# Assessment of sustainable lignocellulosic feedstock potentials in the Ukraine and perspective conversion pathways, including recommendations for the strengthening of the biomass market

***FINAL***

**October 2016**

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## Background

Ukraine is a big Eastern European country with historically highly developed agro-food sector, having been a global breadbasket and still being one of the world's largest grain exporters. Production volumes of agricultural crops are stably high; the yields are gradually increasing (**Fig. 1, 2**). Thus, every year agriculture and related food industry generate a huge amount of different lignocellulosic residues, which can be used for energy. In the crop sector one should mark out the production of cereal crops and sunflower; as for the food industry, the oil extraction plants, sugar plants, breweries and some other sectors are of big interest as the sources of respective wastes and residues.

The Country has extensive fertile farmlands, yet large portions of agricultural land are currently under- or non-utilized. Notwithstanding the importance of agriculture, the share of biomass in the total energy production is currently slightly more than 1.2%. The Ukrainian agro-industrial complex has therefore relevant untapped renewable energy potential in the large quantities of agricultural and food-processing residues.

The growing instability in the region jeopardizing the country's energy security, the introduction of technologies allowing maximizing the use of renewable energy sources thus reducing or replacing the consumption of fossil fuel is of paramount importance. In this context, correct assessment of the potentials and realistic cost/supply estimations are necessary to strengthen the sustainable biomass market, which is a precondition for the deployment of conversion.

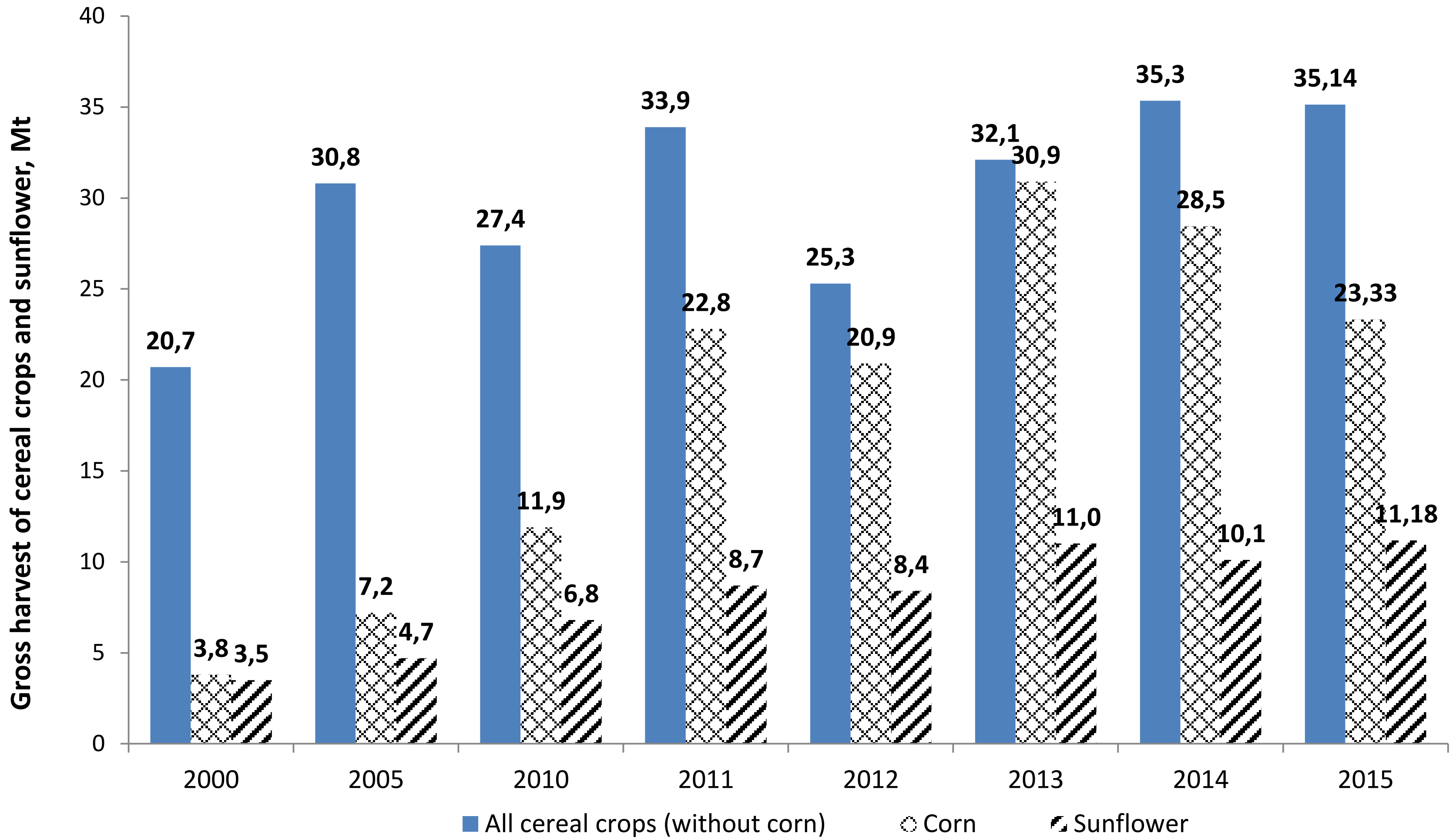


**Fig. 1.** Gross harvest of cereal crops and sunflower in Ukraine

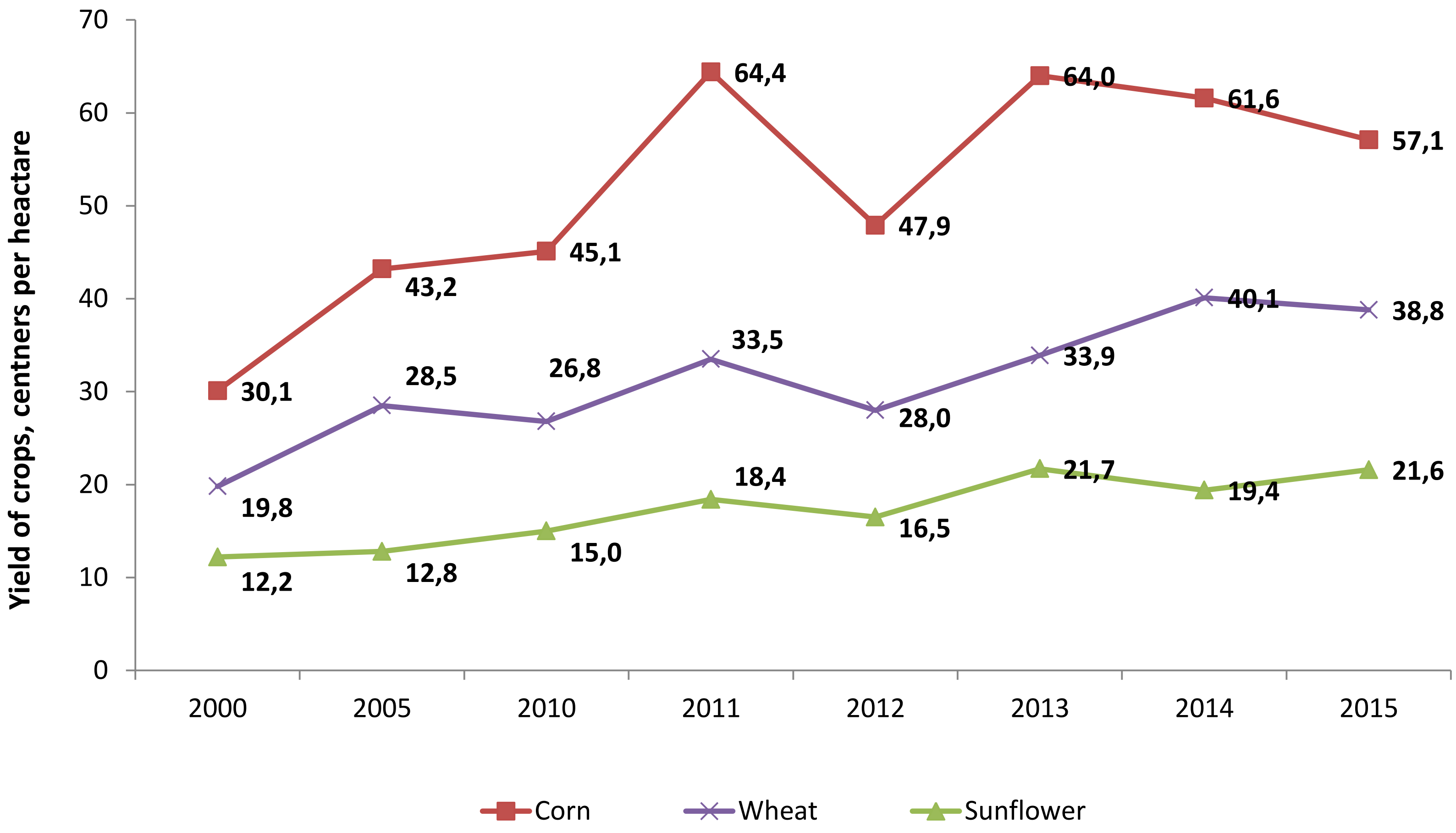


**Fig. 2.** Yield of main agricultural crops in Ukraine (1 centner = 100 kg)

# 1. Assessment of sustainable biomass potential

Main constituents of biomass potential in Ukraine are: primary and secondary agricultural residues, wood biomass, energy crops and food industry residues.

## 1.1. Primary agricultural residues

Primary agricultural residues are those generated on fields during harvesting operations[1]. The main types of residues produced when harvesting agricultural crops are ***straw*** for wheat, barley and other cereals, ***stalks*** (with leaves) and ***cobs*** (trashed ears) for maize and ***stalks*** (with leaves) and ***heads*** (without seeds) for sunflower.

The typical "residue indexes" (the ratio between the quantity of residue and the quantity of associated main product) are presented in **Table 1.1**. The indexes give an opportunity to calculate the total amount of the residues produced (the theoretical potential). In this study, we assess the sustainable potential as a certain share of the total amount of residues generated taking into consideration relevant technical and ecological constraints[2].

**Table 1.1.** Typical residue indexes, technical accessibility indexes and share available for energy for the main agricultural crops

| Crop | Residue index[3] | Share available for energy***[4] |
|---|---|---|
| Wheat | 1.0 | 30% |
| Barley | 0.8 | 30% |
| Rapeseed | 1.8 | 40% |
| Maize | 1.3* | 40% |
| Sunflower | 1.9** | 40% |

** Of the total quantity of the residue, stalks make up 75% and cobs 14%. The rest is leaves and shanks of maize ears.*

*** Of the total quantity of the residue, stalks make up 68% and heads 32%.*

**** Share of the total amount (that is of the theoretical potential).*

Annual volumes (the theoretical potential) of the primary agricultural residues can be assessed at about **96** Mt/yr, of which the share sustainably available for energy comes to over **35** Mt/yr or **8** Mtoe/yr (**Table 1.2**). Major parts of the residues are straw of cereal crops (40%) and maize stalks (29%) (**Fig. 1.1**).

Geographical distribution of the agricultural residues is very uneven. Straw of cereal crops and rapeseed is mostly available in the central and eastern parts of Ukraine. Maize residues are

[1] Secondary residues are those that are generated at plants when processing agricultural harvest. Main types of the residues are considered in the chapter on Food industry residues.
[2] The approach is based on studies of the Bioenergy Association of Ukraine.
[3] According to information from the National Academy of Agrarian Sciences of Ukraine.
[4] According to: Georgiy Geletukha, Tetiana Zheliezna. Prospects for the use of agricultural residues for energy production in Ukraine. UABio Position Paper N 7
http://www.uabio.org/img/files/docs/Position-paper-UABIO-7-EN.pdf

concentrated in the central and northern areas while the biggest amounts of sunflower residues can be found in the central and especially eastern parts[5]. Speaking of the primary agro-residues as a whole, the biggest quantities are in central regions of the country (**Fig. 1.2**).

**Table 1.2.** Potential of major primary agricultural residues in Ukraine (2013)

| Biomass type | Crop yields, Mt | Total amount of waste (theoretical potential), Mt | Share available for energy | Potential for energy (technical/sustainable potential | | | |
|---|---|---|---|---|---|---|---|
| | | | | **Mt** | W, % | LHV, MJ/kg | **Mtoe** |
| Straw of cereal crops | *grain crops (without corn):* 32.1 | 30.6 | **30%** | **9.2** | 20 | 14.5 | **3.2** |
| Straw of rapeseed | *rapeseed:* 2.4 | 4.2 | **40%** | **1.7** | 20 | 14.5 | **0.6** |
| Residues from grain corn production:<br>total, including<br>- stalks (with leaves)<br>- cobs<br>- husk leaves with shanks | *corn:*<br>30.9 | 40.2<br>30.3<br>5.6<br>4.2 | **40%** | **16.0**<br>12.1<br>2.2<br>1.7 | 50 | 8 | **3.0**<br>2.3<br>0.4<br>0.3 |
| Residues of sunflower production:<br>total, including<br>- stalks (with leaves)<br>- baskets | *sunflower:*<br>11.0 | 20.9<br>14.3<br>6.6 | **40%** | **8.3**<br>5.7<br>2.6 | 60 | 6 | **1.2**<br>0.8<br>0.4 |
| **Total** | 76.4 | 95.9 | | **35.2** | | | **8.0** |

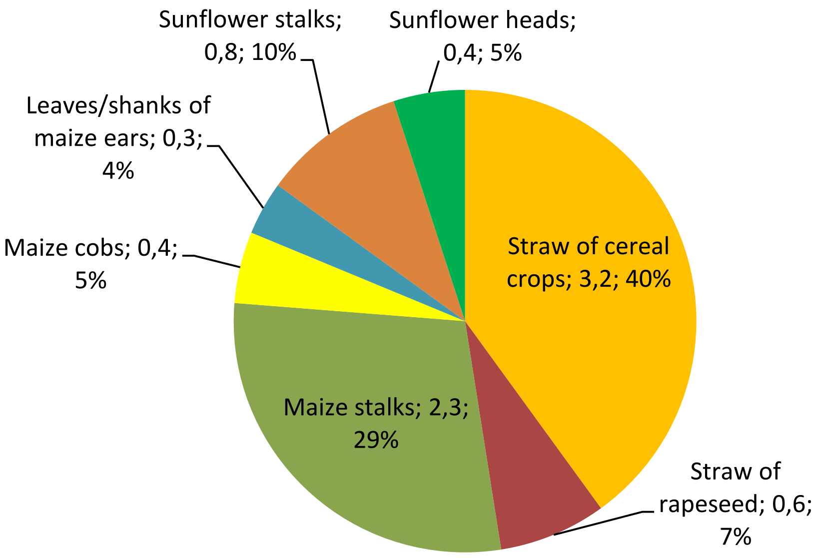


**Fig. 1.1.** Structure of the sustainable potential of the major primary agricultural residues in Ukraine (in total **8.0** Mtoe, 2013)

[5] Figures for Ukraine's regions are presented in **Table A.1** of **Annex 1**.

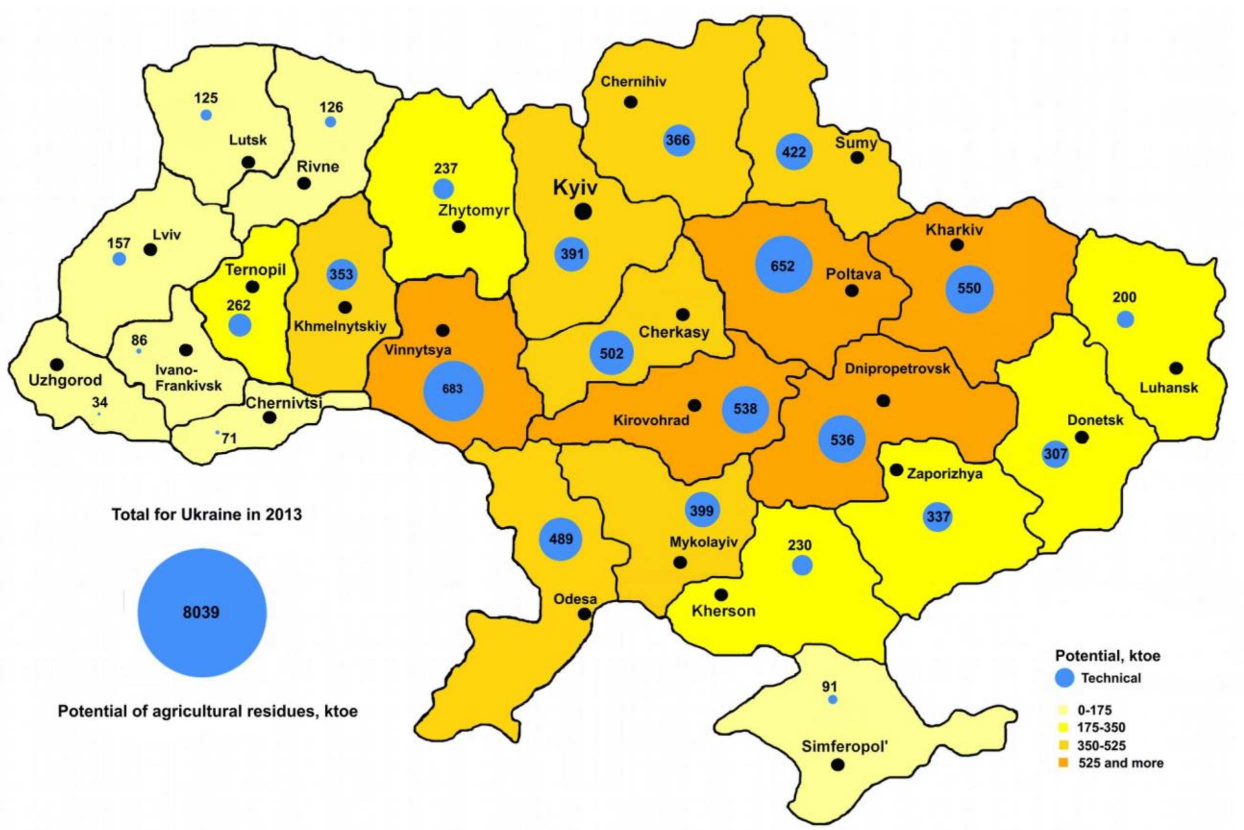


**Fig. 1.2.** Distribution of the technical potential of the primary agricultural residues in Ukraine, ktoe (2013)

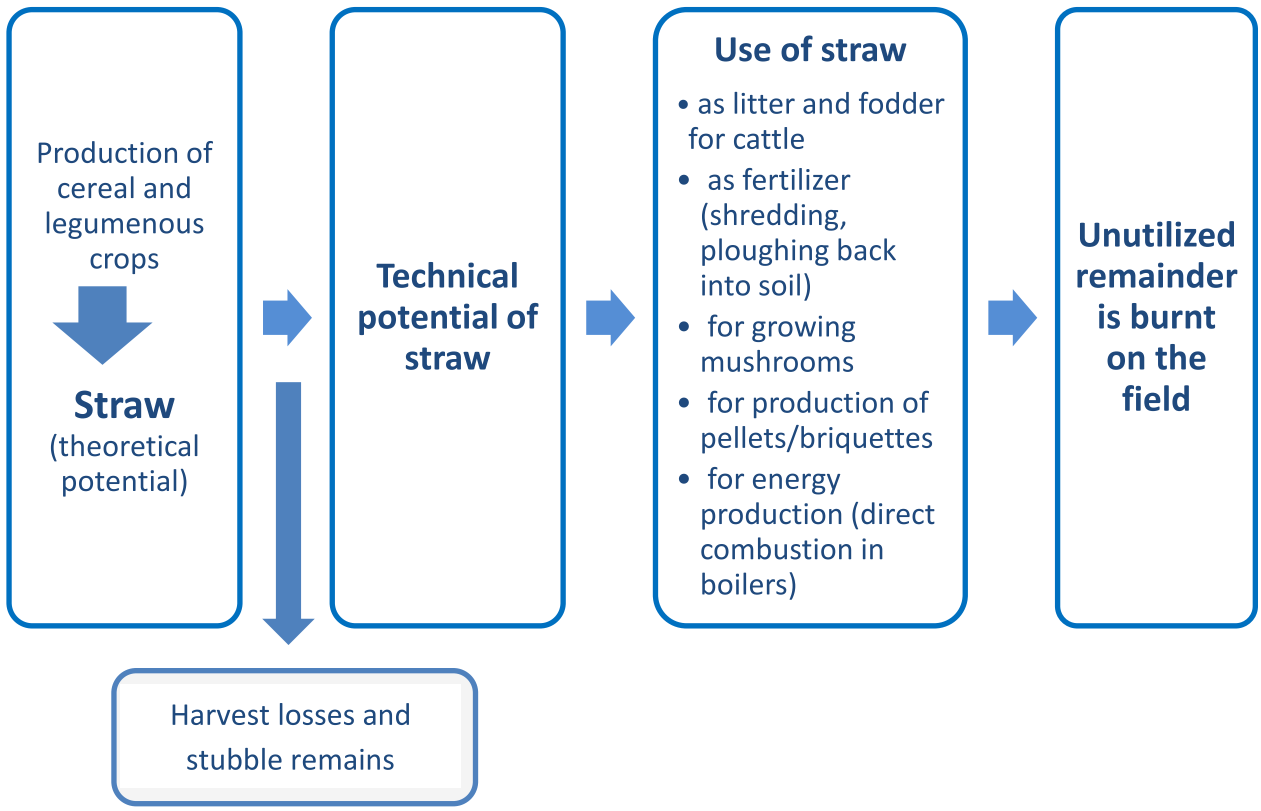


**Fig. 1.3.** Distribution of the technical potential of the primary agricultural residues in Ukraine, (2013)

At present, the common ways of using straw in Ukraine are the use as organic fertilizer and as feed and bedding for animals (**Fig. 1.3**). Some comparatively small amounts are used for energy (combustion of baled straw in boilers, production of pellets/briquettes). Unutilized reminder is often illegally burnt on fields (**Fig. 1.4**).

**Fig. 1.4.** Illegal combustion of straw on fields in Ukraine

## 1.2. Wood biomass

Average percentage of forest land in Ukraine is 15.9%, actual location of forests being very uneven over the country territory (**Fig. 1.5**). The most wooded are western and northwestern regions, the least wooded are eastern and southeastern areas. Stock of wood in the forests is rising as well as the volume of cutting (**Fig. 1.6**).

Felling of wood followed by wood processing and production of finished products is the source of various wastes and residues. Sustainable potential of wood biomass can be assessed at about **1.4 Mtoe/yr**, the contribution of firewood being the biggest, 65% of the total (**Fig. 1.7**). Major part of the potential is concentrated in western and northwestern regions of the country[6] (**Fig. 1.8**).

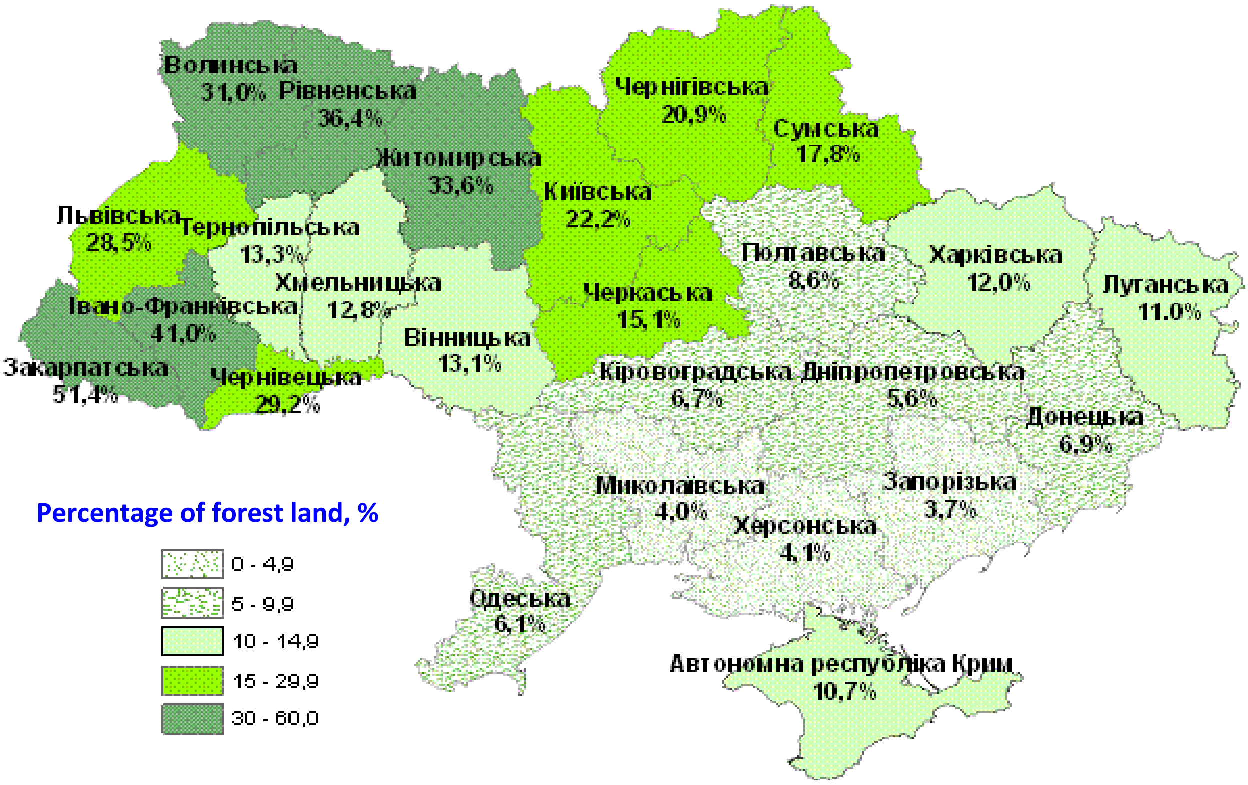


**Fig. 1.5.** Percentage of forest land in Ukraine

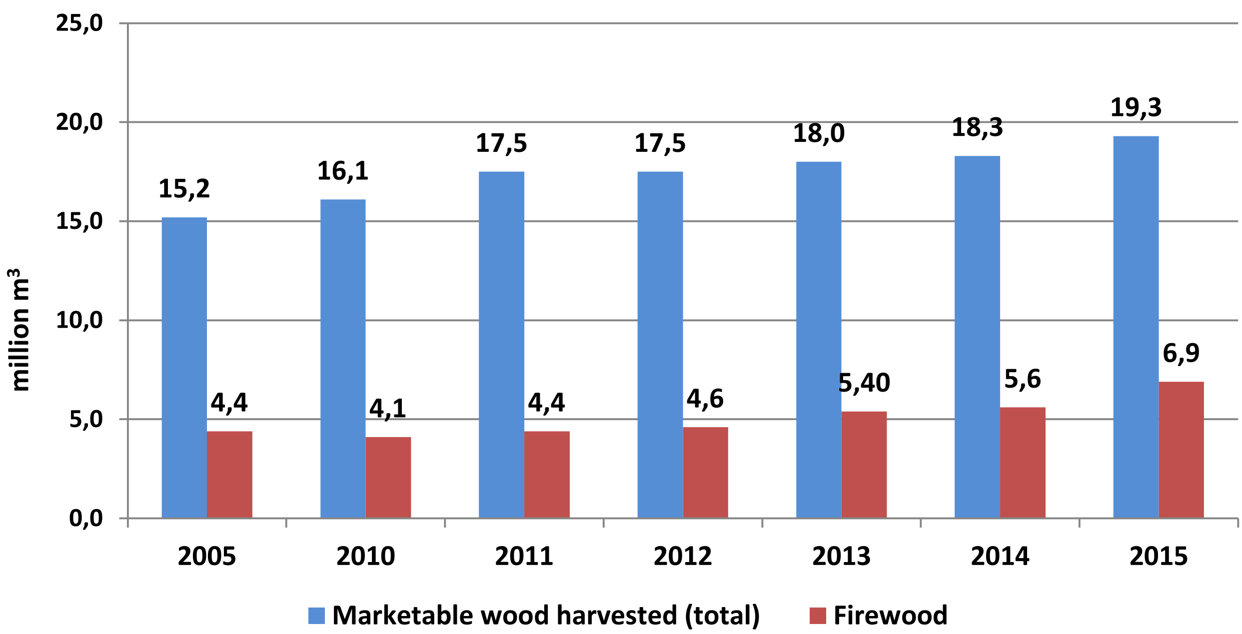


**Fig. 1.6.** Harvesting of marketable wood including firewood in Ukraine

[6] Figures for Ukraine's regions are presented in **Table A.2** of **Annex 1**.

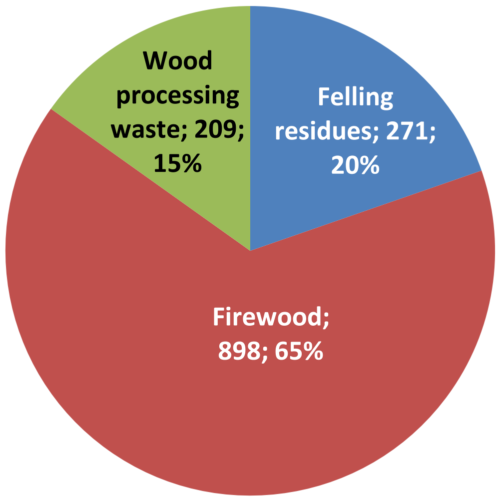


**Fig. 1.7.** Structure of the technical potential of wood biomass in Ukraine (in total **1378** ktoe, 2013)

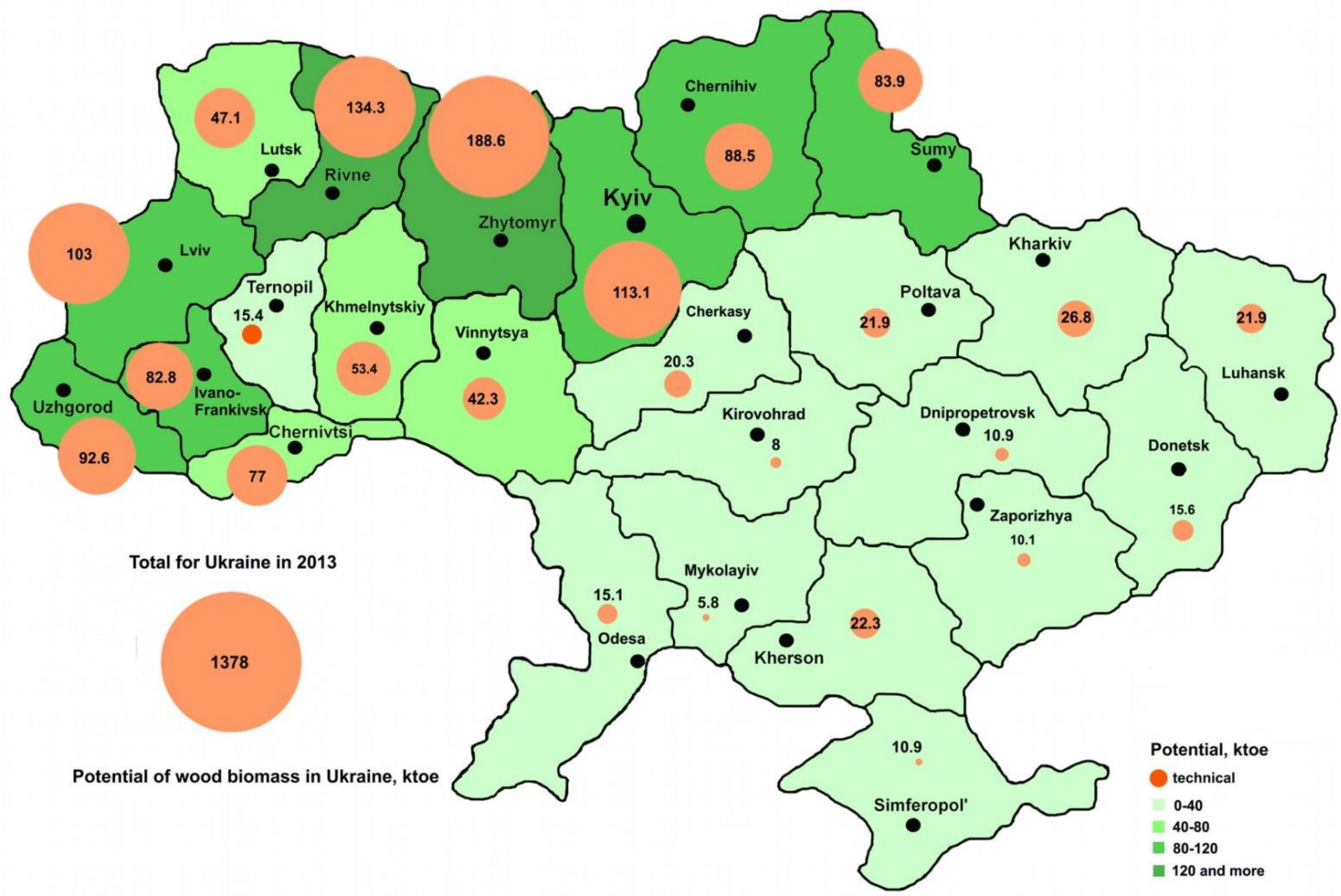


**Fig. 1.8.** Distribution of the wood biomass technical potential in Ukraine, 2013

## 1.3. Energy crops

Some part of agricultural land in Ukraine (**3-3.5** Mha, **Table 1.3**) is permanently unused as the sawn area is less than the available area of arable land (also taking into account the area of fallow land). This unused area can be partly involved in growing energy crops intended for obtaining both solid biomass and biogas. Climatic conditions of the country are favourable for growing such energy crops as willow, poplar, miscanthus, and switchgrass. The sustainable potential of energy crops in Ukraine can be assessed at **7** Mtoe/yr, of which 4.4 Mtoe/yr are crops for solid biomass and 2.6 Mtoe/yr are silage maize for biogas. Assessment of the potential is based on the assumption that 2 Mha will be used under energy crops[7]. The biggest potential of energy crops is in two regions (Zhytomyr and Chernihiv) (**Fig. 1.9**) that is determined by availability of comparatively large areas of unused agricultural land.

**Table 1.3.** Assessment of the area of unused arable land in Ukraine

| Land, 1000 ha | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| Arable land (A) | 32478 | 32476 | 32498 | 32518 | 32525 |
| Sawn area (S) | 26990 | 26952 | 27670 | 27801 | 28329 |
| Fallow land (F) | 1523 | 1465 | 1211 | 1247 | 981 |
| Unused arable land (U = A – S – F)* | 3965 | 4059 | 3617 | 3470 | 3215 |

** Assessments for regions is given in Table A.3 of Annex 1.*

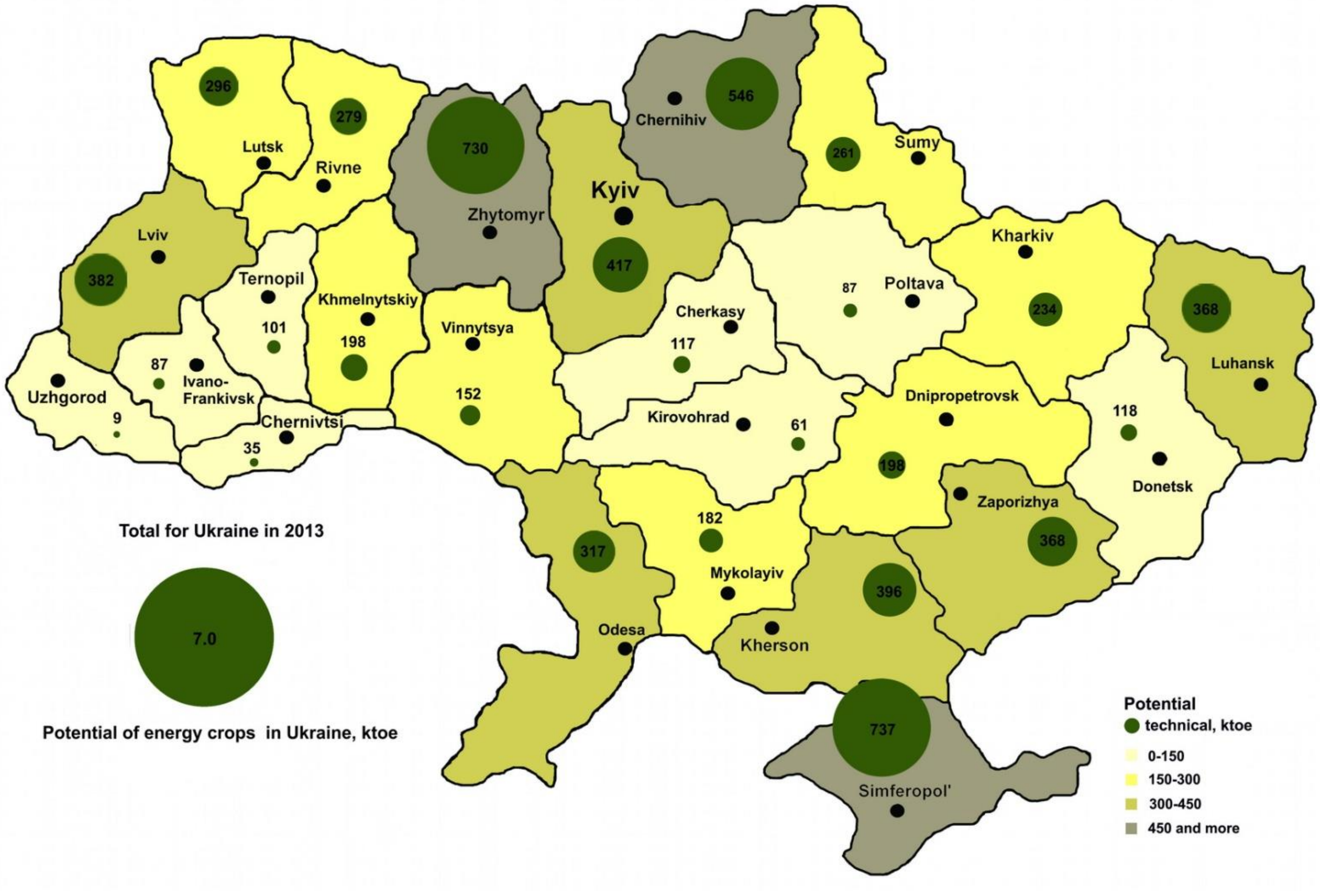


**Fig. 1.9.** Distribution of the energy crops technical potential in Ukraine, 2013

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[7] Figures for Ukraine's regions are presented in **Table A.3** of **Annex 1**.

Actual development of energy crop sector in Ukraine is at its rather early stage now. There are only a few companies operating in this area on a commercial basis. But the general trend is very positive and some new companies gradually enter the market.

## 1.5. Reed

The area of Ukraine's wetland is 981,600 ha[8] that makes up 1.63% of the total territory of the country. Main areas under reed, about **300,000 ha[9]**, are concentrated in Southern Ukraine in Danube delta and Dnieper delta. These areas are located mainly in Odessa region (mainly in 4 districts of the region including 35,000 ha in Kylyysky district), Mykolaiv region and Kherson region (that is in the regions near the Black Sea) (**Fig. 1.9**). According to some available information, some areas under reed are also in Volyn region (10,300 ha), Poltava region (30,000 ha) and some others.

**Fig. 1.9.** Ukraine's regions (red colour) with the main concentration of reed beds.

Based on the assumption that the total area under reed is about 350,000 ha and the average yield is about 5 t per hectare (dry matter), total amount of biomass can be estimated as **1.75 Mt** (d.m) or **0.77 Mtoe** (based on the heating value of 18.5 MJ/kg d.m.[10]).

## 1.6. Perspective conversion pathways

At present, the most feasible conversion pathway for agricultural residues, wood biomass and energy crops is direct combustion in boilers and at CHP plants. At that in most cases, the introduction of a boiler plant is priority as against a CHP plant. It is because biomass CHP plants require comparatively high investment costs and the existing feed-in tariff is not high enough to

[8] Environment of Ukraine. Statistical Yearbook issued by the State Statistics Service of Ukraine, 2014.
[9] Vegetation of Danube delta overflow land and its change under the influence of anthropogenic and climatic factors. Report by Olena Zhmud from Regional Research Center, 2011.
[10] Average yield per hectare (dry matter) and the heating value for reed have been taken from: M. Komulainen, P. Simi, E. Hagelberg et al. Reed energy – Possibilities of using the Common Reed for energy generation in Southern Finland, 2008.

achieve an acceptable payback period. On the contrary, the introduction of biomass boilers in DH and the budget-financed sector is supported by a stimulating heat tariff[11].

**Table 1.5.** Perspective conversion pathways for lignocellulosic biomass for energy in Ukraine

| Type of biomass | Form of biomass | Type of equipment | Comments |
|---|---|---|---|
| Straw | Bales | Boilers (1-10 $MW_{th}$) | Areas of application: DH (***first-priority option)***; industry.<br>Here and then in the table:<br>Boilers are a priority option against CHP plants due to their lower capital cost. |
| | | CHP (1-10 $MW_{el}$) | Areas of application: DH; industry<br>Here and then in the table: under the current feed-in tariff, the introduction of CHP or power plants is not a very attractive option. |
| | Pellets | Boilers (0.1-1 $MW_{th}$) | For the heating of public building (schools, hospitals) |
| | Briquettes | Boilers and stoves (10-50 $kW_{th}$) | For individual households |
| Maize residues | Baled stalks | Boilers (1-10 $MW_{th}$) | In perspective when a baling technology (equipment) is available in the domestic market. Areas of application: DH (***first-priority option)***; industry |
| | Cobs | Boilers and CHP | Comparatively limited potential of collectable maize cobs. |
| Sunflower residues | Baled stalks | Boilers (W<40%) and CHP (W>40%)* | In perspective when a baling technology (equipment) is available in the domestic market. Areas of application: DH (***first-priority option)***; industry |
| | Stalks (W>50%) | Biogas plant | Some additional efforts may be needed to intensify the digestion process. |
| Wood | Wood chips | Boilers (1-10 $MW_{th}$) | Areas of application: DH (***first-priority option)***; industry. |
| | | CHP (1-10 $MW_{el}$) | Areas of application: DH; industry |
| | Pellets | Boilers (0.1-1 $MW_{th}$) | Heating public building (schools, hospitals) |
| | Firewood Briquettes | Boilers and stoves (10-50 $kW_{th}$) | Individual households |
| Energy crops | Chips | Boilers (1-10 $MW_{th}$) | Areas of application: DH (***first-priority option)***; industry. |
| | | CHP (1-10 $MW_{el}$) | Areas of application: DH; industry |
| | Pellets | Boilers (0.1-1 $MW_{th}$) | Heating public building (schools, hospitals) |
| Reed | Briquettes | Boilers and stoves (10-50 $kW_{th}$) | For individual households |

** W is the biomass moisture content*

[11] The legal issues are considered in more details in the respective chapter.

Perspective types of bioenergy equipment and projects in Ukraine are presented in **Table 1.5**. Of them, taking into account some technical and economic factors, the first-priority options are the introduction of boilers operating on straw bales and wood chips for district heating. In perspective these options will also include boilers on maize/sunflower baled stalks. It will be possible as soon as the baling technology and equipment are available in Ukraine's market.

As for the production of 2nd generation biofuels from lignocellulosic feedstock in the country, probably the technologies may be developed and realized in long-run prospect and definitely not at present or the near future.

## 2. Analysis of food industry residues

Along with agriculture, food industry of Ukraine is a powerful source of various residues. Main types of the residues are considered below.

### 2.1. Residues of sugar plants

The number of operational sugar plants in Ukraine was 60 units in 2012[12]. Capacity of sugar plant lies normally in the range from several thousands to 100,000 tons of sugar per season. Depending on the initial sugar content, 7…8 tons of sugar beet is used for the production of one ton of sugar. Specific outputs of some by-products generated during the production of sugar are shown in **Table 2.1**.

**Table 2.1.** Sugar production residue indexes[13]

| Residue type | Residue output per 1 ton of sugar produced | |
|---|---|---|
| | tons of raw material | tons of total solid |
| Sugar beet pulp (unpressed) | 5.744 | 0.373 |
| Molasses | 0.333 | 0.260 |
| Defecation mud | 0.636 | 0.509 |
| Tops | 0.256 | 0.059 |

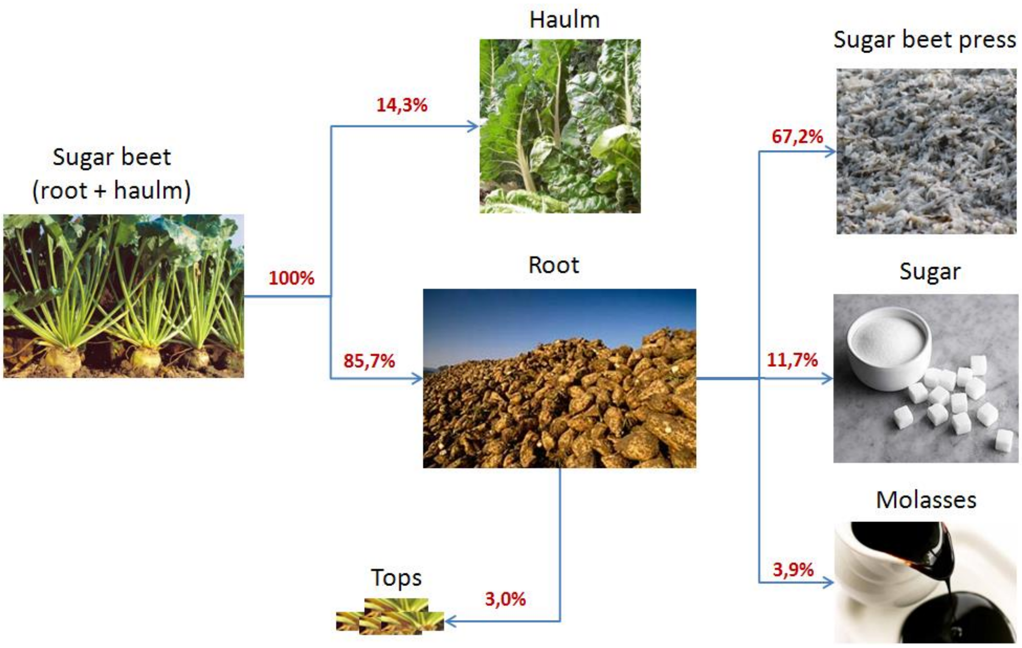



**Fig. 2.1.** Typical mass balance of sugar production

Based on available statistical data on sugar production, estimation of the residues amount in Ukraine's regions has been done (**Fig 2.2)**. One can see that two regions (Vinnytsia and Poltava) have the biggest potential followed by 3 regions with the lesser potential. The rest of the regions have very small or no potential at all.

[12] Source: http://economics.unian.net/ukr/news/150820-golova-asotsiatsiji-ukrtsukor-sogodnishnya-tsina-na-tsukor-tse-svogo-rodu-sos.html
[13] REA data

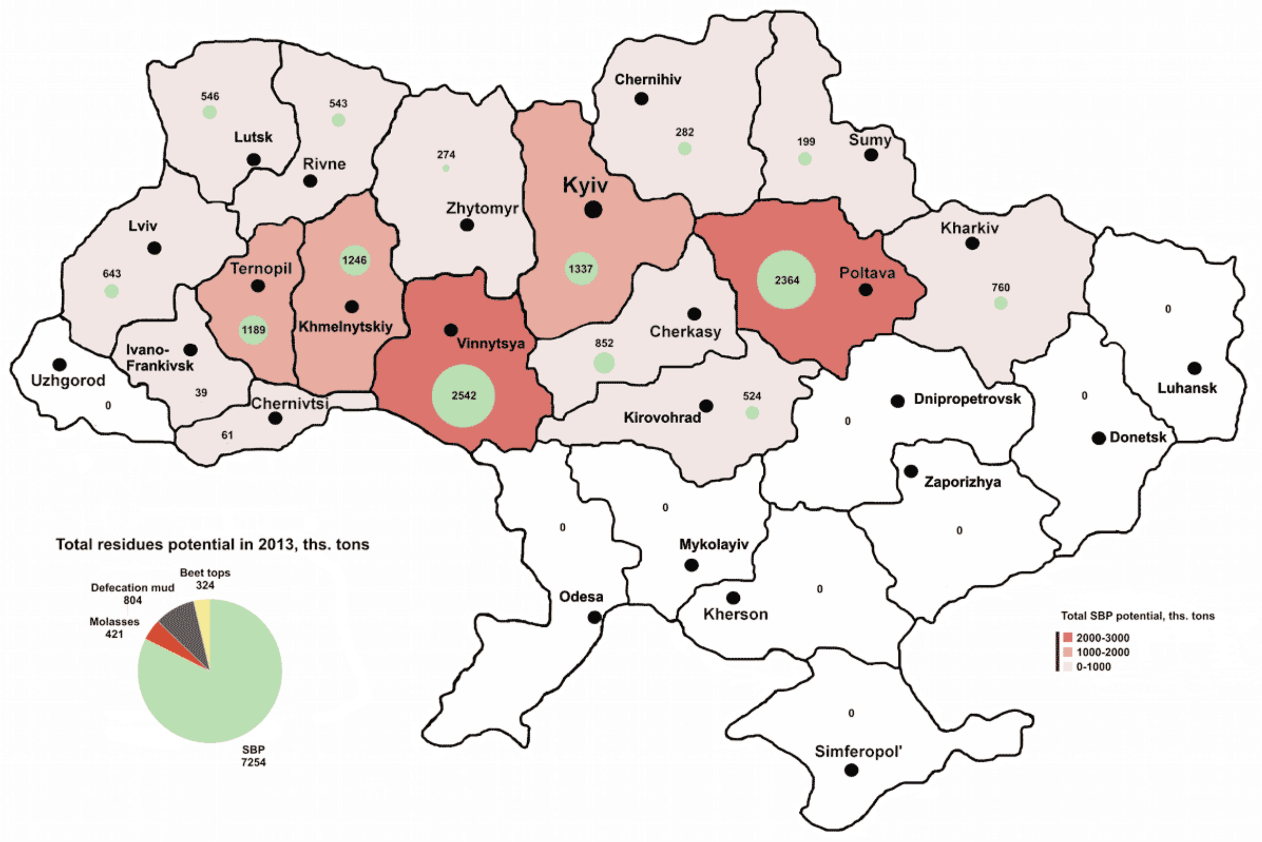



**Fig. 2.2.** Potential of residues of sugar beet plants in Ukraine (raw material), 2013

Production volume of sugar is very variable during a year. The highest level of waste generation (3.3 mln. tons a month) is in October-November (**Fig. 2.3**). The lowest one takes place at the beginning (September) and the end (January) of a sugar production season. Some residual quantity of sugar is produced even in February and March.


| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tops | 16.5 | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.1 | 122.4 | 124.5 | 39.7 |
| Defecation mud | 41.0 | 1.2 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 49.8 | 303.6 | 309.0 | 98.5 |
| Molasses | 21.5 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 26.1 | 159.1 | 161.9 | 51.6 |
| SBP | 369.9 | 10.9 | 3.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 449.9 | 2741.0 | 2790.0 | 888.9 |

SBP – sugar beet pulp

**Fig. 2.3.** Seasonal production of sugar plants residues, 2013

Most of sugar by-products are used in livestock farming, alcohol production and bread baking industries. However, by-products marketability depends on market demand in the region possibility of feasible transportation.

The traditional way to utilize sugar beet pulp (SBP) is using it as fodder for cattle. SBP is used whether in raw or treated (acidified or dried) form. Using raw SBP is limited due to a short period before it turns to its acidified form. Using raw or acidified form of SBP is more suitable where cattle farms are located next to a sugar plant. Transporting sugar beet pulp at a long distance seems to be an unfeasible option. An alternative way for SBP utilization is biogas production. Anaerobic digestion of SBP is not a widespread technology. Nevertheless a few commercial biogas plants exist in the EU. In Ukraine in 2015, a biogas plant operating on SBP and some crop residues was put into operation at Globinsky sugar factory (Poltava region).

## 2.2. Residues of oil extraction plants

In Ukraine, more than 90% of oil is produced from sunflower seeds. Ten largest manufacturers of vegetable oil control up to 90% of the total production. The main types of wastes generated during sunflower oil production are husk of sunflower seeds and extraction cake. Husk is formed at the step of crushing and subsequent separation of the seeds coat from the kernels. Extraction cake is the end-product of the pressing and oil extraction. In the production of refined oil such additional waste stream as soap stock is generated. It is a product obtained in the process of purification of oil by alkaline solutions.

**Table 2.2** shows the specific yields of the main residues for oil extraction process. Based on the statistical data of the oil production, the potential of sunflower oil residues generated in Ukraine's regions has been estimated (**Fig 2.5**).

**Table 2.2.** Sunflower oil production residue indexes[14]

| Residue type | Residue output per 1 ton sunflower oil produced | |
|---|---|---|
| | tons of raw material | tons of total solid |
| Husks | 0.398 | 0.338 |
| Extraction cake | 0.773 | 0.711 |
| Soap stock* | 0.055 | 0.054 |

** Per 1 ton of refined oil*

The sunflower oil residues streams are not constant during a year. The highest level of sunflower oil production takes place after the end of sunflower harvesting until the end of the year (**Fig. 2.6**). From the beginning of a year until August it constantly decreases. Thus ratio between the highest and the smallest volume of wastes is 4.6.

The lion share of sunflower husk is utilized in Ukraine either for heat production (almost all the oil extraction plants have boilers) or for pellet/briquette production. The common use of extraction cake is animal feeding as protein source, mostly in pig and poultry breeding. As a rule

[14] REA data

it is mixed with combine fodder. The quality of extraction cake depends on the technology of sunflower oil production. It could contain impurities like husk particles and chlorogenic acid.

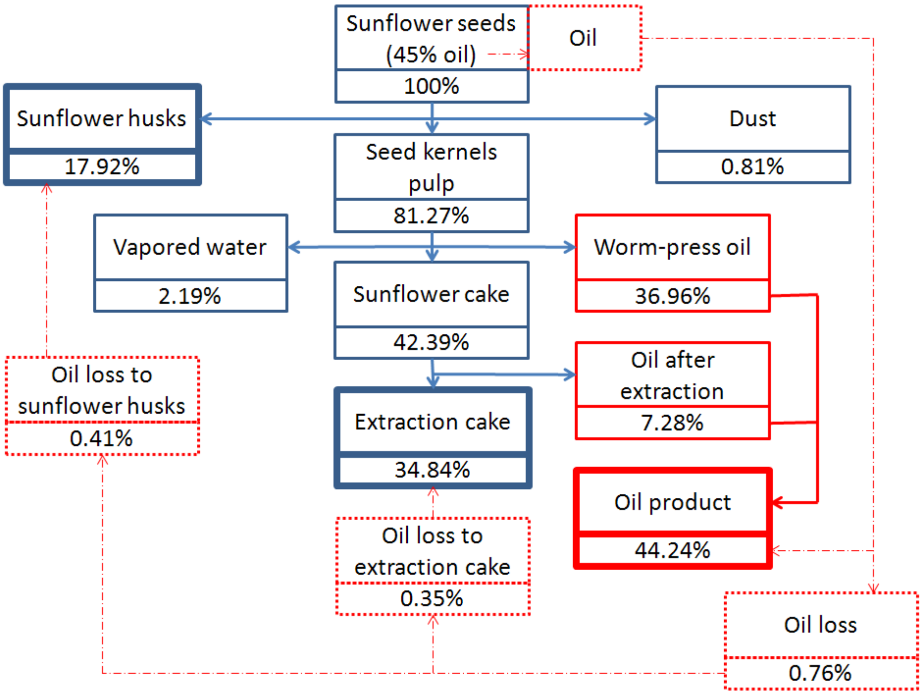



**Fig. 2.4.** Typical mass balance of extractive sunflower oil production

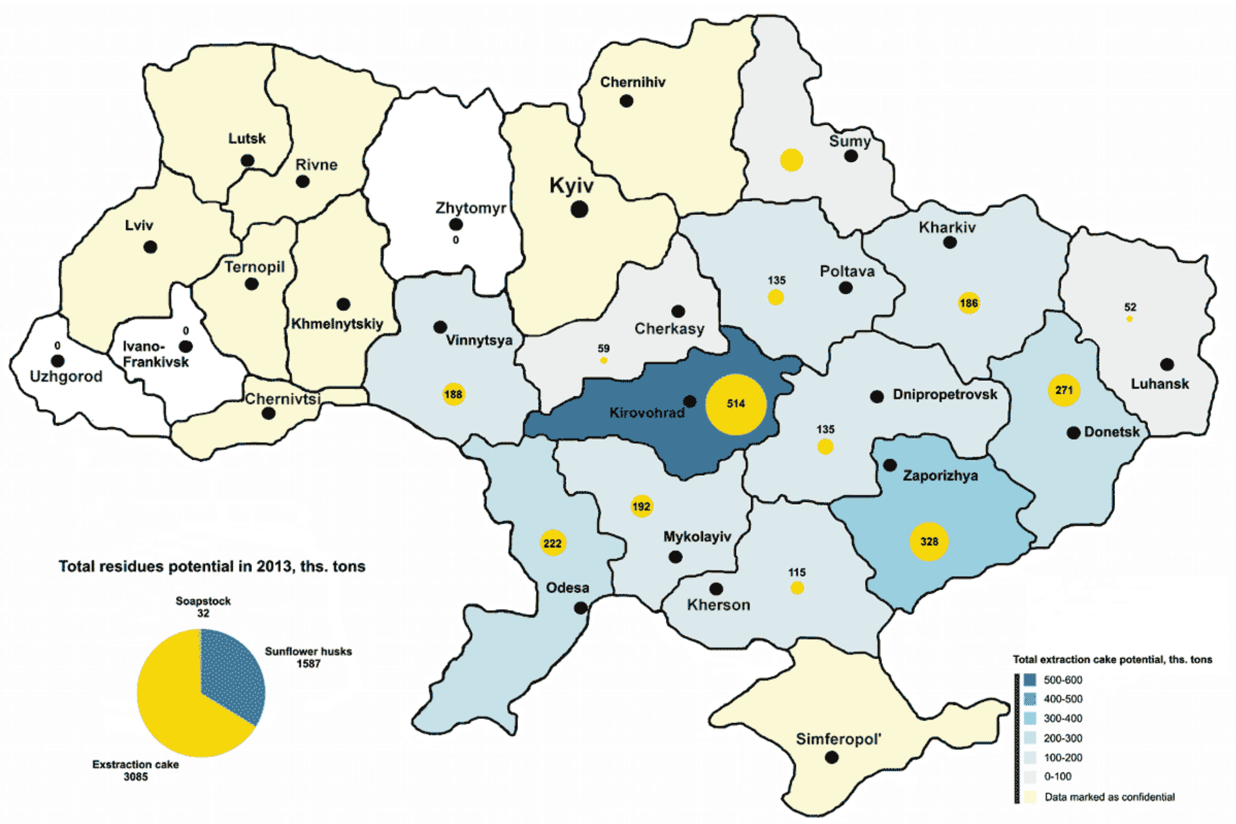
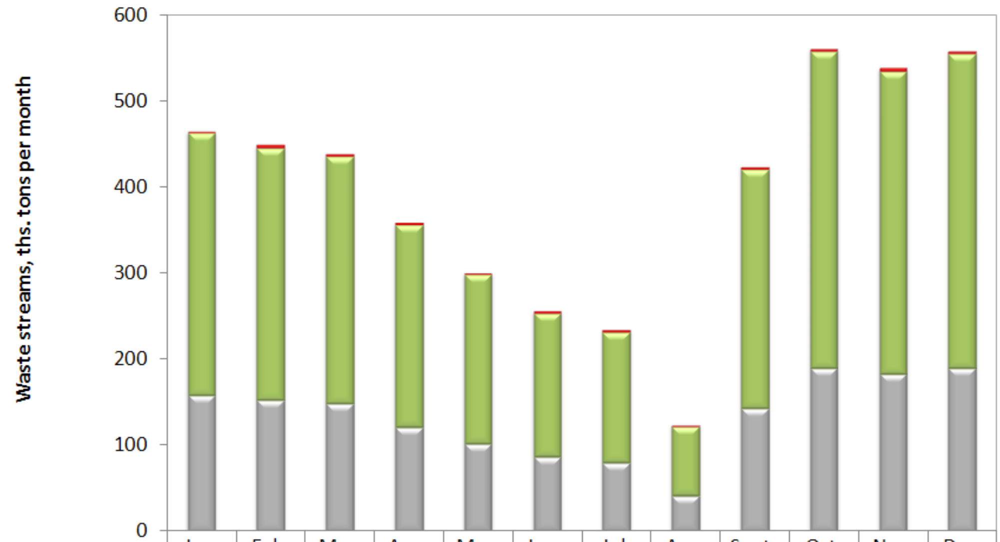



**Fig. 2.5.** Potential of sunflower oil production residues (raw material) in Ukraine, 2013




| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soapstock | 2.3 | 2.9 | 2.8 | 2.7 | 1.9 | 2.5 | 2.0 | 1.7 | 2.9 | 3.5 | 3.4 | 3.3 |
| Extraction cake | 305.4 | 294.4 | 287.9 | 234.8 | 196.8 | 167.3 | 153.1 | 80.2 | 278.0 | 367.8 | 353.2 | 366.3 |
| Husks | 157.1 | 151.4 | 148.1 | 120.8 | 101.3 | 86.0 | 78.7 | 41.3 | 143.0 | 189.2 | 181.7 | 188.4 |

**Fig. 2.6.** Seasonal production of oil-extraction plants residues, 2013

## 2.3. Residues of breweries

Beer production in Ukraine is represented by 36 breweries, 11 of which are owned by five largest players in the beer market. The following main types of residues are generated during beer production:

- Spent grain (SG)
- Spent hop
- Spent yeast
- Kieselguhr sludge

Based on the typical indexes of beer production residues, total volume of the residues can be assessed at about 1 Mt, the amount of spent grain being the biggest (**Table 2.3**).

**Table 2.3.** Beer production residues

| Residue type | Residue output per 1 L of beer produced[15] | | Amount (raw material) in Ukraine*, kt (2013) |
|---|---|---|---|
| | tons of raw material | tons of total solid | |
| Spent grain | 0.328 | 0.046 | 899 |
| Spent hop | 0.009 | 0.002 | 24 |
| Surplus yeast | 0.01 | 0.001 | 27 |
| Kieselguhr sludge[16] | 0.006 | - | 16 |
| **Total** | | | **966** |

** Assessments for Ukraine's regions cannot be done as most of data on beer production in the regions is confidential.*

[15] Food Technology in the examples and problems [Text]: a textbook for university students / Tovazhnyansky L.L. [et al.]. - K. Centre of education books, 2008 - 576 p. (in Ukrainian).

[16] Engineering estimates of beer on high-efficiency equipment and mini breweries. Scientific Information material// VPO "Moscow State University of Food Production." - M .: 2010 (in Russian) (Source: http://www.mgupp.ru/wp-content/uploads/2010/03/Технологические-расчеты-производства-пива.pdf)

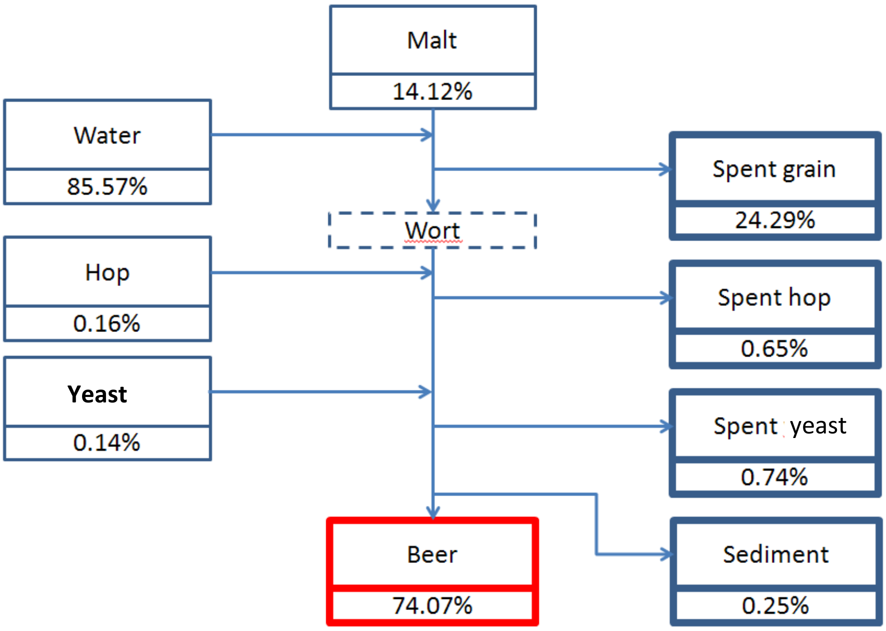
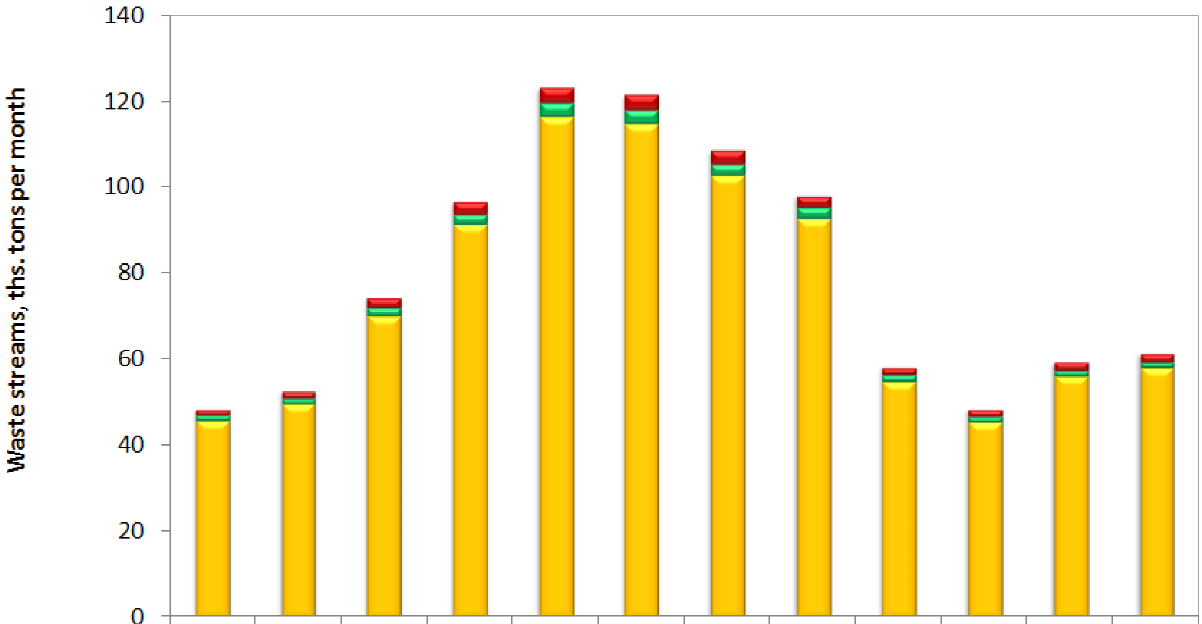



**Fig. 2.8.** Mass balance of beer production

The peak generation of beer production wastes is in the summer period (about 100-120 kt/month) (**Fig. 2.9**). The lowest generation of the wastes is in autumn and winter. The ratio between the highest and the lowest volume of wastes is 2.6.




| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surplus yeast | 1.4 | 1.5 | 2.1 | 2.8 | 3.6 | 3.5 | 3.1 | 2.8 | 1.7 | 1.4 | 1.7 | 1.8 |
| Spent hop | 1.2 | 1.3 | 1.9 | 2.5 | 3.1 | 3.1 | 2.8 | 2.5 | 1.5 | 1.2 | 1.5 | 1.6 |
| Spent grain | 45.8 | 49.7 | 70.3 | 91.4 | 116.5 | 114.9 | 102.6 | 92.8 | 55.1 | 45.7 | 56.1 | 58.0 |

**Fig. 2.9.** Seasonal production of brewery residues, 2013

Characteristics of spent grain restrict its usage. Short time of getting spoilt and high fiber content allows only its limited utilization. Traditional methods of spent grain use/utilization are generally the following: production of low value composts, feed for livestock, disposal at landfill as waste, incineration.

Alternative methods of the use, among others, may include energy production either by direct combustion or by fermentation to obtain biogas. Implementation of direct combustion technology needs dewatering spent grain to at least 50-55% moisture; besides some problems connected with $NO_x$ and dust particle emissions may arise. Dewatering SG from 80% to 50% moisture can be reached in two main steps: mechanical dewatering to 65% and further evaporating through heating. Taking into account the consumption of energy required for dewatering spent grain, still some extra energy can be obtained when combusting the dewatered SG.

As for biogas production, anaerobic fermentation of SG is efficient only if it is divided into a hydrolytic and a methanogenic steps. Biogas yield from the raw material is 105 м$^3$ per ton (about 2260 MJ). A valuable organic fertilizer is the final product of spent grain anaerobic digestion. Hydrolysis of the fiber material in SG is a limiting step for complete degradation of the material. Nevertheless, there are several different pre-treatment possibilities to enhance the rate of fermentation, including chemical-thermal treatment with 0.2 M NaOH at 70°C, crushing by wet rotor grinding or ball milling, as well as enzymatic treatment by cellulase-producing fungi with SG as the sole substrate.

There exists also a technology for the production of steam from spent grain. According to this technology, SG is first mechanically dewatered to 42% moisture, then press water is directed to anaerobic treatment with biogas production, and biogas is used as adding gas for dried SG combustion. As a result 1.38 t of steam per 1 t of SG can be obtained.

## 2.4. Residues of dairy industry

Main types of waste of dairy industry are whey (a by-product of cheese or casein) and Maslyanka (buttermilk), a byproduct of churning butter. Monthly amount of the dairy residues streams is in the range 75-85 kt. There are some fluctuations with the lower production rates in May-June and December-January periods and the higher rates in March and November. Mostly it is related to whey generation. On the contrary the biggest volumes of buttermilk are generated in the summer period.

**Table 2.4.** Cheese/butter production residue indexes

| Residue type | Residue output per 1 ton cheese/butter produced | |
|---|---|---|
| | tons of raw material | tons of total solid |
| Whey | 3.5 | 0.217 |
| Buttermilk | 1 | 0.09 |

Usually whey is returned to farmers as feed for animals or is spread onto the fields. Often whey is discharged as wastewater to municipal sewerage system. For that the whey should be pretreated so that to meet sewerage system norms. Anaerobic digestion is a good method for whey pretreatment and in addition 10-15 m$^3$ of biogas per each cubic meter of the feedstock can be obtained.

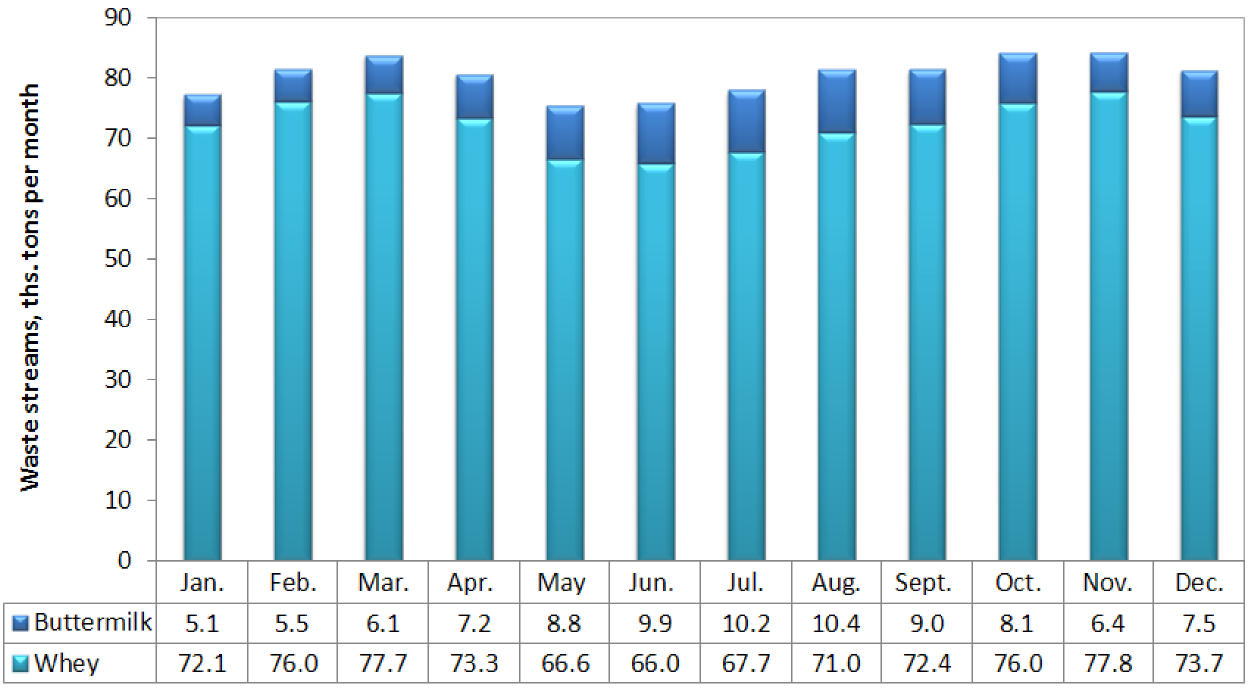



**Fig. 2.10.** Seasonal production of dairy residues, 2013

## 2.5. Residues of distilleries

The main byproduct generated during alcohol production is stillage. It is the end-product after distillation of an alcohol-reach substance. In Ukraine there are three main stillage types: grain-, potato- and sugar beet molasses-based stillage.

**Table 2.5.** Alcohol production residue indexes[17]

| Residue type | Residue output per 1 L spirit produced | |
|---|---|---|
| | tons of raw material | tons of total solid |
| Stillage | 13.650 | 0.990 |
| Surplus yeast | 0.217 | 0.022 |

Stillage is a perishable product that means that it should be processed as quickly as possible. In Ukraine stillage is usually removed to storage lagoons or to sewerage systems after pre-treatment. Sometimes stillage is spread onto the fields as organic fertilizer.

Biogas can be effectively produced from the stillage by anaerobic digestion. From 30 to 50 $m^3$ of biogas can be obtained from 1 ton of the raw material. In Ukraine, there is an experimental facility producing biogas from stillage (Luzhansky distillery in Chernivtsi region). It started operation in 2009 and produces 2,300 $m^3$ of biogas a day. For now, anaerobic digestion of stillage with biogas and organic fertilizer production seems to be the most feasible option for the use of the residue with the purpose of energy production.

[17] Food Technology in the examples and problems [Text]: a textbook for university students / Tovazhnyansky L.L. [et al.]. - K. Centre of education books, 2008 - 576 p. (in Ukrainian).

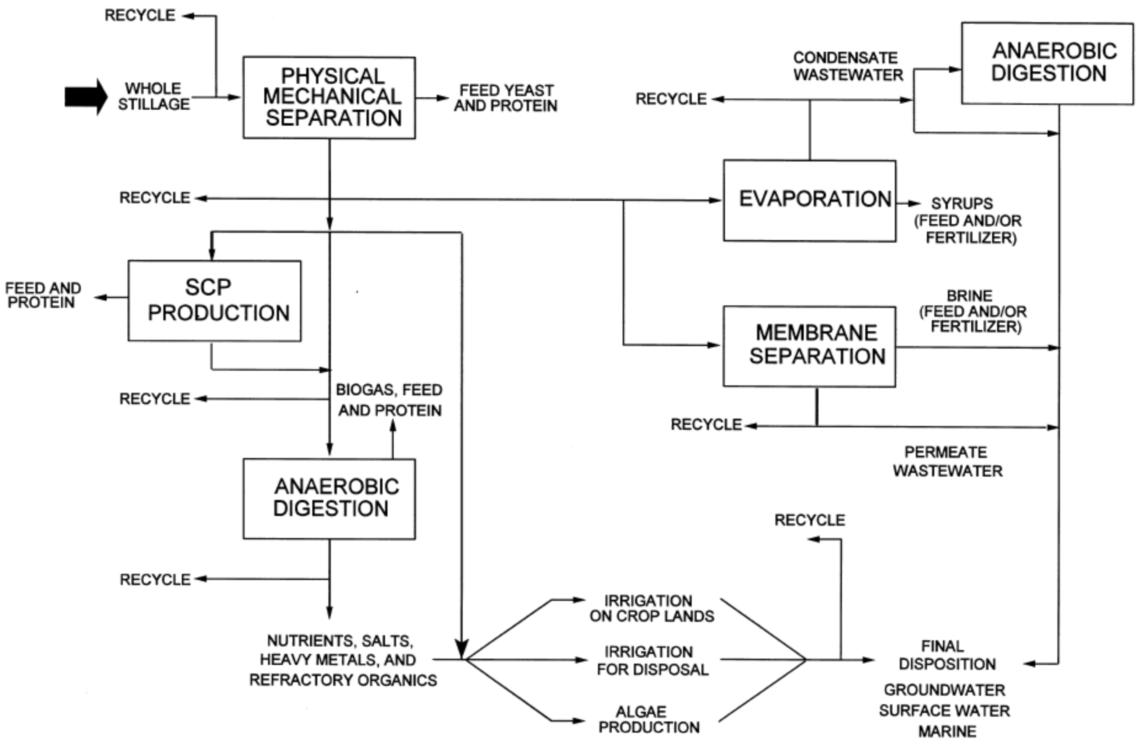



**Fig. 2.11**. Stillage treatment technology and utilization options

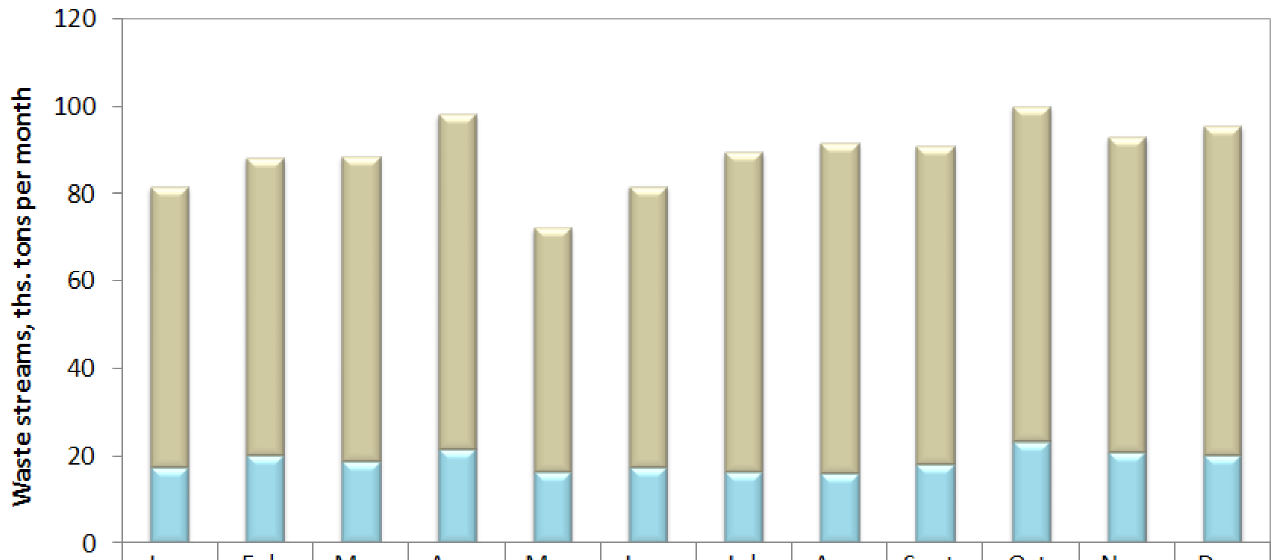
## 2.6. Flour and groats production residues

In the process of flour and groats production the following main by-products and wastes are generated:

- grain shorts,
- bran,
- husks,
- unconditioned grains,
- flour powder,
- corcules,
- crop residues.

Processing different kinds of grain gives different volumes of by-products. Average residue generation rate for all groats produced in Ukraine is estimated as 0.607 tons per ton, and 0.333 tons per ton of flour produced. Some seasonal fluctuation can be observed in flour production. The lowest production rate is in May while the highest rates are in April and October. An average volume of wastes amounts to about 89,000 tons per month. The share of flour production residues in the total volume of wastes in the sector is 77-83%.

The common use of shorts and similar by-products is fodder for animals. Bran is often used in food industry (as bread additive, for flakes and crunches production). Flour/groats by-products can also be utilized as co-substrate for biogas production. In this case some additional grinding might be required to intensify the degradation of organic matter. Yield of biogas can reach up to 350-400 $m^3$ per ton of feedstock. Nevertheless the biogas production from flour/groats main by-products seems to be a feasible option only if they cannot be utilized as fodder.




| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flour | 64.4 | 68.2 | 70.1 | 76.7 | 56.1 | 64.7 | 73.5 | 75.8 | 73.0 | 76.7 | 72.4 | 75.5 |
| Cereals | 17.1 | 19.9 | 18.5 | 21.4 | 16.0 | 17.1 | 15.9 | 15.7 | 17.8 | 23.2 | 20.5 | 19.8 |

**Fig. 2.13.** Seasonal generation of residues of flour and groats production, 2013

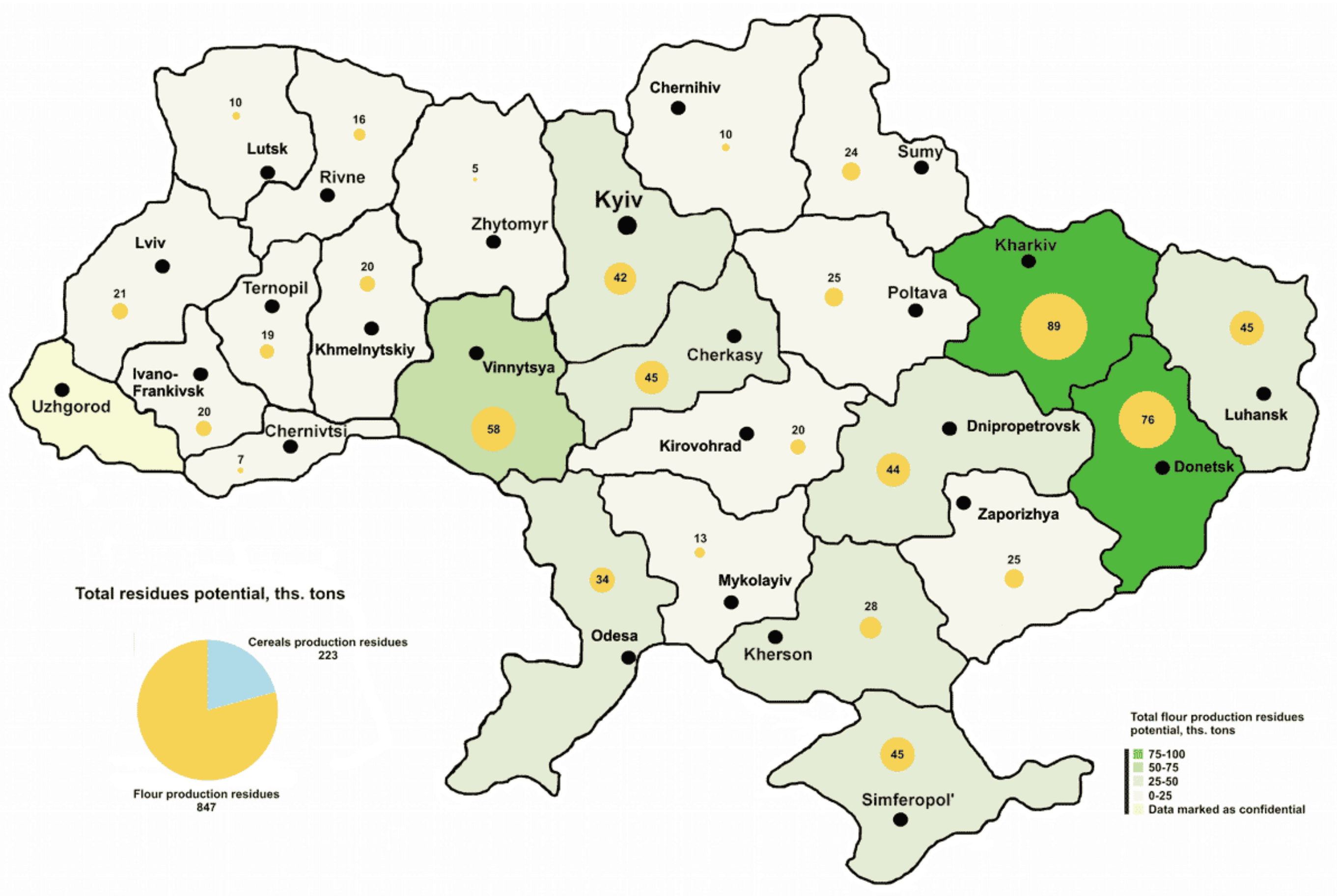



**Fig. 2.12.** Potential of flour and cereals production residues in Ukraine, 2013

## 2.7. Perspective conversion pathways

Perspective conversion pathways for the considered residues of food industry are direct combustion (for sunflower husk) and anaerobic digestion (for the rest of the residues). A preferable option is the introduction of CHP plants at the enterprises that have their own residues, sunflower husk. As usual they are oil-extraction plants or other enterprises of fat-and-oil industry.

Anaerobic digestion of the food industry residues have some peculiarities, which are summarized in **Table 2.6**. Implementation of such projects requires their thorough elaboration. Successful introduction of a biogas plant at Globinsky sugar factory (Poltava region of Ukraine) demonstrates a possibility of the implementation of technology for biogas production from the food industry residues in the country.

**Table 2.6.** Perspective conversion pathways for food industry residues for energy in Ukraine

| Type of biomass | Form of biomass | Type of equipment / technology | Comments |
|---|---|---|---|
| Sunflower husk | Natural form | Boilers and CHP | Area of application: Industry.<br>CHP is a preferable option as an enterprise usually utilizes its own residues and the project has acceptable payback period. |
| | Pellets | Boilers (100-500 $kW_{th}$) | For the heating of public building (schools, hospitals) |
| | Briquettes | Boilers and stoves (10-50 $kW_{th}$) | For individual households |
| Sugar beet pulp | Raw material | Anaerobic fermentation to obtain biogas | Not a widespread technology for SBP though a few commercial biogas plants already exist in the EU |
| Spent grain | Raw material or pretreated feedstock | Anaerobic fermentation to obtain biogas | The technology is efficient only if it is divided into a hydrolytic and a methanogenic steps |
| Whey | Raw material | Anaerobic fermentation to obtain biogas | The method for energy production as well as for the pretreatment of whey before discharging into sewage system. |
| Stillage | Raw material | Anaerobic fermentation to obtain biogas | For the time being, it is the most feasible option for using stillage for energy |
| Grain shorts | Raw material | Anaerobic fermentation to obtain biogas | It seems to be a feasible option only if the residue cannot be utilized as feed |
| Unconditioned grain | Grinded | Anaerobic fermentation to obtain biogas | It seems to be a feasible option only if the residue cannot be utilized as feed |

# 3. Analysis of regulatory frameworks

## 3.1. Waste management issues

In Ukraine, waste management and disposal is regulated by the Law "**On Waste**"[18]. According to the Law, *waste* is any substances, materials and articles that arose in the process of production or consumption and also the goods (products) that completely or partly lost their consumer properties and are of no further use on the place of origin and which the owner wants to utilize or dispose of. Utilization of waste means the use of waste as secondary material or energy resources. Storage and disposal of waste should meet the environmental safety requirements and also ensure maximum possible use of waste or transfer to other users (except for landfilling).

The most important aspect of improving organic waste management in Ukraine is to really begin enforcing environmental regulations against polluting practices. This would force farmers and processors to adopt waste processing measures. Also important is providing state support for more environmentally friendly and effective ways of using waste including production of energy.

## 3.2. Issues related to energy crops and reed

According to Ukrainian legislation, the crops included in *"The State Register of Plant Varieties Suitable for Dissemination in Ukraine"* can be cultivated on agricultural lands. Of all the energy crops, only willow is now included in the Register. It means that other energy crops can be grown only on non-agricultural land. On the one hand, the procedure of including a crop into the Register is rather long and complicated. On the other hand, as was mentioned earlier, Ukraine has 3-3.5 Mha of underutilized agricultural land, which can be partly used for energy crops. To resolve the collision, the State Agency on Energy Efficiency and Energy Saving of Ukraine has developed a draft Plan for the promotion of growing perennial energy crops[19]. Among others, the Plan envisages quick and priority inclusion of energy crops in "The State Register of Plant Varieties Suitable for Dissemination in Ukraine".

According to Ukrainian legislation, harvesting reed should be performed with observance of environmental protection rules. To carry out this activity, it is necessary to get special permission. Harvesting reed on the state forest land is considered to be harvesting secondary forest materials[20]. In this case in addition to the usual permission it is also required to get a so called "forest ticket", which is issued by the State Agency of Forest Resources.

## 3.3. Energy production issues

### *Power production*

Production of power from biomass in Ukraine is stimulated by special Green Tariff[21] (GT). The Green Tariff issues are regulated by the Law of Ukraine "**On Power Industry**"[22]. According to

[18] The Law "On Waste" (N 187/98-BP of 05.03.1998 with amendments) http://zakon2.rada.gov.ua/laws/show/187/98-%D0%B2%D1%80
[19] The document is under consideration and discussion.
[20] Resolution of CMU N 449 of 23.04.1996 http://zakon1.rada.gov.ua/laws/show/449-96-%D0%BF
[21] The national term for the feed-in tariff.
[22] The Law "On Power Industry" (N 575/97-BP of 16.10.1997 with amendments)

the Law, Green Tariff for the power produced from biomass/biogas is set as the retail tariff for the II voltage class consumers as of January 2009 multiplied by GT factor. Current GT factor for biomass/biogas is 2.3 or 2.07 depending on the period when the power plant was put into operation. Current GT for biomass/biogas power plants is 3.2 UAH/kWh (12.6 EUR-cents/kWh[23]) without VAT.

Despite the existing Green Tariff, at present there is rather limited number of plants generating power from solid biomass and biogas. Moreover, proliferation of such power plants is not expected in the near future. Main reasons are a low value of GT (especially for biogas plants) and very strict domestic content requirement determined by the law.

### *Heat production and replacement of natural gas*

**Resolution** of the Cabinet of Ministers of Ukraine (CMU) "On stimulation of replacing natural gas in heat supply area"[24] (2014) introduced a supporting mechanism for using biomass in heat supply for population. Without the mechanism the use of biomass in this area is not feasible yet due to the artificially low price of NG for population and therefore a low heat tariff. The mechanism consists in covering by the state the difference between the actual heat production tariff and the heat production tariff established for population.

Though the Resolution is considered progressive and important for the development of bioenergy sector in the country, it has several *shortcomings* that limit its general positive influence. One of them is that the introduced mechanism (the stimulating heat tariff) does not apply to heat produced by CHP plants. Another shortcoming is that a biomass heat producer must get approval for his heat tariff from the National Commission for State Regulation of Energy and Communal Services (NCRECS). The tariff is calculated as the prime cost plus (max) 21% profitability. If the tariff is below a certain value then the stimulating heat tariff for the producer is less than that for the producer whose tariff (approved by NCRECS) is above that value.

Another **Resolution** of CMU "On stimulation of replacing natural gas for the production of heat for budget-financed institutions"[25] (2014) was adopted with the purpose to promote the use of biomass and other fuels (except for NG) for heat supply to budget-financed consumers. The stimulation is performed by means of favourable tariff. The point is that the tariff will be high enough to make the related project feasible. The tariff is to be set by NCRECS or by local authorities. The described mechanism is applied to heat production at boiler plants and is not valid for CHP plants (that is its disadvantage).

Ukrainian Government elaborated and approved **"Plan of short- and middle-term measures for reducing consumption of natural gas until 2017"[26]**. One of main activities planned is replacement of NG by renewable energy sources, the major of which is biomass. Among others the Plan envisages the following measures:

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http://zakon1.rada.gov.ua/laws/show/575/97-%D0%B2%D1%80

[23] Exchange rate: 1 EUR = 25.39 UAH (as of 7 April 2015).

[24] Resolution N 293 of 09.07.2014 (with amendments).

[25] Resolution N 453 of 10.09.2014.

[26] Approved by Resolution of CMU N 1014-p of 16.10.

- The state will partly cover credits raised by entities for purchasing energy-saving equipment including heat-generating equipment running on any fuel except for NG (2015-2017).
- The state will partly cover credits raised by population for purchasing energy-efficient equipment and materials (2015-2017).
- The state will provide guarantee of credits raised by entities for the implementation of projects aimed at reduction or replacement of NG consumption (2015-2017).
- Definition of "biomass" in Ukrainian legislation will be harmonized with that in the European Directive 2009/28/EC.
- Technical specifications for the admission of biomethane into Ukraine's gas-transport system will be elaborated; stimulating mechanisms for the production and consumption of biomethane will be developed.

An important draft law **"On amending the Law of Ukraine "On Heat Supply" as for encouraging heat production from alternative energy sources"** (N 4334 of 30.03.2016) was adopted in the first reading on 22.09.2016. The core of the draft law is that heat tariff for alternative fuels (including biomass) for the consumers financed from the state and local budgets and also for population is fixed at 90% of the existing heat tariff for natural gas. As a result, biomass plants will be more profitable than they are now.

### *Biofuels*

There are some support instruments for the producers and consumers of biofuels in Ukraine. The instruments are mainly in the form of tax benefits determined by the **Tax Code**[27]. Regarding the agricultural residues in question, the problem lies in the definition of "biofuel" and "producer of biofuel" that is given by the Law "**On Alternative Fuel Types**"[28]. The Law defines *biofuel* as a solid, liquid and gaseous fuel, which is produced from biologically renewable feedstock (biomass) and may be used as a fuel or component of other fuels. According to the definition, stalks of maize and sunflower, maize cobs and sunflower heads are not considered to be biofuel as they are not "produced" from biomass. An unclear question is whether straw bales may be considered biofuel. The same applies to the concept of "producer of biofuel". The Law defines *producer of biofuel* as an entity that directly produces biofuel from biomass. So, it is still unclear whether producers and consumers of baled straw as a fuel can claim the tax benefits envisaged by Ukrainian legislation.

### *Development of RES sector*

A general document that sets targets for RES (including biomass) by 2020 within Ukraine's commitments as a member of the Energy Community is the **National Renewable Energy Action Plan** (NREAP) (2014)[29]. According to the Action Plan, the share of RES in the gross final energy consumption in Ukraine must be 11% in 2020 including 12.4% in heating/cooling systems, 11% in power industry and 10% in transport. A big contribution to the targets is expected to be at the expense of biomass. For example, the share of biomass in the RE heating/cooling in 2020 is planned to be 85% that is about 11% of the total heat consumption. The share of power from biomass is supposed to be 16% of the total RE power in 2020 that is

[27] The Tax Code of Ukraine (approved by Law N 2755-VI of 02.12.2010 with amendments)
[28] The Law "On Alternative Fuel Types" (N 1391-XIV of 14.01.2000 with amendments)
[29] Approved by Resolution of CMU N 902-p of 01.10.2014.

about 2% of the total power consumption. The contribution of biofuels to all RES in transport in 2020 is expected to be 77%. NREAP is accompanied with respected *Activity Plan* for its implementation.

Within the general process of European integration, Ukraine adopted **Action Plan for the implementation of Directive 2009/28/EU**[30] (2014). The Plan includes 17 actions, one of which is the elaboration of sustainability criteria for liquid and gaseous biofuels destined for transport and for energy production (until 30 December 2014). Another important action is providing equal rights for producers of biogas with regard to connection to the integrated gas-transport system of Ukraine (until 30 December 2017). It is also planned to develop recommendations for the use of RES in new DH systems. It should be noted that the items of the Action Plan are being implemented with a considerable delay. For example, development of sustainability criteria for liquid and gaseous biofuels started only a few months ago and is in good progress at present.

[30] Approved by Resolution of CMU N 791-p of 03.09.2014.

## 4. Cost assessment

Production of solid biofuels like biomass pellets is a fast developing and very prospective sector of Ukrainian bioenergy. It has grown rapidly during past 5-6 years. At the beginning the main feedstock was wood, then it turned to sunflower, and since 2010 straw has also been used as feedstock for the production of pellets and briquettes. According to the latest available data (2013)[31], production volumes of solid biofuels were: wood pellets – 260 kt, sunflower husk pellets – 900 kt, straw pellets – 50 kt. Before 2013, the lion share of solid biofuels (up to 90%) was exported, mainly to European countries. Then the situation began gradually changing towards some bigger use of the biofuels in the domestic market. That was connected with some problems of exporting to Poland (as the country abolished its green certificates scheme for biomass used at CHP plants) and a growing demand for biomass as a substitute of natural gas in Ukraine. In 2015 Poland is resuming the introduction of an improved version of the green certificates scheme and the exports of solid biofuels to Poland are gradually growing again[32]. Probably it finally will result in some reasonable balance between the export and internal use of the solid biofuels produced in Ukraine.

Main technical and economic parameters of the production of straw pellets are presented in **Table 4.1.** Structure of the production cost is shown in **Fig. 4.1**. It can be seen that over 50% of the production cost is feedstock cost. This is an important fact as biomass market is not well developed in Ukraine yet and often finding a reliable supplier with a reasonable price of feedstock is the crucial issue of the whole business. Another ponderable part of the production cost is electric power cost. It is also important as electricity prices have been rising in Ukraine lately and general tendency is that they should reach the market level. Other components of the production cost are comparatively small.

**Table 4.1.** Main technical and economic parameters of the production of straw pellets

| | |
|---|---|
| Production capacity | 4 t/hr (about 17 kt/yr) |
| Capital costs, EUR | 997 582 |
| *including*:<br>- equipment<br>- premises | <br>595 674<br>276 425 |
| Operating costs, EUR/yr | 1 141 228 |
| *including*:<br>- feedstock<br>- materials, spare parts<br>- electric power<br>- package<br>- depreciation | <br>637 814 (at the price of straw of 34 EUR/t)<br>93 804<br>172 687<br>51 840<br>74 448 |
| **Production cost, EUR** | **66** |
| **Price including VAT, EUR** | **87** |

[31] Viktor Andriyenko. Ukrainian market of solid biofuels. Structure, trends, prospects. Presentation at 9th International Conference on Biomass for Energy, 24-25 September 2013, Kyiv, Ukraine.

[32] Information regarding Poland was obtained via phone consultation with Mykola Kolomyichenko, Head of Ukrainian Pellet Union.

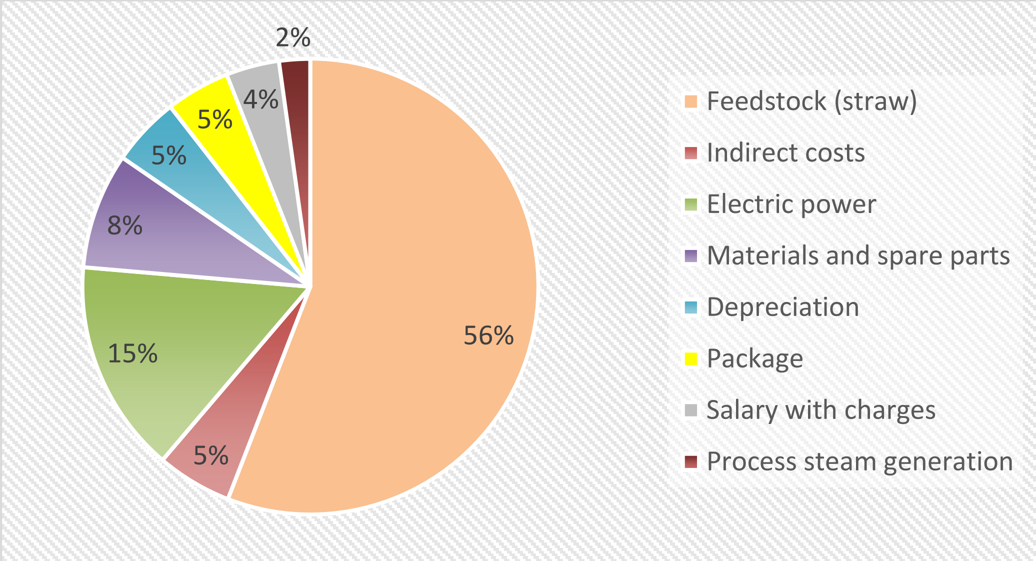


**Fig. 4.1.** Structure of the production cost of straw pellets

The same data for wood pellets are presented below. One can see that principal structure of wood pellets production costs is similar to that of straw pellets. The main difference is that the share of feedstock cost is a bit less (48%) and there is additional component, namely fuel for dryer. Production costs and prices of straw pellets and wood pellets are close to each other, the ones for straw being a bit higher.

**Table 4.2.** Main technical and economic parameters of the production of wood pellets

| | |
|---|---|
| Production capacity | 4 t/hr (about 17 kt/yr) |
| Capital costs, EUR | 338 610 |
| *including*:<br>- equipment<br>- premises | <br>176 594<br>88 062 |
| Operating costs, EUR/yr | 1 069 753 |
| *including*:<br>- feedstock<br>- drying of feedstock<br>- materials, spare parts<br>- electric power<br>- package<br>- depreciation | <br>508 258 (at the price of wood of 19 EUR/t)<br>67 832<br>93 804<br>255 331<br>51 840<br>19 058 |
| **Production cost, EUR** | **62** |
| **Price including VAT, EUR** | **82** |

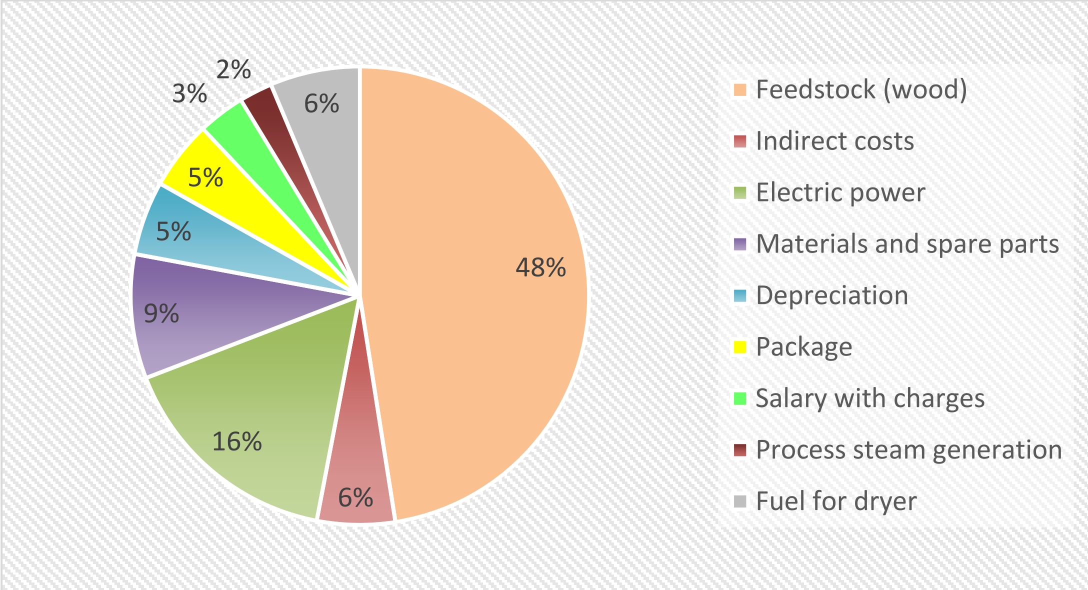


**Fig. 4.2.** Structure of the production cost of wood pellets

## Annex 1

**Table A.1. Technical/sustainable potential of agricultural biomass in Ukraine, ktoe (2013)**

| Country, regions | Straw of cereals | Straw of rapeseed | Maize residues | Sunflower residues | TOTAL |
|---|---|---|---|---|---|
| **Ukraine** | **3178.5** | **586.9** | **3071** | **1202.4** | **8039** |
| *Regions:* | | | | | |
| Crimea | 66.1 | 4.1 | 8.7 | 11.9 | **91** |
| Vinnytska | 205.0 | 61.1 | 362.3 | 55.1 | **683** |
| Volynska | 73.6 | 33.6 | 17.3 | 0.3 | **125** |
| Dnipropetrovska | 237.2 | 40.6 | 130.7 | 127.6 | **536** |
| Donetska | 182.8 | 3.5 | 35.6 | 84.8 | **307** |
| Zhytomyrska | 54.6 | 16.1 | 155.2 | 11.3 | **237** |
| Zakarpatska | 14.0 | 0.4 | 18.7 | 1.1 | **34** |
| Zaporizka | 201.2 | 17.9 | 17.3 | 100.4 | **337** |
| Ivano-Frankivska | 32.6 | 16.1 | 34.6 | 2.2 | **86** |
| Kyivska | 116.0 | 28.8 | 214.4 | 32.3 | **391** |
| Kirovohradska | 159.4 | 31.4 | 214.0 | 133.6 | **538** |
| Luhanska | 95.7 | 0.5 | 34.2 | 69.4 | **200** |
| Lvivska | 79.7 | 38.3 | 39.1 | 4.6 | **157** |
| Mykolaivska | 199.5 | 24.3 | 72.9 | 102.4 | **399** |
| Odeska | 275.0 | 48.9 | 80.1 | 84.6 | **489** |
| Poltavska | 155.1 | 12.1 | 405.4 | 79.4 | **652** |
| Rivnenska | 58.7 | 16.0 | 50.4 | 0.4 | **126** |
| Sumska | 118.6 | 17.5 | 240.2 | 45.6 | **422** |
| Ternopilska | 100.4 | 39.0 | 119.3 | 3.3 | **262** |
| Kharkivska | 260.6 | 7.9 | 159.5 | 121.7 | **550** |
| Khersonska | 129.3 | 24.9 | 37.1 | 38.8 | **230** |
| Khmelnytska | 119.6 | 44.3 | 181.2 | 8.0 | **353** |
| Cherkaska | 140.0 | 43.8 | 264.7 | 53.1 | **502** |
| Chernivetska | 21.7 | 7.5 | 40.5 | 1.8 | **71** |
| Chernihivska | 88.5 | 22.8 | 223.7 | 31.2 | **366** |

**Table A.2. Technical/sustainable potential of wood biomass in Ukraine, ktoe (2013)**

| Country, regions | Felling residues | Wood waste | Firewood | TOTAL |
|---|---|---|---|---|
| **Ukraine** | **271** | **209** | **898** | **1378** |
| *Regions:* | | | | |
| Crimea | 1.0 | 0.5 | 9.4 | **10.9** |
| Vinnytska | 10.2 | 2.0 | 30.2 | **42.3** |
| Volynska | 15.4 | 10.4 | 21.3 | **47.1** |
| Dnipropetrovska | 1.1 | 2.6 | 7.2 | **10.9** |
| Donetska | 1.1 | 5.9 | 8.5 | **15.6** |
| Zhytomyrska | 43.4 | 19.0 | 126.2 | **188.6** |
| Zakarpatska | 17.9 | 6.0 | 68.7 | **92.6** |
| Zaporizka | 0.4 | 5.5 | 4.2 | **10.1** |
| Ivano-Frankivska | 16.7 | 28.9 | 37.2 | **82.8** |
| Kyivska | 24.8 | 3.3 | 85.0 | **113.1** |
| Kirovohradska | 2.8 | 2.7 | 2.4 | **8.0** |
| Luhanska | 2.8 | 3.2 | 15.9 | **21.9** |
| Lvivska | 19.1 | 16.5 | 67.5 | **103.0** |
| Mykolaivska | 0.5 | 0.5 | 4.8 | **5.8** |
| Odeska | 1.4 | 0.7 | 13.0 | **15.1** |
| Poltavska | 6.3 | 2.2 | 13.3 | **21.9** |
| Rivnenska | 24.3 | 69.9 | 40.0 | **134.3** |
| Sumska | 15.5 | 11.3 | 57.2 | **83.9** |
| Ternopilska | 4.1 | 1.2 | 10.1 | **15.4** |
| Kharkivska | 6.1 | 2.6 | 18.0 | **26.8** |
| Khersonska | 2.0 | 0.2 | 20.2 | **22.3** |
| Khmelnytska | 9.0 | 0.4 | 44.0 | **53.4** |
| Cherkaska | 9.3 | 3.1 | 7.9 | **20.3** |
| Chernivetska | 14.3 | 4.7 | 58.1 | **77.0** |
| Chernihivska | 22.0 | 7.1 | 59.4 | **88.5** |

**Table A.3. Technical/sustainable potential of energy crops in Ukraine, ktoe (2013)**

| Country, regions | Unused arable land (total), 1000 ha | Area under energy crops (possible), 1000 ha | Energy crops for solid biofuels, ktoe | Energy crops for biogas, ktoe | TOTAL, ktoe |
|---|---|---|---|---|---|
| **Ukraine** | **3216** | **2000** | **4.4** | **2.6** | **7.0** |
| *Regions:* | | | | | |
| Crimea | 443 | 220 | 482 | 255 | **737** |
| Vinnytska | 88.6 | 50 | 94 | 58 | **152** |
| Volynska | 144.8 | 85 | 197 | 98 | **296** |
| Dnipropetrovska | 90.9 | 65 | 123 | 75 | **198** |
| Donetska | 52.7 | 35 | 77 | 41 | **118** |
| Zhytomyrska | 289.2 | 210 | 487 | 243 | **730** |
| Zakarpatska | 5.4 | 3 | 6 | 3 | **9** |
| Zaporizka | 163.7 | 110 | 241 | 127 | **368** |
| Ivano-Frankivska | 32.1 | 25 | 58 | 29 | **87** |
| Kyivska | 192.5 | 120 | 278 | 139 | **417** |
| Kirovohradska | 32.5 | 20 | 38 | 23 | **61** |
| Luhanska | 173.9 | 110 | 241 | 127 | **368** |
| Lvivska | 172.0 | 110 | 255 | 127 | **382** |
| Mykolaivska | 87.9 | 60 | 113 | 69 | **182** |
| Odeska | 154.7 | 100 | 201 | 116 | **317** |
| Poltavska | 30.5 | 25 | 58 | 29 | **87** |
| Rivnenska | 116.3 | 80 | 186 | 93 | **279** |
| Sumska | 112.7 | 75 | 174 | 87 | **261** |
| Ternopilska | 55.8 | 30 | 66 | 35 | **101** |
| Kharkivska | 108.8 | 70 | 153 | 81 | **234** |
| Khersonska | 213.8 | 130 | 245 | 151 | **396** |
| Khmelnytska | 105.8 | 65 | 123 | 75 | **198** |
| Cherkaska | 62.3 | 35 | 77 | 41 | **117** |
| Chernivetska | 21.4 | 10 | 23 | 12 | **35** |
| Chernihivska | 253.6 | 157 | 364 | 182 | **546** |