2] and to the estimation of around 4 million ha (2019) non-utilized agricultural land, a potential for growing energy crops is also identified.

The initial survey showed that the largest non-utilized potential of solid biomass waste was found in the agricultural sector, therefore, the focus of this note is solid biomass waste from the agricultural sector. The potential for increasing the production of energy crops (e.g. miscanthus, poplar, and willow) and utilization of these feedstocks locally is not treated in this note because of the focus on urgency.

Not all solid biomasses are suitable as feedstocks in the thermal power plants (TPPs) and the thermal combined heat and power plants (CHPs). Therefore, the note provides an overview of which local solid biomass residues are suitable as fuels in the combined heat and power plants and power plant technologies that is included in the UTC.

Furthermore, agricultural producers face constraints due to the lack of specialized equipment for biomass collection, making it a costly and complex activity. The supply chain for biomass is challenging to arrange compared to natural gas for energy production. Therefore, this note also touches on how to carry out collection and transportation of the most relevant solid biomass agricultural residue.

The economic feasible potential for bioenergy (solid biomass) in Ukraine is estimated to be app. 800 PJ (19 Mtoe) taking into account also the potential for growing energy crops. Solid biomass agricultural waste accounts for almost half of this potential. Forestry biomass and woody energy crops makes up almost three fourths of the remaining potential. The outlining of the overview of the potential of solid biomass residues suitable for thermal energy production and the current utilisation of the potential is primarily based on existing surveys, literature, and references.

The bioenergy production in Ukraine has been increasing in the 10 years before 2021 with on average 16% annual growth [1][3]. Biogas makes up a considerable share of this. Regardless of this increase, it is estimated

1 Only thermal energy conversion of the solid biomass is included; organic energy conversion, e.g. production of biogas and biomethane (upgraded biogas) is not included and only mention shortly.

2 https://www.worldometers.info/world-population/ukraine-population/ and https://www.ine.es/prodyser/demografia_UE/img/pdf/Demograhy-InteractivePublication-2021_en.pdf.

3 [1] Prospects for Bioenergy Development in Ukraine: Roadmap until 2050, Ukraine Ecological Engineering & Environmental Technology 2021, 22(5), 73-81, Georgii Geletukha1, Tetiana Zheliezna, Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, Marii Kapnist Street, 2a, Kyiv, 03057.

that 4-7% of the potential energy resource from the solid biomass waste from agriculture in Ukraine is currently being utilized for energy production [1], [2][4]. Thereby, a significant underutilization of the potential for local solid biomass waste from agriculture in Ukraine is identified. Lack of knowledge about the process has been pointed out as a barrier to utilizing this potential on a larger scale.

In the National Renewable Energy Action Plan for 2030, it is expected that bioenergy as a part of the gross final energy consumption in Ukraine should grow at least two times in the span between 2020-2030 reaching 6 Mtoe including all biofuels (forestry waste, agricultural waste, and energy crops)[5], while all renewables, including bioenergy, will increase 5 times by 2050 compared to 2020 according to the Ukraine's Energy Strategy 2050.

The utilization of biomass in Ukraine also faces significant challenges across other domains. Organizational and regulatory issues include the absence of a marketplace to balance biomass supply and demand, lack of a roadmap for increased biomass use, and illegal wood logging, which makes illegally logged wood more price competitive. Additionally, bioenergy is not included in strategic development plans, hindering its growth.

Economically and financially, biomass is not considered CO_2 neutral, and the CO_2 tax makes biomass projects less viable. Biomass is more expensive than subsidized natural gas, and low-interest loans for agricultural producers are limited. The lack of subsidies and high inflation further complicates the economic viability of biomass projects.

War-related challenges exacerbate the situation, with a significant shortage of workforce, extensive demining needs, and the destruction of biomass-fired plants. These factors significantly hinder biomass utilization and energy production in Ukraine.

4 [2]https://uabio.org/wp-content/uploads/2021/03/ZHelyezna_EU4USociety_AgroBM_26-02-2021.pdf.

5 Ukraine's National Renewable Energy Action Plan for 2030.

2. Current utilization of renewable energy sources in Ukraine

The role of renewable energy sources (RES) is growing year by year. According to the latest available official data (2020), the share of RES in Ukraine's total primary energy supply was 6.6%, and biofuels and waste account for $^3/_4$ of the RES share, with wind, solar, and water accounting for the remaining $^1/_4$ (Figure 1). Specifically, the amount of waste and biomass utilized is increasing and has doubled between 2015 and 2020.

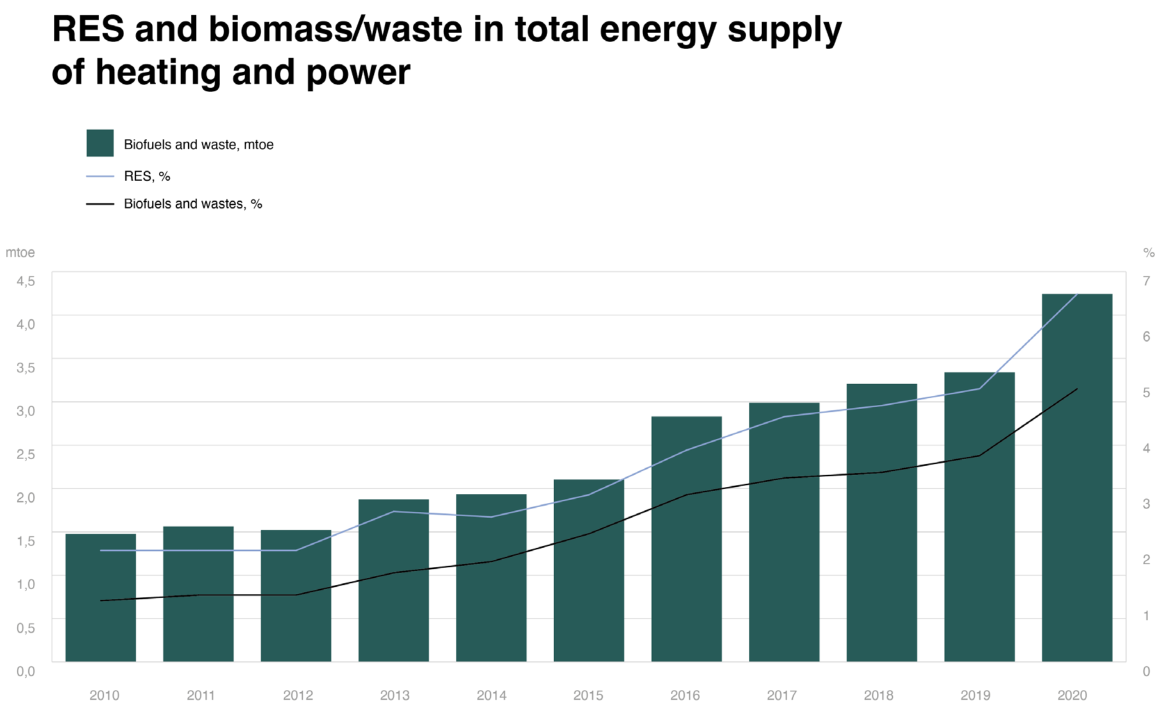

Figure 1: RES and biomass/waste in total energy supply of heating and power[6]

Since February 2022, the Russian army has been targeting Ukrainian power plants and energy infrastructure. In this context, the importance of decentralized renewable energy (RE) has grown, bolstering the country's overall energy resilience. Therefore, it is crucial to mobilize all available renewable energy sources. In this note, focus is particularly on solid biomass from agricultural crops and forestry residues. Firstly, to emphasize the importance of the issue; additionally, there is a general trend of increasing the importance of solid biomass usage for heating and independent electricity supply by businesses and local (rural and urban) authorities during the war, which can be multiplied throughout the country.

6 https://www.ukrstat.gov.ua/operativ/operativ2021/energ/En_bal/Bal_2020_ue.xls.

2.1. Current trends of electricity production from all renewable energy sources in Ukraine

In 2020, the total electricity production in Ukraine was 150 TWh; in 2022, it was 115 TWh, a reduction of almost 25%.

Ukraine hosts over a thousand renewable energy companies, operating 1 767 RES power facilities. These facilities produced approximately 8 TWh of green electricity in 2022-2023. However, wind power plants experienced the largest decline in electricity production in 2023, dropping by 43%, primarily due to the Russian occupation or destruction of power plants and energy infrastructure in the southern regions. In contrast, electricity production by solid biomass increased by 61% from 2022 to 2023[7].

In 2023, the installed capacity of renewable energy source (RES) power plants in Ukraine (solar, wind, hydro, and bioenergy) increased by 238 MW, reaching a total of 8 773 MW. The new RES power installations included 65 new installations. Of these, 157 MW are wind turbines, 56 MW are solar cells, and 23.6 MW are solid biomass power plants, all operating under a feed-in tariff.

None of these new installations received an allowance for the local component; a “local content premium” which is a bonus to feed-in tariff for maintaining the level of use of Ukrainian-made equipment. Consequently, the total number of facilities with an allowance for the local component in 2023 was 181 units, including 120 solar energy units.

Detailed description of electricity production from biogas or upgraded biogas (biomethane) is not included in this note.

The total installed capacity of biogas facilities has not changed during 2023 and accounted for 135 MW. There were 43 companies with 68 biogas installations that received a feed-in tariff in 2023, including 12 companies with surcharge for local components.

In 2023, the total volume of electricity production from biogas increased by 15% to 580 GWh. The average utilization rate of the installed electrical capacity of biogas plants is 49%. Of the total number, 20 installations did not produce electricity at all. Only five plants had indicators of installed capacity use at the level of 75-82%.

2.1.1. Current electricity production from solid biomass

The capacity of the thermal TPP and CHP utilizing solid biomass makes up approx. 2% of the total installed RES power capacity in 2023 in Ukraine. In 2023, the capacity of thermal power plants (TPPs) and combined heat and power plants (CHPs) in Ukraine utilizing solid biomass was increased by approx. 15% (23.6 MW), reaching a total of 178 MW across 24 facilities. The average capacity of TPP/CHP is 7.4 MW, which is relatively low.

In 2023, the average annual utilization of the biomass plants increased by 40%, as the average capacity factor increased from 21% in 2022 to 30% in 2023. Hereby, the annual electricity production from biomass rose by 61%, from 288 GWh (1.0 PJ) in 2022 to 464 GWh (1.7 PJ) in 2023.

Notably, electricity-producing plants in Ukraine only utilize sunflower husks or woodchips. In 2023, more than 78% of the solid biomass electricity was generated by sunflower husks and around 22% by woodchips. In 2023, TPP/CHPs utilizing sunflower husks have an installed capacity of approximately 110 MW, while TPP/CHPs of an installed capacity of approximately 67 MW are utilizing wood chips.

7 https://uabio.org/materials/14656/.

3. Potential for small scale power production utilizing solid biomass residues in Ukraine

Ukraine has a significant production of agricultural and forestry products. This production generates considerable biomass waste that could potentially be used for energy purposes. These include grain straw, maize stalks and cobs, sunflower husks, stalks and heads, trees, branches, animal manure and poultry waste, and organic matter found in household waste. In the analyses in this note, only solid biomasses are included.

3.1. Summing up on applicability and potentials for utilization of solid biomass residues for power and CHP production

In the previous sections, we highlighted that even under the current situation, there is a significant untapped potential for thermal utilization of solid biomass in Ukraine, particularly for power generation and combined heat and power (CHP) production from agricultural and forestry residues. Among these resources, agricultural residues represent a vast, underutilized opportunity, with notable potential for the utilization of straw from grain crops.

In the near term, it is estimated that substantial amounts of grain straw could be used to fuel thermal power plants (TPPs) and CHP facilities. This opportunity is particularly promising for several reasons. Firstly, the energy technology required to convert grain straw into power is well-established and reliable. Secondly, the methods and equipment for collecting and handling straw are widely known and already extensively used. Additionally, insights gained through interviews reveal strong connections between Ukrainian and Danish agriculture, including valuable experiences of Ukrainian agricultural workers in Denmark. Finally, the machinery required for handling grain straw is neither highly specialized nor prohibitively expensive, making implementation more practical and feasible.

This combination of factors suggests that harnessing the potential of agricultural residues, particularly grain straw, could provide a practical and efficient pathway to expand Ukraine's biomass energy sector in the near future.

3.2. Overview of the energy potential of local solid biomass residues

The theoretical and economic potentials for energy derived from solid biomass residues in Ukraine (as of 2019) are presented in Table 1. The theoretical energy potential for solid biomass residues amounts to nearly 1 400 PJ (not including the potential for energy corps), with 80% originating from the agricultural sector and 20% from forestry.

The economic potential for solid biomass residues in Ukraine is estimated at 570 PJ, representing slightly more than 43% of the theoretical potential. For most agricultural solid biomass waste types, particularly primary agricultural residues left in fields, it is assumed that only 40% or less of the theoretical potential is economically viable for energy production. In contrast, sunflower husks, a secondary agricultural residue produced at factory premises, demonstrate significantly higher collection efficiency, with 100% of their theoretical potential deemed economically feasible for energy use. Forestry residues show an average economic feasibility of 68% of their theoretical potential. Consequently, agricultural residues account for 59% of the total estimated economic potential of solid biomass for energy purposes.

Additionally, by cultivating solid biomass energy crops such as miscanthus, poplar, and willow on 1 million hectares of unused agricultural land, Ukraine could increase the economic potential for solid biomass energy by 36%, assuming full utilization of the theoretical potential for these energy crops. Thereby, the economic potential for solid biomass energy is 774 PJ per year.

Today, hundreds of burning boilers with a capacity of up to 1 MW each are available in Ukraine, but they are mainly used by agricultural entities for their production purposes (e.g., drying of grain or timber) and by local municipalities for local centralized heating in rural areas and small towns, but not for electricity supply to the power grid. The cases of energy use of other agricultural solid biomass (e.g. corn and sunflower stalks and energy crops like miscanthus, willow etc.) are quite limited or fully absent[8]. Energy crops were cultivated by a few companies on an area of 6 175 hectares in 2021[9].

Table 1 also shows that currently, agricultural residues are only utilized to a very limited extent, on average 7% (41 PJ/year), despite the high potential.

Thus, the agricultural residues are largely left in fields and burned in Ukraine, despite strict legal prohibitions against this practice. The persistence of crop residue burning stems from barriers such as a general lack of machinery, techniques, and experience in collecting and handling most residues (except straw). Additionally, there is a lack of market opportunities for these residues[10].

Table 1: "Theoretical potential" and "Economical potential (%)" 2019/2020 for solid/dry agricultural residues and forestry residues. Based on Table 1 in "Prospects for Bioenergy Development in Ukraine: Roadmap until 2050", Ecological Engineering & Environmental Technology 2021, 22(5), 73-81. The PJ was obtained from Mt based on the lower heat of combustion of biomass, provided that the biomass was air-dried to a moisture content of between 15-25%[11].

Solid biomass	Theoretical potential (2019)	Economic potential of the theoretical potential	Share of total economic potential for solid biomass residues	Currently (2019) utilized for energy of economic potential	Unused economic potential (2019)
Agricultural residues	PJ/year (Mt/year)	% (PJ/year)	%	% (PJ/year)	PJ/year
Straw of grains	525 (37.5)	30% (158)	28%	4% (6.3)	151
Straw of rapeseed	89 (5.9)	40% (36)	6%	4% (1.4)	34

8 Prospects for Bioenergy Development in Ukraine: Roadmap until 2050

9 Trypolska G. Dedicated energy crops: support policies in Europe and in post-war Ukraine. International Journal of Foresight and Innovation Policy 2023, Vol. 16, No. 2-4, PP. 185-202.

10 Analysis of barriers to the production of energy from agribiomass in Ukraine, UABIO Position Paper N 21, 2019, Georgii Geletukha, Tetiana Zheliezna, Semeon Drahniev, Bioenergy Association of Ukraine.

11 Database of the physical and chemical composition (processed) of lignocellulosic biomass, micro- and macroalgae, various raw materials for the production of biogas and biochar.

Stalks and cobs of maize	374 (46.6)	40% (149)	26%	-	149
Stalks and heads of sunflower	174 (29)	40% (70)	12%	-	70
Husk of sunflower	44 (2.6)	100% (44)	8%	75% (33)	11
Total agricultural residues	1 206	38% (456)	80%	9% (41)	415
Forestry residues (woody biomass)	**PJ/year**	**% (PJ/year)**		**% (PJ/year)**	**PJ/year**
Wood biomass such as fuel wood, logging residues, wood working waste	76 (7.4)	95% (72)	13%	99% (71.3)	0.7
Wood biomass such as deadwood, wood from shelterbelt forests, bio-mass from agrarian plantation pruning and removal	93 (8.8)	45% (42)	7%	99% (41.6)	0.4
Total forestry residues (woody biomass)	169	68% (114)	20%	99% (113)	1
Total all solid biomass residues	1 375	43% (570)	100%	27% (154)	417
Solid biomass Energy Crops: mis-canthus, poplar, and willow (1 mln ha*)	204 (11.5)	100% (204)	+36%	n.a.	n.a.
Total solid biomass including energy crops	1 579	774		+154	+417

On the contrary, Table 1 shows that almost all of forestry residues are already being utilized. A considerable share of the forestry residues is currently exported for wood pellet or woodchip production abroad or used for wood pellets or wood chips produced in Ukraine and exported afterwards. At the same time, a considerable amount of the woody biomass is used locally as firewood in small wood stoves or boilers.

The total electricity production by biomass in 2023 in Ukraine is stated to be 464 GWh[12] (1.7 PJ). This also includes the production from biogas, meaning that less than 7 PJ[13] of the solid biomass was utilised for electricity production in 2023. Comparing this amount with the consumption of solid biomass in total 220 PJ/year (in Table 1), it can be concluded that less than 3% of the solid biomass currently used for energy purposes is used for electricity production.

3.2.1. Changes in arable land in Ukraine 2021 to 2024

The potential for solid biomass residues in Ukraine, as shown in Table 1, is based on estimates from the period before the war. The war has temporarily altered the area of arable land in Ukraine. Figure 2 illustrates the changes in land area suitable for economic activity in Ukraine between 2021 and 2024. The figure shows that after 2021, the area of agricultural land (including arable and fallow land) decreased by approximately 21-32%. The smallest agricultural land area was recorded in 2022, while the largest was observed in 2024. Similarly, the area of land available for forestry decreased by 12-26% during the same period.

Despite these reductions, it is important to note that on average, less than 10% of agricultural waste was utilized in 2019/2022. Therefore, even under the present circumstances, there remains a significant amount of solid biomass that could potentially be used for electricity and heat production in thermal power plants and combined heat and power facilities.

12 in section 2.1.1 "Current electricity production from solid biomass".

13 30% efficiency is assumed for the electricity production.

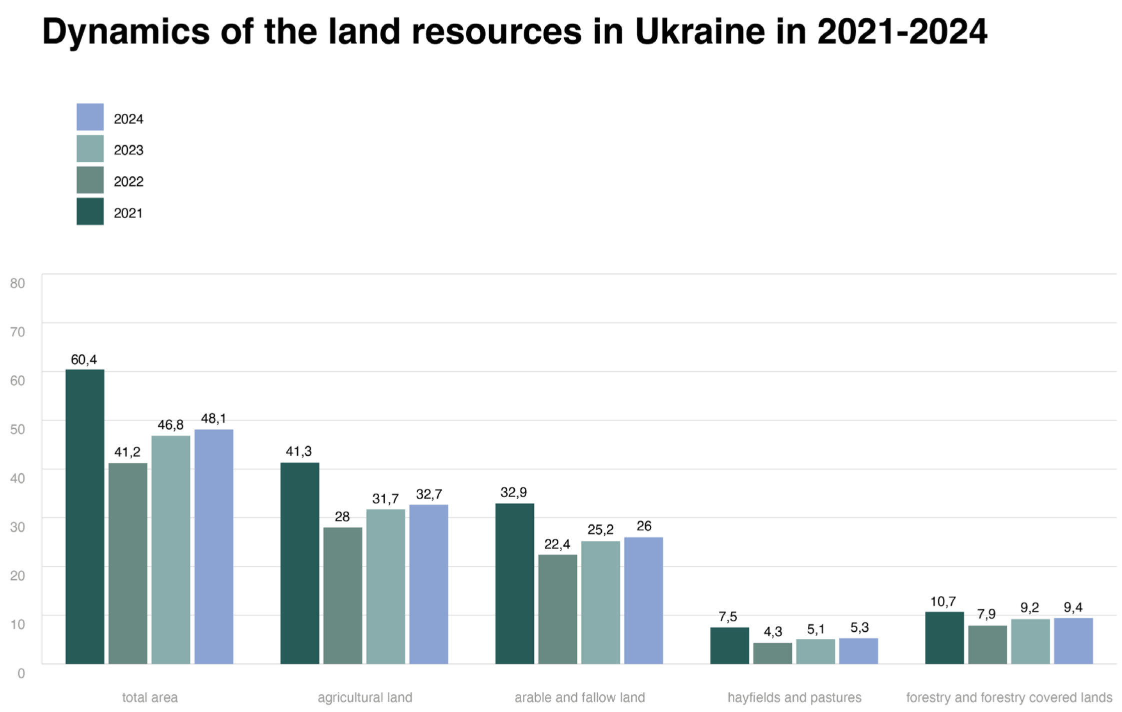

Figure 2: The area of the territories of Ukraine suitable for conducting economic activity in million ha for the years 2021-2024 Agricultural Outlook Ukraine 2024-2033 Report summary /3. The Ukraine country model in AGMEMOD[14]

The solid biomass agricultural residues are further described in Annex 1.

3.3. Sustainability of utilization of the different solid biomass types for energy purposes

Not all types of solid biomass are suitable for use in every energy conversion technology. Consequently, the suitability of various types of solid biomass, whether derived from residues or cultivated as energy crops in Ukraine, has been evaluated. The results are presented in Table 2, which provides a comprehensive overview of the assessment.

Before utilization in energy plants, biomass typically requires preprocessing. Common preprocessing methods include drying, baling, making into pellets, and ensiling. While these pretreatment steps are critical for efficient energy conversion, they are not detailed in this note. Instead, the focus here is on evaluating the suitability of different biomass types for various energy technologies, assuming that appropriate preprocessing has already been applied.

14 Agricultural Outlook Ukraine 2024-2033 Report-summary, 2024, M.Bogonos, A.Chmil, R.Nazarkina, O.Nykolyuk, P.Pyvovar, H.Stolnikovych.

Table 2: Evaluation of biomass feedstock suitability for various energy conversion technologies. "+" indicates that the biomass can be used in the energy technology, and its use is widespread with good and robust experiences in its application. "(+)" indicates that the biomass can be used in the energy technology, but it is not widespread, so it is not considered immediately straightforward, and there are no robust experiences with it. "-" indicates that the biomass is assessed to be unsuitable for use in the energy technology.

**Pellets made from straw from grains can be utilized for bedding material and potentially anaerobic digestion, but straw pellets cannot be used for combustion or gasification.*

	Suitable for:			
Technologies	Power and CHP directly via combustion	Thermal gasification (synthetic gas)	Anaerobic digestion (biogas)	Pelleting for export for energy purpose
Agricultural residues				
Straw of grains	+	(+)	+	-*
Straw of rapeseed	(+)	(+)	-	-
Stalks and cobs of maize	(+)		+	-
Stalks and heads of sunflower	(+)	-	+	-
Husk of sunflower	+	(+)	-	+
Forestry residues products				
Wood pellets	+	+	-	+
Wood chips	+	+	-	+

3.3.1. Solid biomass residues suitable for electricity production

Table 2 reveals that among the agricultural residues evaluated, only for grain straw and sunflower husks, there is a long-standing and robust experience of them as fuel sources for thermal power plants (TTPs) and combined heat and power (CHP) facilities. These biomass types are deemed particularly suitable for such applications, which form the core focus of this analysis. The same applies to forest residues, such as woodchips and wood pellets.

Combining the information in Table 2 and the potential estimates presented in Table 1, it can be concluded that Ukraine has an untapped annual potential of 162 PJ/year in local solid biomass agricultural waste, which could be utilized for producing electricity and combined heat and power using well-known small-scale technologies based on technologies that are widespread with good and robust experiences.

Table 2 further highlights that other agricultural residues are theoretically suitable for use in TPPs and CHP facilities. However, there is insufficient documented evidence or operational experience to confirm their viability in these applications.

This indicates that while these residues show promise, their utilization remains less proven compared to grain straw, sunflower husks, and forest residues. As a result, they are currently excluded from the UTC catalogue. Nevertheless, they represent a viable long-term feedstock option for Ukraine's power system.

4. Techniques and technology for handling of solid biomass

This section outlines the techniques and technologies required for handling biomass, including its collection and pre-treatment before utilization in the energy plant. It covers both current methods and potential improvements.

Since the first and third places among the residues with the greatest potential for electricity generation stand by grains and sunflower, techniques and technologies for handling them are presented below.

4.1. Straw

Ukraine, as a major global grain supplier, produces substantial annual quantities of straw, a portion of which could be utilized for power and heat generation.

Over the past 40-50 years, Denmark has accumulated significant expertise in straw management and its conversion into heat and power across small- and large-scale heating plants, as well as combined heat and power (CHP) facilities.

This section outlines key Danish practices and systems that could be adapted to Ukraine's context. The analysis draws heavily on insights from the publication "Straw for Energy Production" by the Centre for Biomass Technology and the more recent report "Straw to Energy – Technologies, Policy, and Innovation in Denmark".

Available resources

Table 1 indicates that Ukraine, under normal circumstances (2019-2022), produces approximately 38 million tonnes (Mt) of straw annually. For comparison, Denmark typically generates 5-6 Mt of straw annually, of which 3 Mt (50%) is allocated to bedding and energy generation. Over 2.5 Mt remain unused or are ploughed back into the soil.

The economically feasible potential for utilizing grain straw for energy in Ukraine is estimated at approximately 30% (~11 Mt), while current utilization stands at only 3-4% (1-1.5 Mt). This indicates significant untapped potential[15].

Straw for energy

Straw is highly suitable for combustion in medium- and large-scale grate boilers for hot water or steam generation, which can subsequently be used for electricity and heat production. However, challenges arise due to the low melting temperature of straw ash. Above a certain threshold, the ash becomes sticky, leading to fouling and slag buildup. Consequently, straw is best suited for combustion in loose form, where temperatures can be precisely controlled.

[15] Table 1. Bioenergy potential in Ukraine in 2019, Ecological Engineering & Environmental Technology 2021, 22(5), page 73-81

Combustion of pelletized straw has proven problematic in both residential-scale boilers and large-scale systems. Conversely, straw is well-suited for anaerobic digestion in biogas plants, provided it is pre-processed through methods such as briquetting, making into pellets, or used as bedding material.

4.1.1. Straw handling

To ensure a large-scale supply of straw with satisfactory quality at reasonable prices, straw handling must be optimized for efficiency. Straw producers and purchasers in Denmark have focused on streamlining supply chain elements, particularly transport and storage logistics. While most supplies still involve large bales, optimization efforts have led to increased adoption of midi-big bales, which enable more efficient road transport.

Straw handling has evolved into a specialized discipline within Danish agriculture, relying on heavy-duty machinery operated primarily by large farms and agricultural contractors. Since the 1980s, when large balers became widely available, the sector has invested heavily in equipment such as balers, rakes, front loaders, transport vehicles, and storage facilities to meet the energy sector's demand.

After harvesting, straw remains in swaths in the field. Subsequent steps vary depending on weather conditions and other factors:

- Raking
- Baling
- Pellets, briquettes, and chaffed straw
- Loading and unloading from trucks and lorries
- Field transport
- Decentral storage
- Loading for road transport
- Road transport
- Unloading at the plant
- Registration of weight and moisture content
- Buffer storage (at the plant)

4.1.2. Raking

If weather conditions are favourable during harvest, straw can be bailed immediately after the combined harvester deposits it into swaths. However, if the straw is too wet (typically with an average moisture content exceeding 15%), it must dry in the swath before baling. If rain occurs during this period, raking may need to be repeated.

Modern rakes are designed to either spread the swath across the entire width of the rake, maximizing exposure to air for drying, or gather/turn the straw within the swaths.

4.1.3. Baling

Today, Danish power plants and district heating facilities almost exclusively use large bales or midi-big bales. Small bales are rarely utilized for energy production (except in very small or outdated farm heating systems), while round bales are primarily limited to farm-scale heating plants specifically designed for such formats.

Over the years, numerous efforts have been made to increase the density of large bales and adapt supply chain equipment accordingly. Heavier bales can enhance supply chain efficiency.

Another efficiency improvement involves the growing adoption of midi-big bales alongside traditional large bales. The key advantage lies in reduced road transport costs: trucks can carry three layers of midi-big bales instead of two layers of large bales. Since midi-big bales can be produced at nearly the same weight as large bales, this allows for transporting approximately 50% more straw per truck, significantly lowering costs.

*Table 4: Properties of straw bales (*width times diameter)*

Bale type	Dimensions, L x W x H (cm)	Weight (kg)	Density (kg/m^3)
Small bales	70-90 x 46 x 36	12-15	90-100
Round bales	120 x 170*	220-270	100-120
Mini-big bales	200-240 x 80 x 80	200-250	110-150
Midi-big bales	230-250 x 120 x 90	450-650	160-230
Big bales	230-250 x 120 x 130	450-650	140-170

4.1.4. Pellets, briquettes, and chaffed straw

Baling is the costliest element of the straw supply chain. Research and development efforts have explored whether substituting baled straw with pellets or briquettes, or handling cut straw without baling or pelletizing could improve efficiency.

Figure 3: Example of transporting midi-big bales on the field

Pelletizing or briquetting straw increases density, which typically reduces subsequent handling costs. Additionally, pellets can be unloaded and transported pneumatically within plants, reducing reliance on cranes and further lowering expenses.

However, pellet production still requires baling and transporting straw to a processing facility, resulting in higher total costs compared to traditional large or midi-big bale supply chains. Exceptions may apply if transport distances from field to plant are long enough to justify pellet shipping via sea routes, or if field-based pelletizing technology advances to eliminate the need for initial baling. While such technology exists, it has yet to prove cost-effective and often involves diesel consumption without utilizing process heat.

In the early 2000s, straw pellets were used extensively at Amager Power Station in Copenhagen. Produced at the Køge Bio Pellet Factory 50 km south of the city, they were shipped via water to avoid heavy truck traffic through Copenhagen. Due to technical challenges in the boiler, consistent with issues observed in other straw pellet experiments, the plant now uses wood pellets. Consequently, straw pellets are not recommended for thermal power plants (TPPs) or thermal combined heat and power plants (TCHPs).

Briquetting straw under high pressure has been shown to increase its digestibility in biogas plants as a beneficial side effect. This could make briquetting a viable handling method when straw is intended for biogas production.

In the early 1990s, experiments were conducted with cut straw stored in field haystacks to reduce handling costs. Initial tests suggested potential cost reductions of up to 50%, but practical challenges led to the concept being abandoned by the mid-1990s.

4.1.5. Loading and unloading from trucks and lorries

When loading straw, various equipment options are available, including front loaders, excavators, tractor shovels, telescope loaders, and mini loaders. In principle, the first three types, based on front-installed loading systems, do not differ significantly. However, telescope loaders offer greater lifting capacity and reach, allowing for higher stacking of straw bales, which reduces storage costs. As a result, telescope loaders are increasingly preferred. Mini loaders, though less common, are highly versatile and suitable for use in confined spaces.

The workload varies significantly depending on the equipment used: loading with a front loader is the most labour-intensive, while using a tractor shovel or telescope loader is less demanding, as they can handle two bales simultaneously. In terms of efficiency, loading with a tractor shovel versus a front loader results in a time difference of approximately 2.5 minutes per ton. Although this may seem negligible, it translates to an additional 41 000 hours of work when loading one million tons annually, the typical delivery volume to power plants.

4.1.6. Field transport

Field transport is typically carried out using a tractor and trailer. This setup is employed for transporting straw to field storage or decentralized storage facilities (e.g., on farms), and occasionally for short-distance road transport to energy plants, typically under 10 km.

If the energy plant's buffer storage capacity allows, some bales can be loaded directly onto a lorry/trailer for immediate road transport to the facility.

Figure 4: Harvesting of straw bales

4.1.7. Decentral storage

Danish energy plants typically maintain buffer storage capacity for only a few days, necessitating decentralized storage for the majority of annual straw consumption. Various storage methods exist, ranging from low-cost to expensive solutions. Storage costs per ton closely reflect the quality of straw retrieved, and cheaper storage often results in a higher proportion of unusable bales.

Storage Methods:

- Roofed barns with walls and concrete floors provide high-quality straw but are the most expensive option, particularly if new facilities must be constructed. However, repurposing existing buildings can offer an optimal solution for high-quality supply.
- Barns without walls are widely used, as exposure to normal weather conditions typically does not significantly degrade bale quality.
- Wrapped long-stack storage has grown in popularity due to its lower cost and flexibility compared to permanent structures. These stacks can be placed near production fields and main roads, minimizing field transport and simplifying road loading. Delivery shortly after harvest also ensures fields are cleared for subsequent crops.

Key developments in wrapped storage:

Advancements in equipment over recent decades have driven adoption. Early wrapping machines handled two stacked bales, while modern systems now manage up to 12 bales per transaction. However, users note critical considerations:

- Location: Stacks in low-lying fields risk moisture infiltration; elevated areas are preferable.
- Condensation: High straw moisture content can cause condensation under the plastic, dampening upper bales.

Open storage considerations:

Some suppliers still use open storage, either covering stacks with plastic (secured by top bales) or leaving them fully exposed. While the cheapest method, it often renders many bales unsuitable for heating/CHP plants due to quality degradation. The top and bottom layers are particularly vulnerable to weather and soil moisture.

Alternative use for low-quality bales:

If unsuitable for combustion, these bales could be repurposed for biogas production. Otherwise, disposal costs, including splitting, spreading, and ploughing into soil, may outweigh initial savings.

4.1.8. Road transport

Road transport is typically carried out using a lorry/trailer. For shorter distances (usually under 10 km), tractors and wagons may be employed. Most receiving facilities at energy plants require bales to be loaded in specific configurations – typically in layers of six (arranged 2*3) on the lorry and/or trailer. Some plants also mandate covering the bales with nets during transport to prevent straw from being blown off by wind.

Figure 5: Bale transportation

4.1.9. Unloading at the plant

While many smaller district heating plants in Denmark still rely on front loaders to unload straw bales, larger plants have implemented automated crane systems. These cranes lift entire layers of bales directly from lorries and trailers, placing them into the plant's buffer storage. The same cranes are then used to transfer bales from storage onto conveyor belts, which transport the straw to shredders before it is fed into boiler systems.

Many cranes are equipped with automated technology to register bale weight and moisture content, significantly reducing the time required to unload and document a full lorry of straw. Moisture levels are measured using microwave sensors.

In contrast, when front loaders are used for unloading, weight measurement typically occurs via a weighbridge, while moisture content is recorded manually using a probe-based moisture meter inserted into the bales.

4.1.10. Health and safety aspects

Working in the agricultural sector inherently involves risks, and straw handling is no exception. Beyond the hazards of heavy machinery, straw bales themselves are heavy and require careful handling. For example, when stacking bales, whether in barns or open areas, they must be arranged in layers to minimize collapse risks.

Additionally, strict fire prevention measures are critical, particularly in large storage facilities. Denmark enforces stringent regulations governing:

1. Storage limits: Maximum quantities of straw per storage unit
2. Stack dimensions: Permissible height, width, and length
3. Safety distances: Required spacing from buildings and public roads
4. Fire containment: Measures to control potential fires

These regulations exist because once a straw stack ignites, extinguishing it is nearly impossible; the focus shifts to containment until the fire burns out.

The legal framework aims to:

1. Limit potential losses from a single fire
2. Ensure fires remain controllable
3. Prevent spread to adjacent structures or storage
4. Mitigate road hazards caused by smoke

Straw handling also generates significant dust and fungal spores (if the straw has been wet), posing health risks in enclosed environments. Regular workers should use dust masks to minimize respiratory exposure.

4.2. Sunflower[16]

4.2.1. Harvesting

Sunflowers are harvested using combine harvesters equipped with either special or universal reapers. These reapers can be fitted with adapters or specific attachments designed for sunflowers. Some reapers come with a stalk shredder, which, while increasing fuel consumption and reducing productivity during harvesting, can save on mulching costs. Traditional reapers are suited for sunflower cultivation with a row spacing of 70 cm. The cutting mechanism of the reaper should operate 20-25 cm below the sunflower heads. The combine harvester typically moves along the rows of crops, allowing for efficient collection at speeds up to 9 km/h. The harvested heads and any seeds that have fallen out are directed to the combine's threshing and separating system. The stalks are left standing in the field, forming the bulk of the post-harvest sunflower residues.

Figure 6: Sunflower field (left), sunflower field ready for harvesting (right)

During subsequent technological operations, specialized agricultural machines chop and distribute plant residues over the field. However, some farmers opt to burn the remaining sunflower residues. An alternative to burning is harvesting these by-products for energy production.

4.2.2. Analysis of the supply chain of sunflower by-products

The supply chain for sunflower by-products begins with harvesting. This process generates two types of biomass: one that passes through the combine and another that remains as stalks in the field. Under favourable weather conditions, the stalk biomass can dry out, enhancing its fuel properties.

[16] https://uabio.org/wp-content/uploads/2020/10/uabio-position-paper-25-en-1.pdf.

Historically, farms would divide sunflower fields into smaller plots for local cultivation. Locals would manually harvest sunflower heads with seeds and deliver them to the farm. They also collected stalks by hand, bundling them for use as heating biomass. However, there is limited information on contemporary practices for harvesting sunflower by-products.

Mechanized harvesting of stalk biomass involves cutting and chopping the stalks with a forage harvester. The dry biomass can be used as solid biofuel, while the wet biomass serves as raw material for biogas plants. Biomass that has passed through the combine is collected in a trailer in chopped form. If the raw material is wet (moisture content >25%), it requires drying. Alternatively, the technology used for harvesting corn by-products can be applied, which includes chopping and forming windrows of post-harvest sunflower residues in the field, followed by baling or collecting the chopped material.

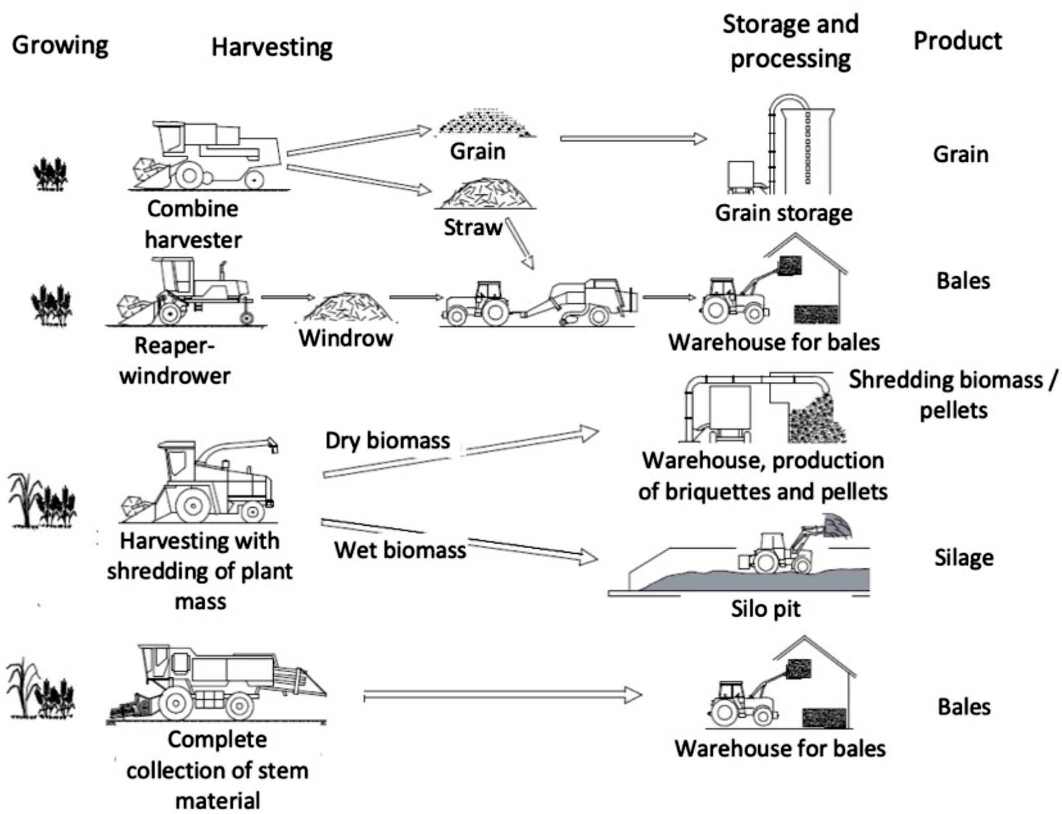

Figure 7: Supply chain of sunflower by-products and other stalk biomass

5. Potential energy resources from forestry biomass residues in Ukraine

Although electricity production from forestry biomass in Ukraine remains very limited (as described in Section 2.1.1.), wood serves as a major source of solid biofuels, including firewood, pellets, and woodchips. The annual availability of wood biomass ranges from 160-180 PJ/year (2.6 to 3.0 Mtoe), with nearly 95% of this potential already utilized. Firewood has long been the most affordable energy source for heating in rural communities and small towns.

From 2022 to 2024, Russia's destruction of municipal and local heating boilers and gas infrastructure has driven a significant surge in firewood demand, particularly in frontline regions. However, overall wood logging declined by nearly 10% in 2022-2023 compared to 2021, primarily due to a 22% drop in harvested roundwood in 2022 and a 19% decrease in 2023 (Figure 8).

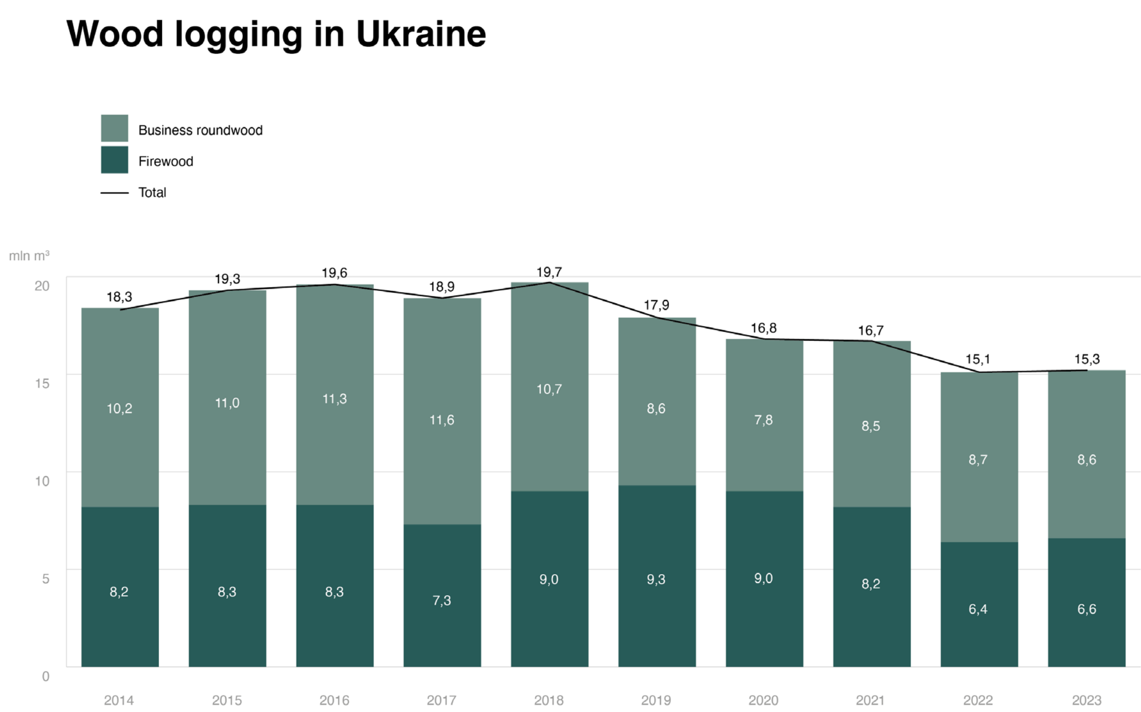

Figure 8: Wood logging in Ukraine[17]

[17] https://www.ukrstat.gov.ua/.

In 2022, roundwood logging in Ukraine experienced significant declines across three natural zones (excluding the Carpathians): a 37.9% reduction in the Steppe, 11.3% in the Forest-Steppe, and 9.6% in Polissia compared to 2021. This reduced wood supply, combined with rising demand, drove a 23% increase in wood material prices in 2022 relative to 2021[18].

The trends observed during 2022-2023 offer insights into potential pathways and characteristics for wood-dependent solid biofuel production (e.g., pellets and woodchips), despite limited statistical and analytical data.

Two sustainable methods could increase firewood availability:

1. Collecting old, dry, dead, fallen, or rotting wood.
2. Processing forest wood waste (e.g., into pellets).

According to expert assessments, these approaches could expand wood supply by 3-3.5 million m^3 annually[19].

5.1. Production of wood pellets and woodchips

Forest residues and energy crops can be made into wood logs, wood pellets or woodchips.

5.1.1. Wood pellets

Ukrainian pellet production was a developing industry that experienced steady growth before the war. Annual production exceeded 700 kt, with up to 85% exported primarily to EU countries. By early 2020, nearly 500 enterprises were involved in pellet production. Most of these producers were small-scale operations, with capacities of less than 10 kt per year, and they were predominantly located in the Vinnytsia, Volyn, Chernivtsi, and Zhytomyr regions[20]. The eight largest pellet producers had a production capacity of 300 kt per year[21].

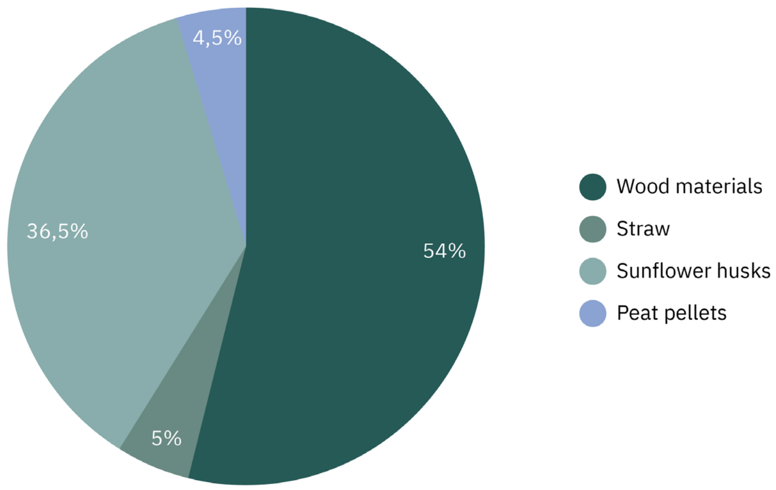

Figure 9: Structure of pellet production by raw materials sources

18 https://forestry-forestmelioration.org.ua/index.php/journal/article/view/420/378.

19 https://rubryka.com/en/article/war-and-forest/.

20 https://agro-business.com.ua/agrobusiness/item/16443-top6-vyrobnykiv-pelet-v-ukraini.html.

21 https://dspace.nuft.edu.ua/server/api/core/bitstreams/04caacb7-9250-453b-97f3-497b98f6d96d/content.

Wood materials are the primary source for pellet production in Ukraine, contributing an average of 54% during the pre-war period. The second largest source is sunflower husks. Combined, these two sources account for 90% of the total pellet production (Figure 9)[22].

During 2022, pellet production faced the problem of rapidly increasing prices for raw wood materials, decreasing the competitiveness of Ukrainian pellets on the EU market[23]. In 2022, 34 certified (ENplus) plants produced 368 kt of pellets (-15% compared to 2021)[24].

5.1.2. Woodchips

Woodchips serve as an energy source for heating and electricity production within the public sector. According to Ukrainian law, until 2022, all public organizations (including health care and education) and heat producers were required to purchase woodchips through Prozorro. From 2018 to 2022, the maximum volume of woodchips contracted through Prozorro was 57.7 kt in 2018, with a gradual decline observed thereafter (Figure 10). In 2023, the total capacity of TPPs/CHPs utilizing wood chips reached 67 MW.

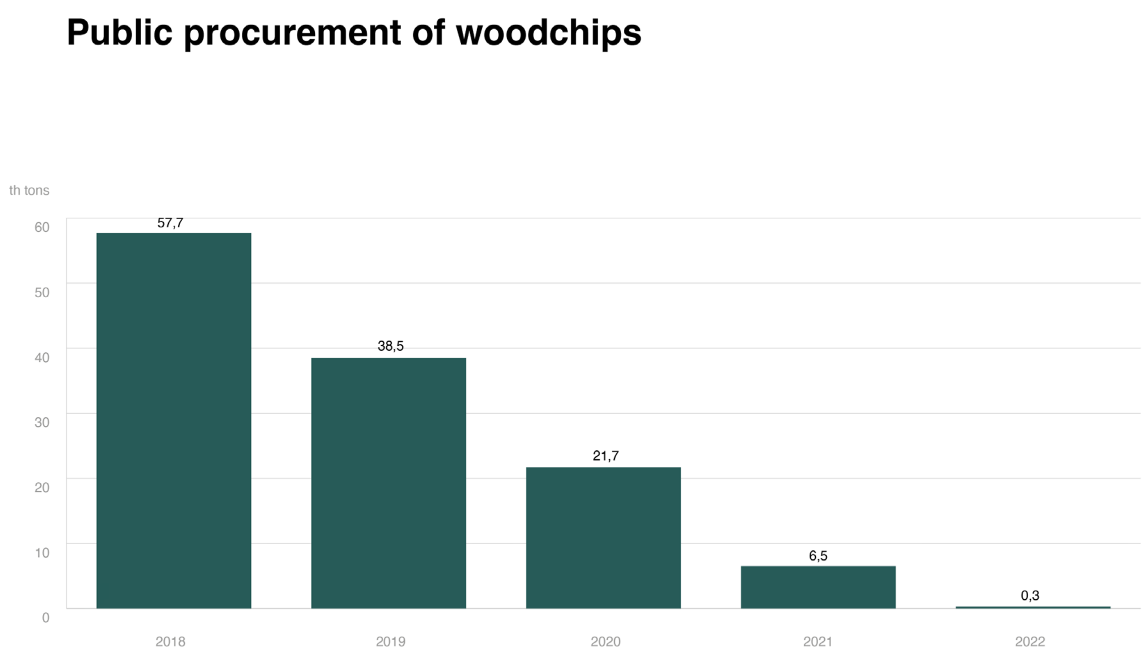

Figure 10: Public procurement of woodchips[25]

[22] The same reference as 21.

[23] https://derevynnyk.com/znyzhennya-czin-na-pelety-v-krayinah-yes-ta-syrovynnyj-rynok-v-ukrayini/.

[24] https://uabio.org/wp-content/uploads/2023/12/5.-Dragnyev-S.-V.-Poperednya-pidgotovka-biomasy-yak-palyvnoyi-syrovyny.pdf.

[25] https://uabio.org/publichni-zakupivli-palyvnoyi-trisky/.

5.2. Energy crops

The Bioenergy Association of Ukraine (UABIO) provides detailed information on energy plantations in Ukraine. These plantations are crucial for the country's bioenergy sector, offering a sustainable alternative to fossil fuels. Because of the urgency of this, the association has developed interactive maps that display the total areas dedicated to energy crops across different regions of Ukraine. These maps also highlight the potential for cultivating energy plants on marginal and unused lands.

Energy crops such as willow, poplar, paulownia, and miscanthus are grown extensively. As of 2022, over 3 300 hectares (6 175 hectares in 2021) were dedicated to these crops, with the Volyn region leading in willow cultivation, the Kyiv region leading with miscanthus cultivation, the Lviv region leading in poplar cultivation, and the Khmelnytskyi region leading with cultivation of paulownia. The potential for expanding these plantations is significant, with up to 4 million hectares of abandoned agricultural land available for energy crop cultivation[26]. An overview of where the cultivation of solid biomass energy crops takes place is shown in Appendix 1.

26 https://uabio.org/statistics/energetychni-plantatsiyi-v-ukrayini/.

6. Issues related to the utilization of biomass in Ukraine today

As mentioned earlier, there are significant challenges related to collection, handling, and thermal energy conversion of solid biomass agricultural residues. In addition to technological barriers, such as the lack of machinery for harvesting crop by-products for energy purposes and limited mature energy technologies for all the types of solid biomass agricultural residues in Ukraine, the main challenges include the following:

- Organizational and regulation challenges
- Economic and Financial challenges
- Constraints of agricultural producers
- War related challenges

6.1. Organizational and regulation challenges

The absence of a marketplace to balance the supply and demand for biomass is a significant issue. The unpredictable supply of biomass is a limiting factor for initiating biomass PPT or CHP projects, as fuel availability is a critical precondition even during the project consideration stage by banking institutions.

- There is no roadmap for increased biomass use in Ukraine.
- Bioenergy is not included in the strategic development plans of communities, including within the framework of regional sustainable development plans, post-war recovery plans, SECAPs, or regional development programs.

Illegal wood logging in Ukraine results in illegally logged wood being more price-competitive than other types of biomass. In 2022, the total volume of illegally harvested timber in Ukraine, according to forest users, reached at least 24 327 m^3, or 0.2% of the total official logging volume[27].

6.2. Economic and financial challenges

- Biomass is not yet considered a CO_2 neutral fuel in Ukraine. The requirement to pay a CO_2 tax makes biomass-firing projects less viable. Draft Law No. 9596[28], which proposes a zero Hryvnia environmental tax rate for CO_2 emissions from biofuel combustion, passed its first hearing in 2023 and is currently awaiting a second hearing. The delay of this legislation is not helpful to the urgent need for reliable heat and electricity supply in Ukraine.

27 Volumes of illegal logging documented by forest users of Ukraine in 2022 (based on public inquiries): Analytical report / NGO "Forest Initiatives and Society"; N.I. Kaplya, D.YU. Karabchuk, T.S. Pyvovar – U.S. Forest Service Project "Fighting Illegal Logging in Ukraine." – L., 2023 – 57 P.

28 https://www.kmu.gov.ua/bills/proekt-zakonu-pro-vnesennya-zmin-do-podatkovogo-kodeksu-ukraini-shchodo-vstanovlennya-stavki-nul-griven-ekologichnogo-podatku-za-vikidi-dvookisu-vugletsyu-dlya-ustanovok-yakimi-zdiys.

- The tariff for heat from biomass is set at 90% of the tariff for heat from natural gas. Natural gas receives subsidies in Ukraine, with households and the non-commercial sector paying EUR 183 per thousand cubic meters[29], compared to EUR 412 for industry[30]. Biomass, however, is not subsidized, making biomass more expensive than natural gas. The 10% discount for heat produced from renewables compared to natural gas in 2022 was insufficient to promote renewable heat production. The government chose not to increase the natural gas tariff to mitigate the impact of high inflation (30%) on the population during the war and post-war recovery[31].
- Low-interest loans (5-7-9% in UAH) for agricultural producers, such as those seeking to purchase equipment for biomass collection, are available for only 3-5 years. In 2024, a state program is in place to compensate farmers for 25% of the cost of agricultural machinery from 44 Ukrainian manufacturers[32]. The equipment list contains a wide range of machinery for agriculture, forestry, and animal husbandry[33], and a limited amount of equipment for biomass waste collection or processing.

6.3. Constraints of agricultural producers

- Agricultural producers generally do not own the specialized equipment needed to collect biomass residues that can be used for energy purposes, as it requires additional investments and changes in the production process. Their primary goal is to benefit from their main activities. Harvesting agricultural biomass residues is a complex and costly activity that is just beginning to develop in Ukraine. While technologies for straw baling are relatively well established, there are challenges with harvesting maize and sunflower stalks due to the lack of necessary equipment in the Ukrainian market.
- There are difficulties in arranging the biomass supply chain. Farmers must make additional efforts to ensure the proper moisture content and other properties of biomass as fuel, which requires extra expenditures.
- Compared to natural gas, biomass is less convenient and safe to use for producing electricity or combined electricity and heating. It requires other technologies, the exhaust gas must be cleaned, due to the high content of particulate matter, the emissions have a different chemical composition (especially straw and corn stalks), and it requires additional maintenance of equipment (such as ash removal) and the development of infrastructure (like storage facilities)[34]. Technologies relevant for biomass are described in the section about biomass in the UTC report.

29 https://index.minfin.com.ua/ua/tariff/gas/.

30 https://www.xe.com/currencyconverter/convert/?Amount=19030&From=UAH&To=EUR.

31 The Law of Ukraine "On Peculiarities of Regulation of Relations in the Natural Gas Market and in the Field of Heat Supply during Martial Law and Further Restoration of Their Functioning" of July 29, 2022 No. 2479-IX.

32 https://me.gov.ua/News/Detail?lang=uk-UA&id=07004c9a-8e2f-4f1d-b63b-f3f684153d56&title=ZroblenoVUkraini-Agrarii.

33 Tractors for agricultural and forestry use, soil cultivation equipment and machinery, seeding and soil treatment complexes, seed hoppers and grain transfer bins, machines for cleaning, sorting, and calibrating seeds of cereal and leguminous crops, grain loaders, machines for applying mineral fertilizers, sprayers for chemical protection of crops, tractor trailers and dump trailers for transporting grain, equipment for keeping pigs, cattle, and calves, milking equipment, machinery and equipment for horticulture and berry farming, and grain drying equipment.

34 https://uabio.org/wp-content/uploads/2020/01/position-paper-uabio-21-ua.pdf.

6.4. War-related challenges

- **Shortage of workforce.** There is a significant shortage of workers needed to collect biomass, particularly forest biomass. In 2022, the Head of the State Forest Resources Agency, Mr. Yuriy Bolokhovets, highlighted this issue, stating that there is an urgent need for more workers. Some regions are critically short-staffed. For example, the Chernihiv region requires an additional 45 crews, the Kyiv region needs 19 crews, and the Vinnytsia region needs 13 crews. They are in need of entrepreneurs with available personnel and equipment (tractors, trucks, etc.) to join the harvesting efforts. Some forestry enterprises also need full-time employees. They offer training and a decent salary[35].
- **Demining needed.** As of September 2024, more than 30% of Ukraine's territory (174 000 km^2, including 13 500 km^2 of water bodies) needed demining. The Kherson, Zaporizhzhia, Mykolaiv, and Kharkiv regions are particularly dangerous. However, the Kyiv and Chernihiv regions are also at risk (Figure 3.5), highlighting the scale of the demining task.
- **Demining cost.** The estimated cost of demining such an area exceeds €8.5 billion. The demining process is usually very lengthy (5 years or more). Economic activities in these areas may be suspended for an extended period to avoid human casualties, which, among other consequences, could result in issues with the harvesting of bioenergy feedstock.
- **Destruction of existing plants.** Some of the biomass-fired CHPs were destroyed throughout the full-scale war. One of the largest bio-TPPs in Ukraine, the Ivankiv bio-thermal power plant (Kyiv region)[36], was destroyed. The operation of this plant allowed for annual savings of about 15 million m^3 of natural gas. Additionally, military actions damaged 10-15% of installed capacity of biomass power plants, particularly in the Kharkiv, Chernihiv, and Sumy regions[37]. In some cases, the Russian soldiers looted the equipment. During 2022 alone, about 28% of installed biomass and biogas capacities were destroyed[38].

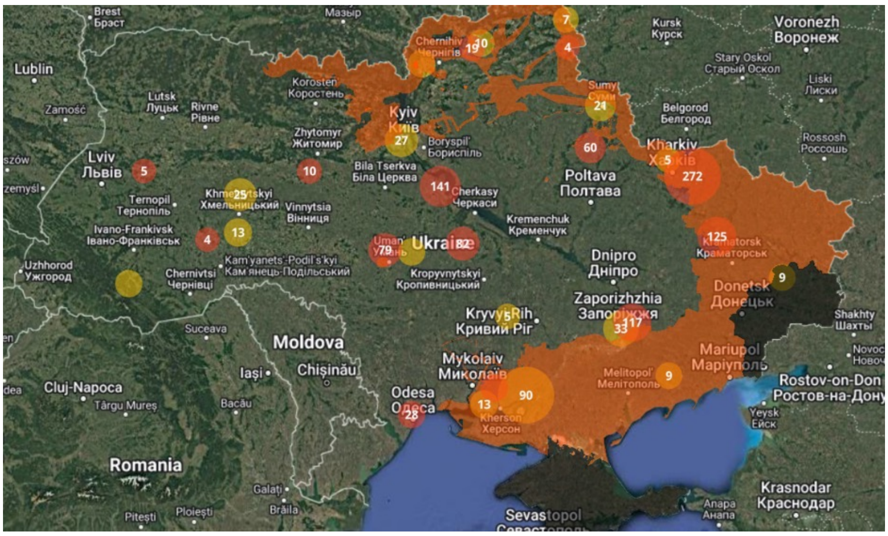

Figure 11: A map of territories that may potentially be contaminated with explosive ordnance, Source: The Mine Action Service of the State Emergency Service of Ukraine https://mine.dsns.gov.ua

35 https://ua-energy.org/uk/posts/ukraina-dlia-opalennia-vzymku-zahotuie-rekordnu-kilkist-drov.

36 http://ecotes-ivankiv.com.ua.

37 Stanislav Ignatiev. Ukraine's green energy sector, destroyed by the war, is on the verge of bankruptcy. What will happen next? Solar Generation, 12.04.2022.

38 UNDP (2023) Towards a Green Transition of the Energy Sector in Ukraine. Update on the Energy Damage Assessment June 2023.

7. Current legislative frameworks, policies, action plans, and roadmaps

7.1. National Energy and Climate Plan of Ukraine 2025-2030

The National Energy and Climate Plan (NECP) of Ukraine[39] aims to coordinate energy and climate policies for sustainable development and economic recovery. It's a strategic document prepared in accordance with EU requirements that includes experts from think tanks and government agencies. However, the ongoing war with Russia poses challenges, affecting energy infrastructure and workforce availability. Attacks on energy facilities disrupt supply and exacerbate the energy crisis. The NECP plays a crucial role in Ukraine's energy future despite these challenges.

- Energy Supply and Impact of War:
  - During Nov 2022 to Feb 2023, electricity supply was limited for 3.8 million consumers, with a maximum of 13.5 million affected during systemic power system accidents.
  - Approximately 50% of available generating capacity and substations were temporarily lost due to war-related damage and occupation.
  - Cyber-attacks increased significantly, affecting the energy sector.
  - Environmental damage exceeded €56 billion, with ongoing investigations into ecocide and ecological warfare.
- Challenges in Developing NECP:
  - War consequences, destruction uncertainty, and recovery pace affect policy implementation.
  - Economic downturn and energy poverty hinder market-based pricing.
  - State institutions face challenges in crisis management and policy reform.
  - Accumulated debt in gas and electricity supply chains requires attention.
- Energy Union Goals for Ukraine:
  - Target: 65% reduction in greenhouse gas emissions by 2030 (compared to 1990).
  - Aim for climate neutrality in the energy sector by 2050[40].

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39 in English: https://zakon.rada.gov.ua/laws/show/587-2024-%D1%80?lang=en#Text, in Ukrainian: https://zakon.rada.gov.ua/laws/show/en/587-2024-%D1%80?lang=uk#Text.

40 https://me.gov.ua/Documents/Detail?lang=uk-UA&id=f7088035-142e-4912-9aa0-6fe2def80c1b&title=ProektNatsionalnogoPlanuZEnergetikiTaKlimatuUkraini2025-2030.

7.2. Roadmap 2050 and action plan 2025

The need for developing a long-term strategy for Ukraine's bioenergy sector and a roadmap is driven by several important factors. Ukraine's National Renewable Energy Action Plan sets an ambitious goal to achieve 6 million tons of energy from biomass, biofuels, and waste in the overall primary energy supply by 2030. However, there are currently no documents (roadmap or action plan) specifying which types of biomass/biofuels, technologies, and equipment (such as boilers, CHP plants, and power plants) will most effectively contribute to reaching this target.

Another critical factor is Ukraine's international commitments to reduce greenhouse gas emissions according to the Paris Climate Agreement. Currently, this commitment aims for a 65% reduction relative to 1990 emissions levels by 2030 and that emissions may decrease to approximately 15% of the 1990 emissions levels by 2050, before reaching carbon neutrality by 2060, as described in the National Economic Strategy until 2030, approved by the Decree of the Cabinet of Ministers of Ukraine of March 3, 2021 #179[41].

To achieve this new goal, Ukraine must transition to a low-carbon economy, significantly reduce fossil fuel consumption, actively promote energy efficiency, and adopt renewable energy sources. Bioenergy is expected to play a substantial role in meeting Ukraine's international obligations.

Additionally, the aging equipment of most coal-fired thermal power plants in Ukraine poses a challenge. Furthermore, by 2050, all (minimum 12 out of 15) potential extensions for operating nuclear power plants will expire.

A bioenergy development strategy for the period up to 2050 should demonstrate how biofuels, bioenergy installations, and technologies can contribute to replacing the capacity of fossil fuel-based and retiring nuclear power plants.

In short:

- Bioenergy is a promising energy source globally and in Ukraine.
- Biomass can be used directly (burning woodchips, straw) or processed into liquid or gaseous biofuels.
- Bioenergy significantly reduces greenhouse gas emissions.
- In Ukraine, bioenergy contributes to heat production and stable electricity generation.
- It plays a crucial role in decarbonizing the energy sector[42].

41 Updated Nationally Determined Contribution of Ukraine to the Paris Agreement.

42 https://saf.org.ua/wp-content/uploads/2021/06/Dorozhnya-karta-rozvytku-bioenergetyky-v-Ukrayini-do-2050-roku-i-Plan-dij-do-2025.pdf.

8. Appendix 1

8.1. Potential energy resources from agriculture residues in the current situation

As shown in section 3.3, Ukrainian agriculture holds significant untapped energy potential, particularly in the form of solid biomass suitable for power and heat production. The notable exception is sunflower husks that have a high utilization rate. This is largely due to the fact that many sunflower processing plants in Ukraine have installed facilities to burn husks or husk pellets, generating heat and/or electricity for their operations and, in some cases, for the market.

However, the majority of the solid biomass residues energy potential comes from grain straws (525 PJ), stalks and cobs from maize (374 PJ), and stalks and heads from sunflowers (174 PJ). In total, the energy potential remains underused[43]. Despite the presence of numerous small-scale boilers (up to 1 MW each) across the country, these are mainly employed by agricultural enterprises for their own production needs and by local municipalities for heating in rural areas and small towns.

The use of other types of agricultural solid biomass, such as maize and sunflower residues, and energy crops, is quite limited or virtually non-existent[44]. Specifically, energy crops are cultivated by only a few companies, covering an area of less than 5.5 thousand hectares[45].

8.1.1. Change in sown areas for agricultural crops

Figure 12 illustrates the changes in sown areas across different regions in Ukraine, encompassing all types of crops for the years 2020 and 2022. The figure visualizes the trends in crop production, with a particular emphasis on the noticeable decrease in the eastern regions of the country (especially affected regions as of 2022 – Donetska, Luhanska, Kharkivska, Zaporizhska, Khersonska, and Mykolaivska). In 2020, the total sown area was approximately 28 million hectares. However, by 2022, this area had reduced significantly (by approx. 18%) to about 23 million hectares. This decline could be attributed to various factors, including but not limited to the Russian invasion of Ukraine[46].

43 https://uabio.org/wp-content/uploads/2021/03/ZHelyezna_EU4USociety_AgroBM_26-02-2021.pdf.

44 https://ihe.nas.gov.ua/index.php/journal/article/download/489/413/.

45 https://www.epravda.com.ua/columns/2021/05/24/674199/.

46 https://agrostats.uhmi.org.ua/.

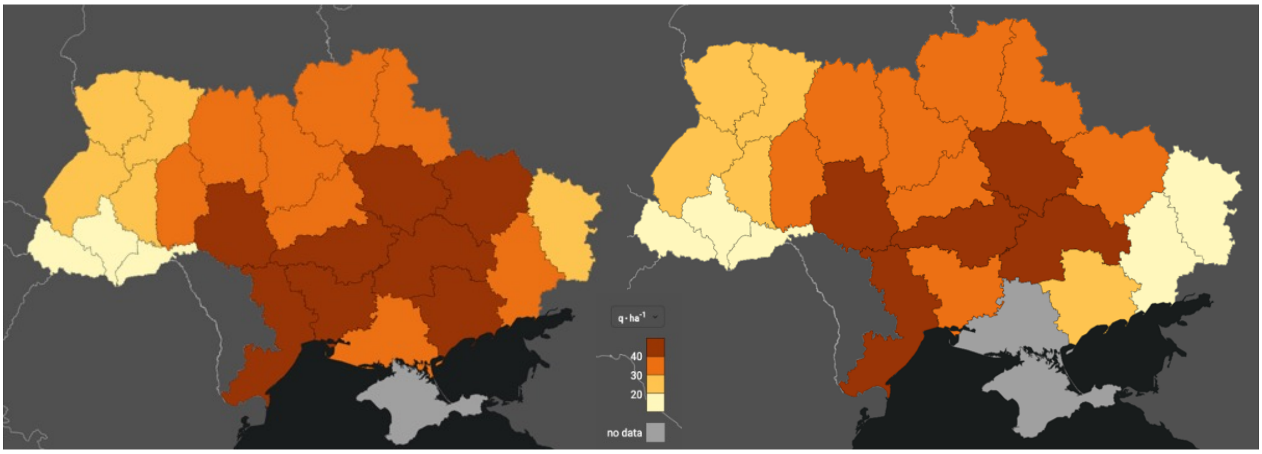

Figure 12: Sown area, all crops in 2020 (left) and 2022 (right), (AgroStats)

Figure 13 illustrates the sown area of all grains including corn. In 2022, the sown area had decreased by more than 3 221 hectares compared to 2020. The regions most affected are in the east, south-east and north-east, specifically Khersonska, Zaporizhska, Donetska, Luhanska, Kharkivska, and Chernihivska.

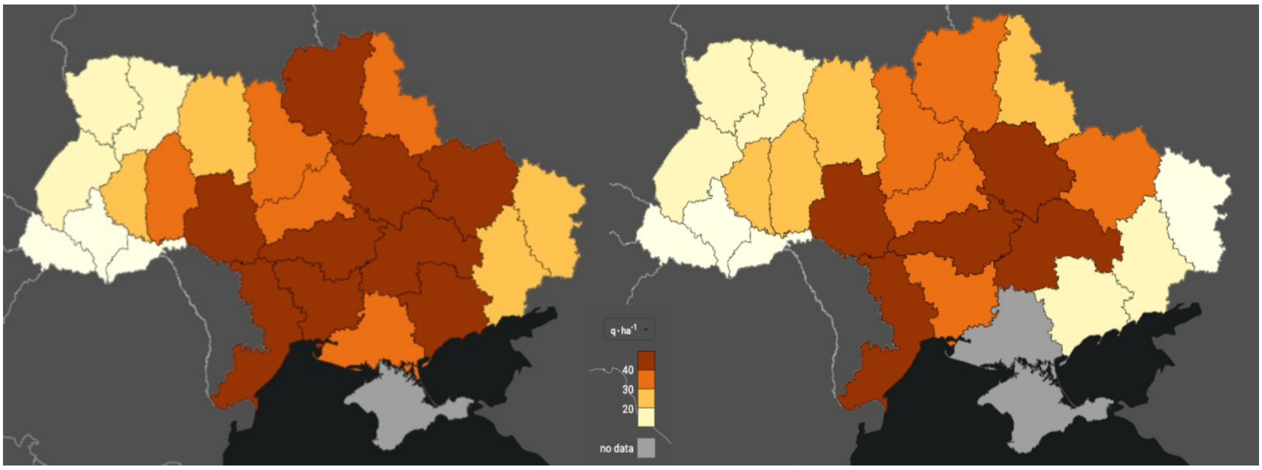

Figure 13: Sown area, all grains in 2020 (left) and 2022 (right), (AgroStats)

Figure 14 illustrates the sown area of corn. In 2022, the sown area had decreased from 5 392 hectares to 4 125 hectares. The regions most affected are in the east, specifically Khersonska, Zaporizhska, Donetska, Luhanska, Kharkivska, and Chernihivska.

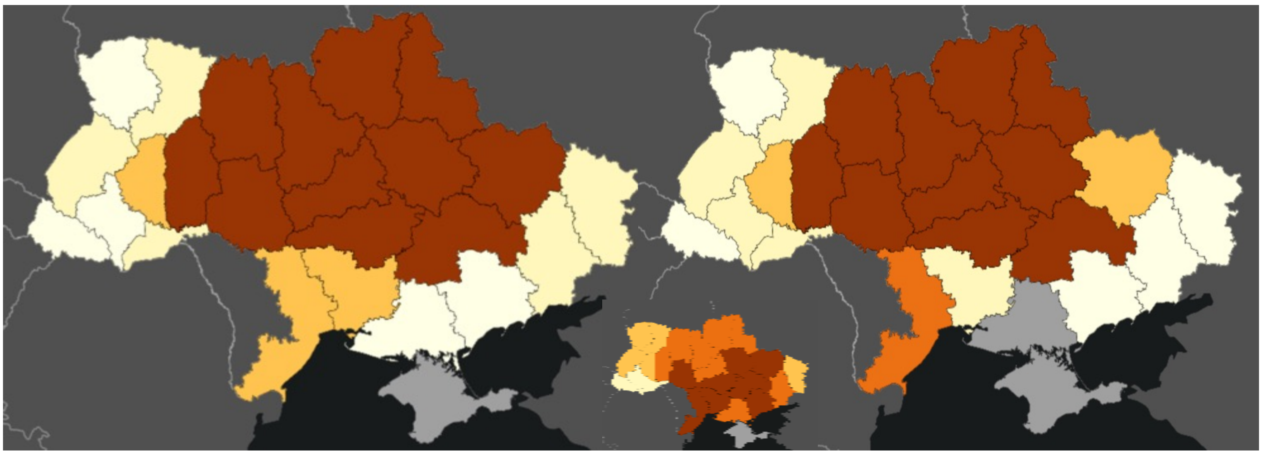

Figure 14: Sown area, corn in 2020 (left) and 2022 (right), (AgroStats)

Figure 15 shows the sown area of sunflowers. The total sown area in 2020 decreased by over 1 243 hectares, which is about a 19% decrease in just two years. The most affected areas are the eastern regions of Khersonska, Zaporizhska, Donetska, and Luhanska.

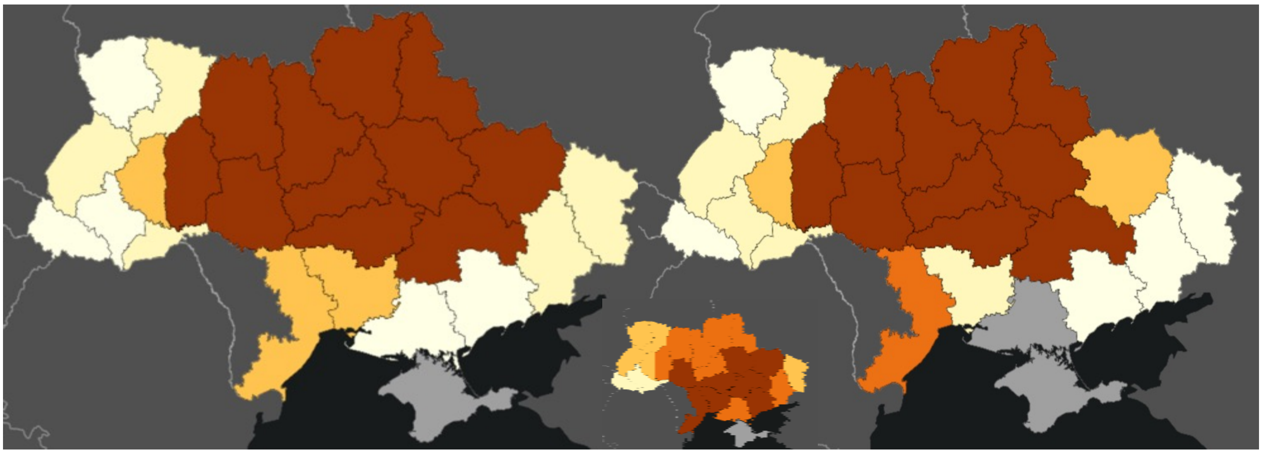

Figure 15: Sown area, sunflower in 2020 (left) and 2022 (right), (AgroStats)

Figure 16 visualizes the sown area of rapeseed in Ukraine. In 2022, there was about 4% more sown area than in 2020, but it can be seen from the maps that the production has been moved to the western regions of Ukraine, while the eastern regions have been affected by decrease.

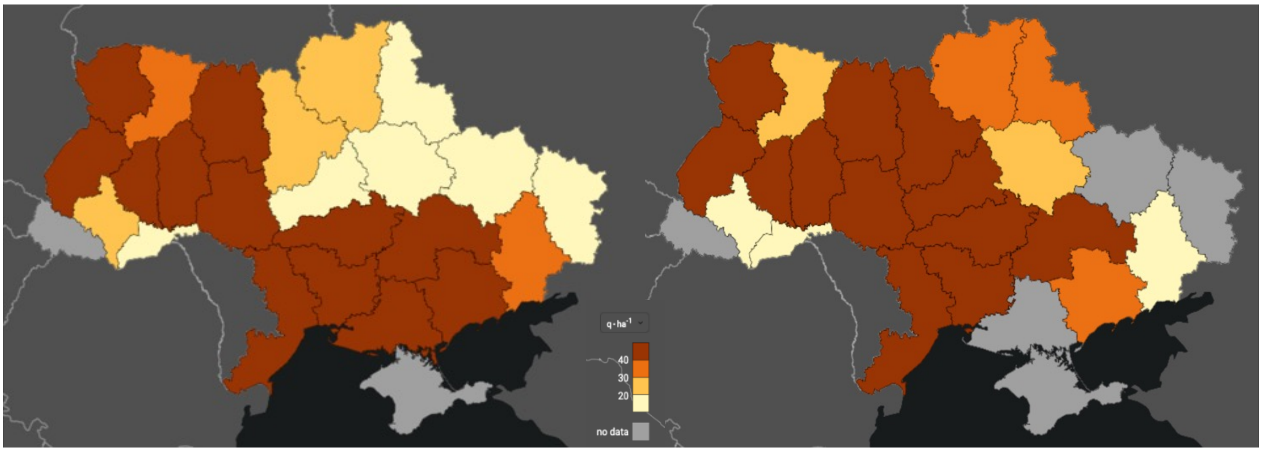

Figure 16: Sown area, rapeseed in 2020 (left) and 2022 (right), (AgroStats)

The significant reduction in sown areas for most agricultural crops in Ukraine from 2020 to 2022 highlights a concerning trend. This decreases, particularly in the eastern regions such as Khersonska, Zaporizhska, Donetska, Luhanska, Kharkivska, and Chernihivska, suggests several potential underlying factors: the ongoing Russian-Ukrainian war disrupting agricultural activities, economic instability hindering investment in farming, adverse weather conditions affecting viability, and logistical issues affecting the distribution of essential farming inputs. Addressing these issues will be crucial for stabilizing and potentially increasing the sown areas in the future.

8.2. Overview of the cultivation of solid biomass energy crops

Willow is the most extensively cultivated energy crop in Ukraine (Figure 17), covering a total of 2 295 hectares across various regions. The majority of this cultivation is concentrated in the Volyn region.

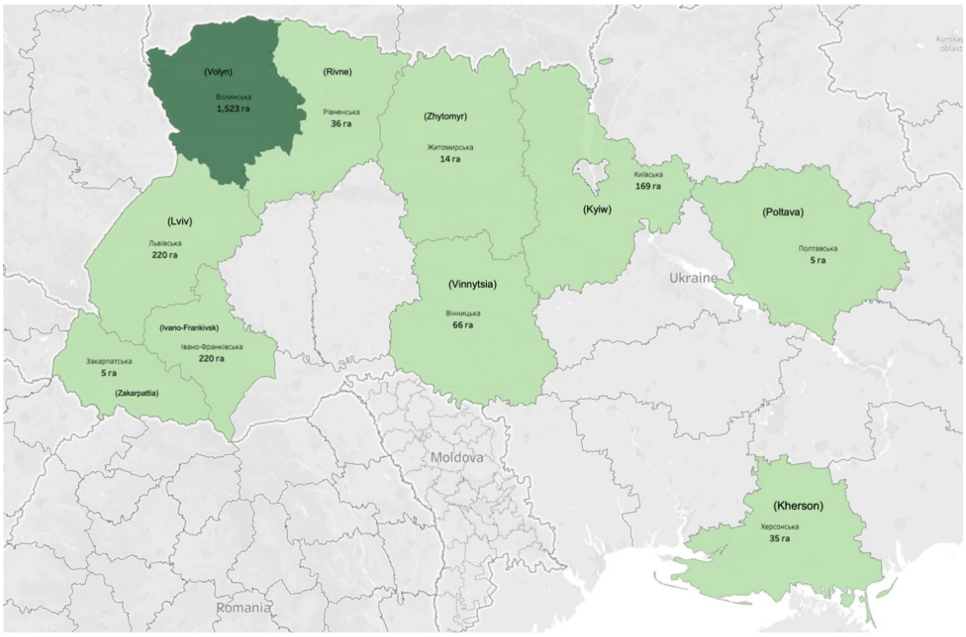

Figure 17: Willow cultivation regions in Ukraine, 2022, "ГА" refers to "hectares" (UABIO)

Miscanthus is the second most extensively cultivated energy crop in Ukraine (Figure 18), covering a total of 697 hectares. The two major regions leading in Miscanthus cultivation are Kyiv, with 280 hectares, and Khmelnytskyi, with 207 hectares.

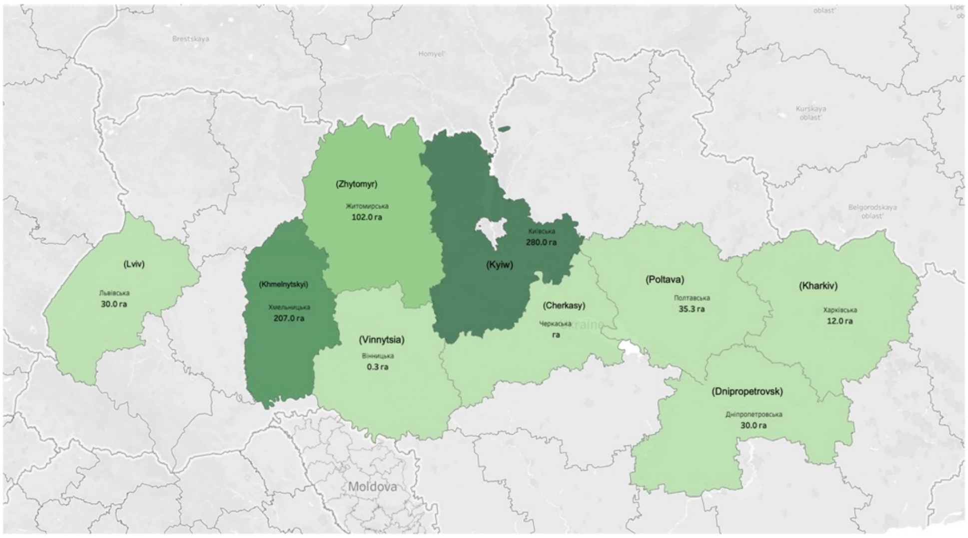

Figure 18: Miscanthus cultivation regions in Ukraine, 2022, "ГА" refers to "hectares" (UABIO)

Poplar cultivation (Figure 19) ranks third among energy crops in Ukraine, covering a total of 325 hectares across three regions. The majority of this cultivation is in the Lviv region, with 200 hectares. Ivano-Frankivsk follows with 80 hectares, and Zhytomyr has about 45 hectares.

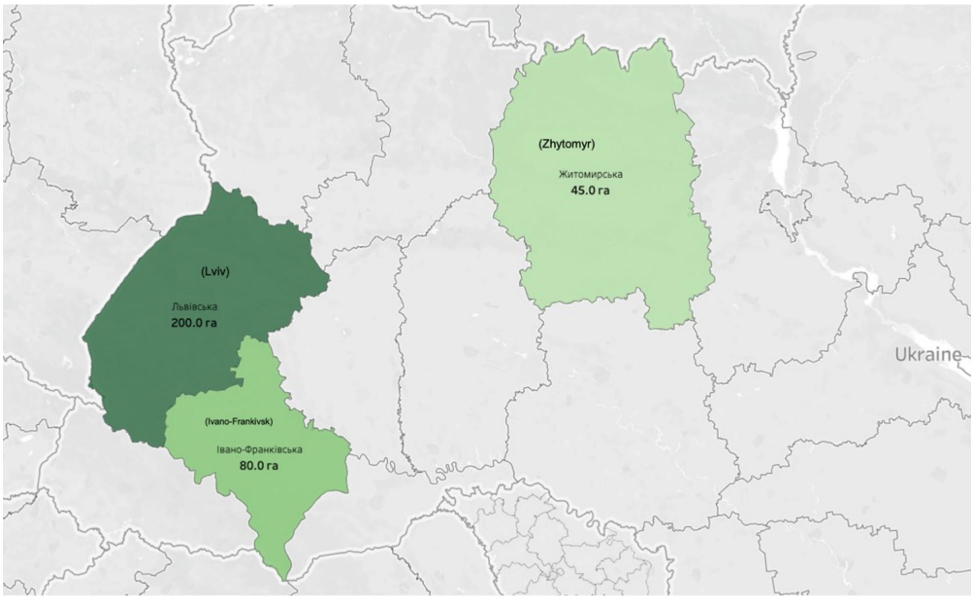

Figure 19: Poplar cultivation regions in Ukraine, 2022, "ГА" refers to "hectares" (UABIO)

Approximately 20 hectares of paulownia are cultivated in Ukraine (Figure 20), with the majority concentrated in the Khmelnytskyi region, covering about 17 hectares. The Rivne region follows with around 2.7 hectares. The remaining cultivation is distributed between the Volyn and Ternopil regions.

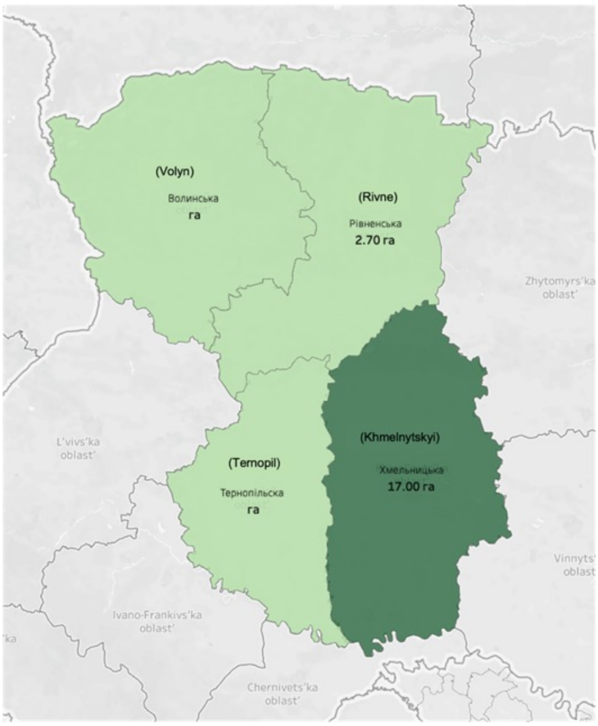

Figure 20: Paulownia cultivation regions in Ukraine, 2022 "ГА" refers to "hectares" (UABIO)

Marginal and unused land in Ukraine covers an area of 451 000 hectares (Figure 21) and holds significant potential for the cultivation of energy crops. These crops could yield approximately 2 200 tons of energy equivalent, contributing substantially to the country's renewable energy resources. The energy potential of these crops is estimated to be around 92 PJ, highlighting their capacity to support sustainable energy initiatives and reduce reliance on fossil fuels. This potential underscores the importance of developing and expanding energy crop cultivation on marginal and unused lands to enhance Ukraine's bioenergy sector.

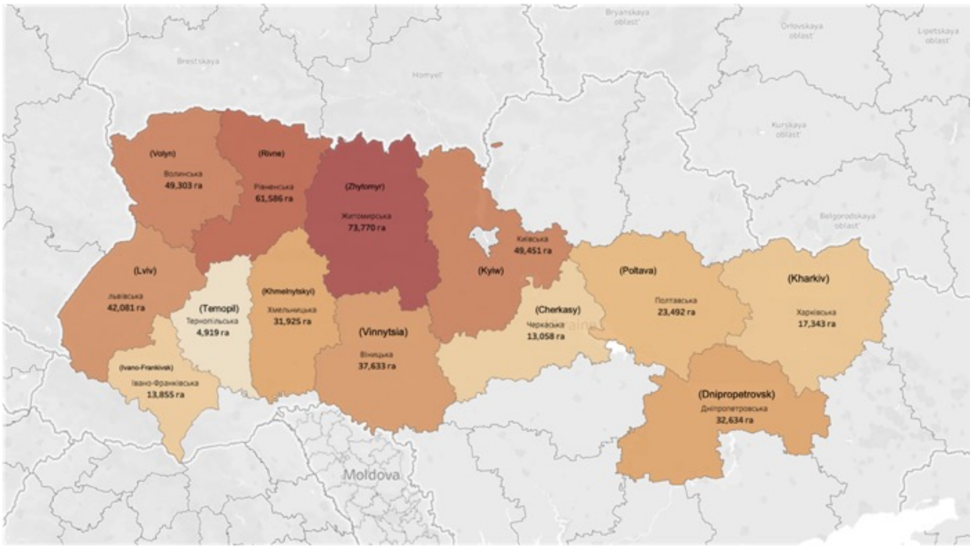

Figure 21: Marginal and unused land in Ukraine, 2022 (UABIO)