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SUSTAINABLE RAW MATERIALS SUPPLY OF LIGNOCELLULOSIC BIOFUELS IN HUNGARY

D. SZALAY[1*] – A. VÁGVÖLGYI[1] – I. CZUPY[1] –
SZ. KERTÉSZ[2] – S. BESZÉDES – C. HODÚR[2] – V. PAPP[1]

[1]*Institute of Forest and Environmental Techniques*
Faculty of Forestry, University of Sopron
[2]*Department of Process Engineering, Faculty of Engineering, University of Szeged*
**szalay.dora@uni-sopron.hu*

Abstract: The current publication summarizes the main results of the lignocellulosic biofuel research carried out within the project *Sustainable Raw Material Management Thematic Network – RING 2017*. In the first part of the paper, we explore the different type of currently available biomass residues potential and summarized for each Hungarian county. In the next part, we identify the main factors that significantly influence the sustainable raw material supply of a lignocellulosic biofuel production plant and investigate the additional feedstocks, which may be useable in the future. The results show a large amount of available biomass residues with more than 330 PJ energy potential. Particularly, the amount of generated agroresidues is outstanding, almost half of which can be used for energy production. However, the collection, storage and utilization for biofuel production of agroresidues is less developed than for woody material.

Keywords: *lignocellulosic biofuel research, biomass, dendromass,*

1. INTRODUCTION

Biofuels have a key role to play in combating climate change in the future through lowering greenhouse gas emissions. The prescribed biofuel ratio target values for member states of the EU is also encouraging the application of biofuel blends. According to the RED II (Renewable Energy Directive II) regulation, member states will have to meet targets of 14% renewable energy use in road and rail transport by 2030. At the same time, decision-makers have recognized that crop-based biofuels encroach upon land used for food crop production through indirect land use. According to estimates, the land area used for growing biofuel feedstock in 2018 covered about 5% of the total crop area [1]. The growing areas for corn, sugar cane, or palm were enlarged through the conversion of rainforests and grasslands. This has reduced the net carbon dioxide absorption capacity and increased emissions. Droughts, forest fires, biotic and abiotic damage are becoming more frequent as a result of the changing climate. Carbon stored in forest biomass is released and contributes to climate change.

The occasional yield loss of conventional biofuel raw materials is already a problem today. A doubling of cereal consumption for food and animal feed due to population growth and changes in consumption structure in the 21st century only adds to this problem [2]. The intensified application of mechanical soil cultivation technology with irrigation and the vast use of fertilizers has made the satisfaction of cumulative demands possible. However, fertilizer production is an energy-intensive industry [3]. For these reasons, the EU legislation restricts the use of food crops for energy purposes. The maximum contribution of conventional biofuels will be frozen at 2020 consumption levels, plus an additional 1% with a maximum cap of 7% of road transport fuel in each member state. The proportion of advanced fuels to be achieved must grow gradually and its proportion was set at least 3.5% by 2030. With the help of lignocellulosic biofuels there is an opportunity to meet the target.

Commercial-scale production of lignocellulosic biofuels from forestry and agricultural by-products is under development, and its increased use in transport sector will be viable in the near future [8]. The use of wood industry by-products is already largely realized today.

The conversion of lignocellulosic feedstock to liquid biofuels requires much more complex technology than first generation biofuels. Overall, conversion rates and production capacity are lower, but the investment cost can be up to ten times higher compared to advanced biofuels [4]. To achieve a sustainable raw materials supply for the planned expansion, an extensive raw material analysis is absolutely necessary.

2. METHODS

The following methodology was used to calculate the available raw material potential reserves. As a starting point for calculations of forest residue amounts, we used Hungary's wood use data from the compilation of Statistical Mirror in 2013, "Features of Forest Management", by the Hungarian Central Statistical Office (KSH) [5]. Subsequently, this logging data was updated from the 2016 Forest Balance Sheet and created the gross volume of timber harvested per county per tree species. The by-product volume is worth an average of 17% relative to the gross volume of timber produced. The data were retrieved in a humid state while 50% moisture content was assumed. When cubic meters were converted to metric tons, the wood weight ratio of the species harvested by clear cutting in the country based on the 2016 forest balance sheet data was considered and multiplied by the density values specific to the tree species.

National wood use data as described for forest residues were calculated to estimate the stump and root amount. Larger quantities of stumps can only be technically harvested in areas where clear-cutting has been executed within the end use. However, stumping and subsequent rotational soil preparation are limited to flat or slightly undulating surfaces and can only be performed on some genetic soil types, e.g. sandy soil [6]. Therefore, it mostly takes place with black locust, poplar, and pine as characteristic tree species. After that, the black locust, poplar, and forest pine areas were determined according to the table of the NÉBIH Forest Inventory by Tree Species Group and the Current Forest Association Group, followed by the gross volume count of these trees. Root stump logs account for 15–25% of the aboveground tree mass for black locust and up to 10–20% for poplar and pine [6].

The potential estimation of grape and fruit tree areas was derived from the Hungarian Central Statistical Office (KSH) 2017 Land by Field Cultivation Table [7]. According to the methodology of the Statistical Office, grape-growing areas producing propagating material are also included. Vineyards produce about 1–2.5 tons of pruning residues per hectare per year, with an average of annual 1.5 t/ha. Fruit tree thinning produces a smaller amount of prunings annually, with larger amounts every 4-5 years; on average, we can count on 2.5 t/ha per year. Since the by-products can only be cost-effectively collected in vineyards with larger contiguous areas, only vineyards above 3 ha were taken into account during the calculation. The breakdown by size categories made in 2005 and 2007 Census of Vine and Fruit Plantations was used for the calculations.

Since woody energy plantations are also a potential lignocellulosic biofuel feedstock, we conducted a survey of these as well. The survey was based on the area data collected by the Forestry Directorate of the NÉBIH in 2018. Furthermore, we used the average yearly yields for the calculations.
Table 1 summarizes the characteristics of dendromass feedstock.

Table 1

Features of dendromass base materials [8, 9]

Type of by-product	Generated by-product [t/ha or %]	Heating value (at w% 15−20) [MJ/kg]
Forest residues	12%	14−15
Grape pruning	1.5 t/ha	14.5−15
Orchard residues	2.5 t/ha	14.5−15.5
Woody energy plantations	10 t_{dry}/ha	18

For comparison, the by-products of arable herbaceous plant production have also been surveyed. Hungary has a great deal of arable land due to favorable weather conditions; the volume of agricultural residues in the country is remarkable. Calculations were completed by determining the harvested area of different agricultural crops based on KSH 2018 data tables. Area size changes every year due to crop rotation. As a result, five-year averages (2013–2017) were considered. By-product mass determination was possible using KSH 2018 main product yield data. We also considered 5-year averages here due to crop yield fluctuations. Data in the literature on the main product ratio (seed:stem ratio) to the by-product were collected and used to determine the residue amounts. *Table 2* summarizes these data.

Using formulas (1) and (2) the determination of the theoretical and energetical biomass potential is possible.

Table 2

Features of by-products of herbaceous plants [10, 11, 12, 13, 14, 15, 16]

Type of stem, stalk	**Seed:stem ratio**	**Heating value at harvest [GJ/t]**	**Moisture content at harvest [%]**
Corn stem	1 : 1.5	12	30–40
Wheat straw	1 : 1.2	13	10–15
Barley straw	1 : 1.2–1 : 1.5	13	15–20
Rye straw	1 : 1.8	13	15–20
Oat straw	1 : 1.3	13	15–20
Triticale straw	1 : 1.2	13	15–20
Sunflower stem	1 : 2	14	25–35
Rape seed straw	1 : 1.4	14	15–20

Theoretical biomass potential:

The energy potential of the amount of studied annually generated biomass.

Forest residues per county:

$$E_{ei\,for} = \frac{V_{br} * a * k * F}{10^6} \tag{1}$$

where:
$E_{ei\ for}$ – theoretical annual energy potential of forest residues in a county (PJ/yr)
i – county (i=1 to i=20)[1]
V_{br} – gross volume of wood use in the county (m^3/yr)
a – crop yield relative to main product (~17%)
k – average multiplication factor at m^3 to metric ton conversion (national ave. approx. 0.6 for dry wood)
F– calorific value of the residues (MJ/kg).

Agricultural residues per county:

$$E_{ei\,agr} = \frac{\sum_n T_n f_n m_n F_n}{10^6} \tag{2}$$

where:
$E_{ei\ agr}$ – theoretical annual energy potential of agricultural residues in a county (PJ/yr)
i – county (i=1 to i=20)
T_n – 5-year average of the growing area of the plant type “n” (ha)
f_n – 5-year average yield of the main product of the plant type “n” (t/ha*yr)

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[1] Hungary has 19 counties plus the capital city of Budapest, which is counted here as a county.

m_n – ratio of the yield of the by-product to the main product of the plant type "n"
F_n – calorific value of the by-product of the plant type "n" (MJ/kg).

Gross energy potential of biomass residues in Hungary per county (PJ/yr):

$$E_i = \Sigma\, E_{ei\,for.} + \Sigma\, E_{ei\,agr} \tag{3}$$

Energetical biomass potential

This is the amount of biomass that can be used for energy purposes. To determine this value, we considered the various sustainability, environmental and technical interests, as well as the biomass amounts potential users requires.

In the case of forestry residues, larger quantities of raw material can only be cost-effectively collected in areas practicing clear-cutting within end use. According to the KSH OSAP 1254 data collection, the use of clear cutting occurred in 47% of the total national harvested gross timber volume in 2016 [19]. Only the 3–7 cm thin wood parts from end uses felling can be harvested technically and ecologically, which represents 12% of the total wood weight [6].

In the case of agricultural residues, it would be optimal to return 20–30% of the stem mass to the soil for soil fertilizing [17, 18]. We also determined the average amount of straw used for animal litter per year based on the data from the literature and from the number of Hungarian livestock recorded by KSH *(Table 3)*.

We summarized the biomass demand of currently operating users and potential users (those planning to become users) through the collection of data in the literature and electronically-available data from the website of the companies.

Table 3

Specific straw needs for bedding [20]

Farm animals	**Straw needs for bedding**	
	[kg/head/day]	**[kg/head/year]**
Cattle	3.8	1,400
Sow	1.4	511
Sheep	1.1	220
Poultry	–	3.3

3. RESULTS

3.1. Residues potential

Based on the calculation methods given in the methodology, the nationally generated theoretical annual potential of biomass by-products is shown in *Table 4.*

Table 4
Theoretical annual biomass potential in Hungary [8, 21]

Type of biomass	**Amount (dry) [1000 t]**	**Energy [PJ]**
Forest residue	1,000	11.0
Stump	160	1.8
Fruit tree pruning	165	2.6
Vineyard pruning	57	1.0
Agricultural herbaceous residue (stalk, stem)	22,700	314.0
Short rotation coppice (SRC)	4.4	0.08

3.1.1. Forest residues and stumps

Almost 1 million metric tons of forest residues, calculated in the wet state at the harvest, are generated annually, in theory. Within this figure, about 700,000 tons can be collected, once technical, ecological and economical aspects are taken into account. Roughly 7.7 PJ of energy can be gained through forest residue utilization. Stump amounts are only an additional available potential from forestry. This technology can be mainly used in Somogy, Szabolcs-Szatmár-Bereg, Bács-Kiskun, Pest and Hajdú-Bihar Counties. It is worth mentioning that the annual yield of black locust, poplar, and pine has shown a slight increase over the last five years, but the biomass of root and stump is technically unusable so far.

3.1.2. Orchards, vineyards

According to our survey, the amount of collectable fruit tree prunings is about 165,000 tons annually, which would provide 2.6 PJ of usable energy. In vineyards, 57,000 thousand tons of prunings can be realistically collected, which equals nearly 1 PJ of energy.

3.1.3. Agricultural residues

Corn is the most cultivated crop in Hungary, with a cultivation area of about 1.1 million hectares. This is followed by wheat with 1 million hectares, and sunflower with a cultivation area of 625,000 hectares. According to our calculations, corn production generates more than 11 million tons of by-products in Hungary annually. The amount of wheat straw is also large; on average more than 6 million tons every year. Sunflower stalks amount to 3.3 million tons, while the amount of rapeseed stalks is just over 1 million tons per year. The quantity of barley straw is also significant, around 1.4 million tons per year.

3.1.4 Short rotation coppice

In Hungary, energy plantations are worth mentioning, primarily with regard to woody plantations. However, energy plantation size is not significant when compared to Western European countries. According to 2019 NÉBIH Forestry Directory data, energy plantations in Hungary occupy a total of 4351 ha, of which about 80% is cultivated with poplar due to the suitability of the species in the available areas. Miscanthus plantations only comprise about 360 ha in the country [22].

3.2. Impact of climate change on collectable raw material

Future indirect effects of climate change will increase biotic and abiotic damage. The number of forest pests is forecast to grow due to average annual temperature increases and warmer winters [26]. Most intense forms of damage have occurred in the last 20 years. Moreover, this damage has generally accumulated over the past 10 years [26]. Therefore, in our previous research study we began focusing on forest damage-induced logging, which will affect the useable amount of raw materials for energy recovery in the future [23]. In agriculture harmful effects can be eliminated in a relatively short time period with the help of appropriate agrotechnical methods, while in forestry this is only possible over a longer time frame and only through appropriate tree species choices.

Drought and favorable periods for crop production have a strong impact also on the amount of agricultural by-products generated. Based on KSH data, 2012 was one of the worst drought years of the last decade, and we took this year into account in our research. According to yields, the most favorable weather occurred in 2016. The generated amount of by-products that could be harvested annually nationwide in these two years is compared to the average of 2013–2017 and shown in *Table 5*.

Table 5

Change in the theoretical amount of by-products annually [8]

	National data	**2012 “worst year”**	**2016 “favorable year”**	**2013–2017 “average”**
Corn	growing area [ha]	1,191,291	1,011,563	1,115,955
	average crop yield [t/ha]	4.0	8.6	6.9
	harvestable stalk [t]	**7,147,746**	**13,049,162**	**11,550,134**
Sunflower	growing area [ha]	615,097	629,675	625,488
	average crop yield [t/ha]	2.1	3.0	2.7
	harvestable stalk [t]	**2,583,407**	**3,778,050**	**3,377,635**
Rapeseed	growing area [ha]	164,916	256,679	238,346
	average crop yield [t/ha]	2.5	3.6	3.0
	harvestable stalk	**577,206**	**1,293,662**	**1,001,053**

The amount of rapeseed stalk showed the biggest difference, but this was mainly due to the changing size of harvested area. Crop yield loss per hectare was 30% in 2012 compared to the most favorable year, while in the case of rapeseed stalk, less than half could be collected. Of the examined cereals, corn had the largest yield fluctuation. Less than half of the corn crop and corn stalk could be collected in the worst year compared to the favorable year. The fluctuation is the smallest in the case of sunflower, and there is no significant difference in the harvested area or yields. However, it should be mentioned that only a weak-medium correlation can be detected between the yield of main products and by-products n recent years, which can impair the accuracy of the survey [24].

In addition to the quantitative change caused by climate change, agroresidues are also affected by plant breeding methods *(Figure 1)*. The plant breeding methods have an important role influencing the long-term energy strategies through of the amount of generated biomass.

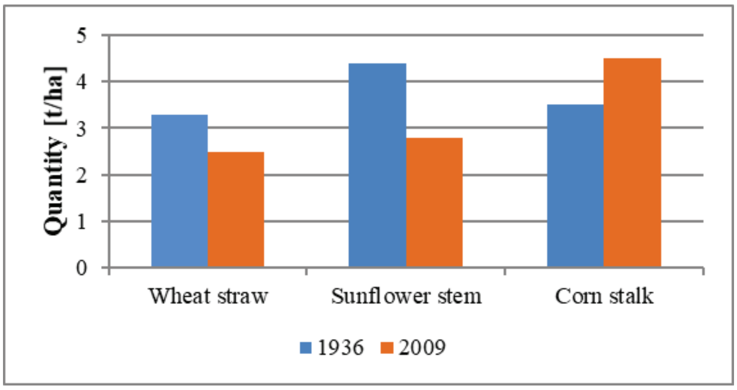

Figure 1
Changes in straw and stem specific quantities due to plant breeding activities [26]

In terms of raw material supply, woody energy plantations can be an additional solution for lignocellulosic biofuel plants, which can be successfully grown even in low-quality agricultural areas. Energy plantations can be much better protected against biotic and abiotic damage. Unfortunately, dry summers represent a high risk, especially in planting years. Up to 50% of shoots planted during dry summers do not sprout and need to be replaced. The expected yield is also far from optimal, since drought inhibits photosynthesis; leaves become smaller; shoots become elongated; leaves untimely wilt and fall; and peak dehydration may occur [27].

The frequency of persistently cold winters is decreasing. Nevertheless, their episodic occurrence in Hungary should be taken into account even with a slightly warmer global climate. In principle, frosts in April–May and September–October will become less frequent, but as the growing season lengthens, the risky periods will also shift towards the cold season. Early frosts shorten the vegetation period, thereby inhibiting the “ripening” of wood [27]. Late spring frost can cause severe damage to some poplar clones; their shoots often die completely. This poses a particular risk to clones originating from less frigid regions [27] *(Figure 2)*. The photos of two different poplar clones were taken in the same area, at the same time. The variety on the left with mostly dead shoots is highly sensitive to spring frost. The plant emerges much later, produces a lower number of shoots, and results in a lower yield at harvest. The poplar variety shown in the picture on the right is not sensitive to late spring frost. Breeding and tree species selection as well as choosing varieties according to the given climatic and soil conditions are of great importance during planting.

Figure 2
Effect of spring frost on different poplar clones [8]

Figure 3 illustrates the yield differences of the different poplar clones under the same climatic and soil conditions.

The annual change in precipitation based on climate scenarios is expected to be characterized by a slightly negative trend in Hungary by 2100. About 90% of the country’s territory is at risk of drought. Drought can change the mechanical properties, the chemical composition of soil, organisms within soils and the wildlife of a plantation over time. In addition to the decrease in soil moisture, a drier climate may also lead to a drop in the groundwater level. This causes a greater decline in yields, especially in summer energy plantations. In addition to direct climatic effects, indirect effects such as plant diseases and pests may also occur. For this reason, it is important to choose the right tree species.

Increasing CO_2 emissions from burning fossil fuels has a fertilizing effect on most plants because CO_2 is a component of photosynthesis. Experiments on the effects of enriched atmospheric CO_2 on plants have been completed in several cases around the world. Based on their results, the mass of aboveground woody biomass may rise by up to 25–38% due to increasing photosynthesis. This may change the mass ratio of plant components, e.g. the mass of leaf, stem, and root system. On the other hand, plant stock characteristics also change due to altered conditions. For example, plant biomass increases, plant stocking density increases, water utilization improves, and the C:N ratio changes, all of which also affects the infectious characteristics of pathogens and the nutritional characteristics of animal pests. However, the beneficial effect can only be achieved if the necessary water supply is available.

Figure 3
Height difference of two different poplar clones with the same environmental and soil conditions [8]

3.3. Utilized residues by main potential users

An important part of the base material survey is the examination of the current operating and planned potential users. Forest and agricultural by-products are only partially collected, and are most often sold to power plants, perhaps to a smaller extent to heating plants, boilers, and pellet and briquette factories.

3.3.1. Dendromass utilization

Different information is available on the currently used quantities because the largest collectors and purchasers obtain some of their by-products from forests in other countries. According to the literature, about 4.5% of the thin wood part of the collectable forest residues is utilized [6].

Pécs Power Plant is the largest forestry residue utilizer in Hungary. Smaller amounts are utilized in the cities of Pornóapáti, Hangony, Csitár-Nógrádgárdony, Mátészalka, Szakoly, Miskolc, Pannonhalma, Homrogd, and Szombathely. In Tiszaújváros, forestry residues are used for wood pellet production. In addition, a common form of forest residue utilization today is collection by local people for their personal use. In the Kiskunság Forestry and Wood Processing Co. (KEFAG) area, for example, the local population harvests 3,000–4,000 m^3 of tree branches to obtain cheap fuel for own energy needs. An additional 10,000 m^3 of logging waste collection is done mechanically.

Tree stumps offer further potential from forest management. There have been attempts to utilize stumps in the country (Pécs, Szakoly), but this is not typical due to challenges with harvesting and burning. Furthermore, the presence of a significant amount of bark and contamination causes problems during biofuel production; hence, we did not include it as a potentially useable base material.

The main users of forestry and woody by-products are pellet and briquette manufacturers. Their number has been rising steadily due to significant export demand. Exports make up about 70% of the total Hungarian production. At the same time, pellet production is largely restrained by the cheap inflow of pellets from Ukraine. The utilization of raw materials is usually done with bark-free by-products in a mixture. Of the larger manufacturers, forest residues are utilized by the Eko Fire Pellet Ltd. in Tiszaújváros, for example.

There are several paper mills in Hungary. Most of their raw material is derived from forests that have been deliberately planted for industrial use. The mills also manufacture products from waste paper. As in Hungary, the global wood-based panel industry primarily uses low quality wood resources and turns them into value-added products. One of the forms of using by-products from forestry and the wood industry is chipboard manufacturing. Falco Zrt. in Szombathely is the best-known chipboard manufacturing plant in Hungary. Furthermore, the Swiss Crono OSB factory in Vásárosnamény started operations in 2016. Veneer sheet production (e.g. Derula Kft. in Szolnok) mainly uses poplar logs, which are produced on industrial plantations. In this process the by-products are not used [29].

Upcoming projects may also modify the available raw material. Mátra Power Plant (Visonta) recently received a permit for the construction of a mixed-fueled (Refuse-derived fuel RDF 75.2% and biomass 24.8%) power plant in Halmajug. This is expected to amount to 84,836 t of BIOMIX per year. About 30% of this is stem and straw, 15% is forest and wood by-product, and the remainder is biomass from food processing. The 49.9 MW wood chip-fired block at Pécs utilizes 400,000 tons of woody biomass each year – mostly residues from forestry and sawmills including wood chips and sawdust, but also sunflower shells. However, by the end of November, about a quarter of the fuel used in the woodchip block may be replaced by the so-called “Mecsek mix”. This product contains commercially available quality-assured fuel biomass and pre-sorted PVC-free plastics, paper, and textiles from Pécs and its surroundings [28].

Despite the cost-effective 50 km transport distance of wood chips, raw material can also arrive at the larger power plants from even longer distances. This implies neighboring counties, and they can, in fact, become potential raw material suppliers.

3.3.2. Agricultural residues (stalk, stem) utilization

Corn stalks represent the largest quantity of agricultural residues. Currently, the most common way of utilizing corn stalks is to simply plow them into the soil, which is done to approx. 93-94% of the stalks [30]. However, large amounts of lignocellulose should not be returned the soil because it launches a pentosane effect (cellulose effect). Optimal values for straw and stem quantities used for soil improvement vary in the literature, but according to most analyses, 20–40% of stem weight is the best [17, 18, 31]. Large amounts of nitrogen fertilizer are needed to avoid cellulose effects; this would significantly increase costs and environmental hazards. From an ecological perspective, we calculated with a max. 50% useable amount together with technical losses.

The utilization of wheat straw in livestock farming is significant. Straw is fed primarily to ruminants, but only in small quantities. Due to its low usable energy concentration, straw cannot replace hay as feed; thus, straw can only be used effectively in small daily doses as supplementary feed. The utilization of by-products as fodder may be higher in drought years if the amount of harvested crop does not meet national needs. However, the amounts used for bedding are significant. According to the calculations described in the methodology, the required amount of litter has increased by 7% in the last two years and by 13% in the last decade. Straw is also utilized in some power plants. The district heating system of Pécs can supply approximately 60% of the region's heat demand, which means 200,000 tons of straw purchased from the local farmers. The Oroszlány Power Plant is capable of burning 100,000 tons of straw annually [32, 33]. The available potential is lower than 1.5 million tons [8].

Rapeseed stem also represents significant quantities of by-products. It can be easily balled; the technology of harvesting is well-known. Its utilization began to be examined during the biodiesel production boom. When mixed with different materials, rapeseed stem could be a valuable raw material for agripellet production [34]. The usable potential of sunflower stems is also significant, but their harvesting is still problematic; therefore, utilization for energy purposes cannot be achieved by current methods.

For the time being, the corn stalk utilization is relatively low. Pécs utilizes about 10,000 tons and the Mátra Power Plant consumes about 100,000 tons of corn stalks. Mátra also uses straw in smaller quantities. Other agricultural by-products are utilized in Szakoly, Szerencs, and Homrogd. The plant in Dorog uses sunflower stems.

As far as potential users are concerned, the biogas plants are mainly based on animal by-products such as manure, animal carcasses, and meat processing industry by-products. A major agricultural products such as silage corn or sugar sorghum silage usually complements these products. It should be emphasized that the whole plant is chopped during the preparation of silage maize, so we did not consider it as a potential raw material in the previous section (3.1.3.). There are only three or four biogas plants utilizing some types of plant stalk or straw, but not to a significant extent.

The annual raw material consumption of agripellet plants in Hungary is not yet significant. In Polgárdi, Vertikál Plc. processes a few hundred tons. In Szentes the amount of annually produced pellets is 3,600 tons/year, which includes wheat, corn and rapeseed stalk. In Agárd-Pálmajor, Agripellet Ltd. produces 4,200 tons of pellets per year, of which rapeseed straw and sunflower husk represent a smaller portion. In addition, straw pellets are produced in smaller quantities in some plants (Jászladány, Vép). In the future, it will be possible to produce torrefication pellets from agricultural by-products, but the technology is not yet widespread [34].

In the neighboring countries, larger biomass recovery plants located near the Hungarian border could be a further source of demand. There is a plan to develop an advanced bioethanol production plant based on agricultural by-products with a capacity of 50,000 tons (63 million L/year) in Leopoldov, Slovakia [35]. It will be located at a distance of 110 km from the border, which can only show an uptake market in drought years, because of the larger collection area due to smaller yield. In October, 2014, Beta Renewables and BioChemtex signed an agreement with Energochemica SE to produce commercial lignocellulose based ethanol from 55,000 tons of wheat straw, rapeseed, and maize stalks in Strazske, also in Slovakia [36]. A demand for raw materials could be manifested, since Strazske is less than 50 km from the border.

A biofuel plant with fermentation technology, which is expected to use wheat and other cereal straw to produce 63 million liters of biofuel per year, is planned for construction in southwestern Romania. However, the realization of this plant is not yet certain.

3.4. Gross energy potential of biomass residues per county

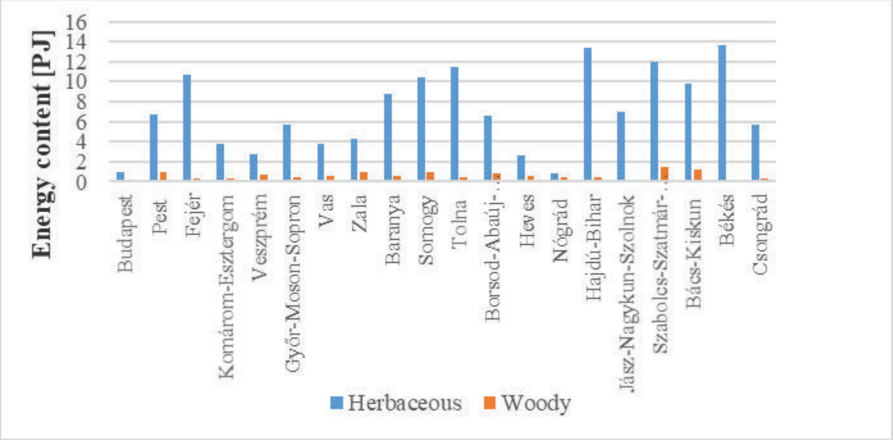

Figure 4
Distribution of energy originated from herbaceous and woody collectable by-products by county [8]

The amount of generated woody and herbaceous by-products were aggregated for each county. *Figure 4* shows the amount of agricultural by-products is dominant and adds up to 92% of the total energy content of potential that can be obtained with its utilization. However, the collection, storage, and utilization of soft-stemmed by-products all are less developed compared to those of woody by-products.

The total energy amount of collectable by-products in Hungary is about 152 PJ.

3.5. Evaluation of raw materials so far not used for energy purposes

Meeting the needs of potential users can be facilitated by planting new woody energy plantations. The 250,000–300,000 hectares of uncultivated land area in Hungary could be well utilized for this purpose. Based on data from the Forestry Directorate of NÉBIH, the creation of energy plantations for energy recovery has been completely absent over the past year. Lack of support and the start of a rival grant F 5 billion tender for the planting of new woody plantations for industrial purposes are the reasons for this. The main priority of support is to promote carbon sequestration in agriculture and forestry. Furthermore, optional additional activities include the establishment of electric fences (4.8 EUR/m) and fences (5.8 EUR/m) if appropriate conditions are met. The smallest eligible area is 0.5 hectares. The requirement for disbursement of support is the sale of more than 50% of the generated dendromass for wood industrial purposes within 20 years; the establishment of woody and short rotation plantations for energy production purposes are ineligible activities.

However, woody industrial plantations also generate large amounts of residues (10%) and bark (15–17%) that can be used for energy purposes. The production of industrial wood is about 70%. According to [39], the average increment of the total wood yield is 27 m^3/ha/year at age 12. Calculating the data reveals that up to 5 t/ha of usable biomass per year can be generated. Approximately 1.0–1.5 t/ha/year of biomass can be used for energy recovery if bark residues are excluded from the calculations. However, if we use 49% of biomass for energy purposes, an additional 5 tons of absolute dry matter becomes available. Besides, we can calculate in the material from pruning, which is generated during the formation of the 6–8 m high branch-clear trunk in the first three years of the plantation.

Agroforestry is an intermediate solution. This can be a highly advanced production method today and is becoming a viable option for land use as it offers many ecological and environmental benefits [40]. Agroforestry is a type of climate-smart agriculture practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems. Through intercropping, the carbon sequestration in trees compared to herbaceous plants occurs in the deeper layers of the soil, due to their deeper root system. Therefore, these cultivation systems are a good tool for increasing carbon sequestration in the agricultural field. In addition, intercropping technology helps to prevent the growing fire risk of dendromass production, especially in southern European countries [41].

Several EU projects are working on extending the amount of raw materials via the agroforestry method. The aim of the AgroCop project is to maximize the production of both high quality timber and wood for energy use by combining the available advantages of agroforestry systems (AFS) and short rotation coppice (SRC) [45]. The AGFORWARD project (2014–2017) aimed to promote agroforestry practices in Europe that will advance sustainable rural development with the active participation of Hungarian partners [46]. The AFINET project is an ongoing project with Hungarian participants (University of Sopron Cooperative Research Centre Non-profit Ltd.) [47].

Another possible raw material is waste wood, which has not been utilized yet due to the problem of surface treatment (except of untreated waste wood for pellet and briquett production). At the same time, research studies from abroad claim the chemicals used for surface treatment can be degraded, thereby enabling use of the material for energy purposes to have low environmental risk [42, 43, 44]. We calculate 0.5–0.7 million m^3/year of wood material from this area in the longer term [38].

4. DISCUSSION

The choice of biofuel feedstock has undergone a strong transformation in the last decade. The range of raw materials that are less dangerous to the food supply but at the same time sustainable has expanded. The advantage is that several types of raw materials can be introduced into the system at the same time with proper construction.

However, based on the described results, it will become increasingly difficult to plan the raw material supply for both food crop-based and lignocellulosic biofuel plants in the future. The increased frequency of extreme weather events, especially droughts during the growing season, will increase the uncertainty of a sustainable raw material supply. The consequence of the crop loss for biofuel production was also manifested in the drought period of the year of 2007. Many of the planned bioethanol plants at that time did not materialize. Although the climate in Hungary is more favorable for corn production than it is in most countries in Western Europe, Hungary's yield is still below the average of many other EU countries. This is accompanied by the above-mentioned yield fluctuations. For example, in 2003 and 2007 less than 35–40% of corn was produced in Hungary compared to the national average of in that decade. The same value was at most 18% in Austria and Germany [26]. The yield loss could be decreased in Hungary by using appropriate agricultural technology. Furthermore, as a result of climate change, we can expect a rise in temperature in Hungary, which may lead to a narrowing of the growing area of rapeseed, which is a raw material for biodiesel production that prefers cooler, wetter areas.

Increased use of forest and agricultural residues is necessary on the one hand to avoid food conflicts and on the other hand to comply with legal requirements. Forestry labor shortages make it increasingly difficult to harvest the forest residues. Mechanization development would help alleviate this, but it would entail higher costs. Beyond forestry residues timber harvested by forced cutting is likely to be used for energy purposes. The pyrolytic utilization of this material is aided by the fact that the damaged wood can be harvested with relatively low moisture contents; thus, instead of drying the wood, the energy can be used to produce heat and electricity, which improves the economy of the industry.

Agricultural by-products demonstrate high potential, but their low bulk density makes transportation costly over long distances. In addition, the conversion rate of agricultural by-products is also low. Extreme weather effects must be taken into account when planning biofuel plants; these effects can increase the collection area of agroresidues by up to 70% [37]. Meeting ecological needs (soil improvement) doubles the base material footprint. Furthermore, agricultural by-products are also used in animal husbandry. Harvesting and storing corn stalks with high moisture content is still cumbersome. Nevertheless, according to the raw material footprint – which is suitable for given the collection area – forest residues require higher raw material collection for biofuel production with the same energy content. Moreover, the risk of Indirect Land Use Change (ILUC) can be reduced with the use of agricultural residues. Short rotation coppices (SRC) requires the smallest collection area [37].

Overall, a large amount of useable residues is available for the supply of raw material to potential lignocellulosic biofuel plants in Hungary. However, it must be considered that for all forestry and agricultural lignocellulosic feedstocks, more frequent plant protection activities should be conducted to mitigate effects of climate change threats. These activities will increase CO_2 emissions as well as costs through the use of machinery and the production of pesticides.

5. SUMMARY

The course of the survey in 2018 revealed that many agricultural by-products, especially corn stalk, are available for energy production purposes. However, the harvesting and utilization of these by-products for biofuel production have not been fully developed.

Climate change, together with the current operating and potential users, significantly influences the locally usable amount of biomass. Hereby, the raw material supply of a scheduled plant can be accomplished with longer transport distances. Commercially operated decentralized technology primarily enables the utilization of dendromass. Although harvesting of forest residues is still problematic, forestry development in this direction is underway. Occasional biotic and abiotic damage events in forests increase the amount of dendromass that can be used for energy purposes.

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REFERENCES

[1] Biodiesel Magazine (2020). *Biofuels require little arable land but provide many benefits*. http://biodieselmagazine.com/articles/2516887/biofuels-require-little-arable-land-but-provide-many-benefits

[2] Spiertz, J. H. J., Ewert, F. (2009). Crop production and resource use to meet the growing demand for food, feed and fuel: opportunities and constraints. *NJAS – Wageningen Journal of Life Sciences*, 56 (4), pp. 281–300.

[3] Neményi M. (2009). *Megújuló energiaforrások kutatási-fejlesztési tevékenysége a karon*. (Research and development activities on the field of renewable energy sources in the faculty.) http://www.mtk.nyme.hu/fileadmin/user_upload/szti/biomotion/biofuels_in_hungary.pdf

[4] Szalay D., Papp V., Marosvölgyi B. (2018). Lignocellulóz biohajtóanyag üzemek alapanyag-felhasználásának jelenlegi helyzete. In: Kiss T., Dolgosné Kovács A., Vér Cs., Máthé P.: Sustainable Resource Management. *I. RING – Conference*. Pécs, Magyarország, pp. 168–175. (Current situation of raw material use in lignocellulosic biofuel plants.)

[5] Hungarian Central Statistical Office (KSH): *013-as erdőgazdálkodás jellemzői statisztikai tükör (Statistical Mirror in 2013 Features of Forest Management)*. https://www.ksh.hu/docs/hun/xftp/stattukor/regiok/orsz/erdogazd12.pdf

[6] Szakálosné M. K., Horváth B., Major T., Horváth A. (2013). *Magyarországi erdők energetikai célokra hasznosítható faanyaga*. Alföldi Erdőkért Egyesület Kutatói Nap: Tudományos eredmények a gyakorlatban. Lakitelek (Woody biomass sources of hungarien forestries for energy purposes. Researchers' Day of the Association for the Great Plain Forests: Scientific results in practice).

[7] Hungarian Central Statistical Office (KSH): *2017 Land by Field Cultivation Table* (2017-es évre vonatkozó Földterület művelési ágak szerint megnevezésű tábla). https://www.ksh.hu/docs/hun/xstadat/xstadat_eves/i_omf003.html

[8] Szalay D. (2018). *Energetikai célú dendromassza termesztés és hasznosítás lehetséges szerepe a lignocellulóz biohajtóanyag üzemem alapanyag ellátásában*. Doktori értekezés. Soproni Egyetem. Sopron. (Production and Utilization of Dendromass for Energy Purposes and Possible Role in the Base Material Supply of Lignocellulose Biofuel Plant. PHD Thesis. University of Sopron.)

[9] Boris, C., Zoran, S., Novic, D. (2011). Geographic distribution of economic potential of agricultural and forest biomass residual for energy use: Case

study Croatia. Energy 2011 https://www.researchgate.net/publication/223006293_Geographic_distribution_of_economic_potential_of_agricultural_and_forest_biomass_residual_for_energy_use_Case_study_Croatia 2015. 10. 11.

[10] Sembery P., Tóth, L. (2004). *Hagyományos és megújuló energiák*. Szaktudás Kiadó Ház, Budapest (Conventional and renewable energies. Szaktudás Publishing House).

[11] Fogarassy Cs. (2001). *Energianövények a szántóföldön*. SZIE GTK Európai Tanulmányok Központja, Gödöllő. ISBN 963 9256 47 1 (Energy crops on the arable land. Center for European studies of SZIE GTK).

[12] Radics L. (ed.) (1994). *Szántóföldi növénytermesztéstan*. Egyetemi jegyzet, Budapest (Crop production on plow land. University note).

[13] Barótfi I. (ed.) (2003). *Környezettechnika*. Mezőgazda Kiadó, Budapest, ISBN: 978 963 9239500 (Environmental technology. Mezőgazda Publiusher).

[14] Papp V., Marosvölgyi B. (2010). A pelletálás energiamérlegének vizsgálata. Tudományos eredmények a gyakorlatban. Szolnok, pp. 101–105. (Investigation of the energy balance of pelletization." Scientific results in practice.)

[15] Papp, V., Beszédes, S., Szalay, D. (2019). Opportunities and challenges of agripellet production in Hungary. *Agriculture and Food*, Vol. 7, pp. 197–204.

[16] Papp V., Szalay D., Gaál L. (2016). Agripellet előállítás alapanyagbázis vizsgálata Magyarországon. *Journal of Central European Green Innovation*, 4, 2, pp. 89–102.

[17] EBTP (2013). European Biomass Technology Platform-Agricultural residues as feedstocks for biofuels production. http://biofuelstp.eu/agri-residues.html.

[18] Kline, R. (2014). *Estimating crop residue cover for soil erosion control*. Soil factsheet. Ministry of Agriculture. British Columbia, pp. 1–4.

[19] Hungarian Central Statistical Office (KSH). KSH OSAP 1254 sz. adatgyűjtése. *Beszámoló az erdősítésekről és a fakitermelésekről a 2016. évben.* (KSH OSAP 1254 data collection report on national reforestation and harvested gross timber volume in 2016), https://portal.nebih.gov.hu/documents/10182/206281/M%C3%A9rleg-2016.pdf/a723b1fd-c5b2-497c-8049-4f149fb99bd0.

[20] Maga J. (2012). *A szalma energetikai hasznosításának lehetőségei Szlovákiában. Innovációval a zöld jövőért*. Konferenciakiadvány (Opportunities for energy utilization of straw in Slovakia. Innovation for a green future. Conference proceedings).

[21] Szalay, D., Jákói, Z., Papp, V. (2019). Possible Role of Agricultural Woody By-products in Lignocellulose Biofuel Production In Hungary. *Journal of*

International Scientific Publications: Agriculture & Food Journal, Vol. 7, pp. 211–220.

[22] Miszkuly S. (2019). Szóbeli tájékoztatás (personal communication).

[23] Papp, V., Babiczki, L., Grédics, Sz., Szalay, D. (2019). Timber Harvest Due to Biotic and Abiotic Damage by the Example of Egererdő Plc. In: Czupy, I. Exceeding the Vision: Forest Mechanisation of the Future. *Proceedings of the 52nd International Symposium on Forestry Mechanization*. Sopron, Hungary e-book. pp. 495–502.

[24] Bai A., Tarsoly P. (2011). *A hazai melléktermék-hasznosítás. Agrárium*. Debreceni Egyetem (Utilisation of by-product in Hungary. University of Debrecen).

[25] Szalay D. (2009). *Biomassza alapú cseppfolyós üzemanyag előállításának lehetőségei, különös tekintettel a második generációs bioüzemanyagokra*. MSC-diplomadolgozat, Nyugat-magyarországi Egyetem, Sopron (Possibilities for the production of biomass-based liquid fuels, especially second-generation biofuels. MSc Thesis, University of West Hungary).

[26] Szalay D., Palocz-Andresen M. (2013). A biomassza termesztés és feldolgozás függősége a klímaváltozástól. Alföldi Erdőkért Egyesület, Kutatói nap kiadványa, Lakitelek, pp. 89–93. (Dependence of biomass cultivation and processing on climate change. Association for the Great Plain Forests, Researcher's Day Publication).

[27] Liebhard P. (2008). *Energetikai faültetvények. Rövid vágásfordulójú faanyagtermelés. A jövő nyersanyaga*. Cser Kiadó, Budapest (Energy tree plantations. Short - cut timber production. The raw material of the future. Cser Publisher).

[28] Veolia (2019). *Újabb lépés a körforgásos gazdaságért: speciális tüzelőanyag-mix a pécsi erőműben* (Another step for the circular economy: a special fuel mix at the Pécs power plant). https://www.veolia.hu/hu/hirek/ujabb-lepes-korforgasos-gazdasagert-specialis-tuzeloanyag-mix-pecsi-eromuben

[29] DERULA (2019). *Cégünkről* (About our Company). http://www.derula.hu/hu/s/3195/cegunkrol

[30] Haszon Agrár (2010). Mit kezdjünk a kukoricaszárral? (What to do with the corn stalk?) http://www.haszon.hu/agrar/noevenytermesztes/533-mit-kezdjuenk-a-kukoricaszaral.html

[31] Mann, L., Tolbert, V., Cushman, J. (2002). *Potential environmental effects of corn (Zea mays L) stover removal with emphasis on soil organic matter and erosion*. Agriculture, Ecosystems & Environment.

[32] Energiainfo: *3,5 milliárdért venne szalmát a pécsi biomassza erőmű* (The Pécs biomass power plant would buy straw for 3.5 billion). http://www.energiainfo.hu/35-milliardert-venne-szalmat-pecsi-biomassza-eromu/.

[33] Vértesi Erőmű Zrt.: *Általános információk* (General Information). http://www.vert.hu/altinf.aspx.

[34] Papp V. (2018). Energetikai pelletek előállításának és hasznosításának öko-energetikai vonatkozásai. PhD-disszertáció, Soproni Egyetem, Sopron. (Eco-Energy Aspects of Production and Utilization of Energetic Pellets.) PhD thesis, University of Sopron.

[35] Biofuel News: Advanced biofuels plant to be built in Slovakia https://biofuels-news.com/display_news/12889/advanced_biofuels_plant_to_be_built_in_slovakia/

[36] Chemicalparks (2014). Green chemistry investment by Energochemica SE group for Ethanol at Strážske Chemko in Slovakia. https://chemicalparks.eu/investment-projects/500

[37] Szalay, D., Papp, V., Czupy, I. (2018). Analysis of the Base Material Footprint of Conventional and Lignocellulosic Biofuel Production. *IOP Conference Series: Earth and Environmental Science*, 159 (1), p. 8.

[38] Molnár S., Pásztory Z., Komán Sz. (2013). A faenergetika minőségi fejlesztésének szakmai megalapozása (mire elég a magyar dendromassza?!) FATÁJ online. (Professional foundation for the quality development of wood energy (what is the Hungarian dendromass enough for?!) www.fataj.hu.

[39] Nagy I. (2016). Csodavárás helyett egy lehetséges megoldás – jövőnk az iparifa-ültetvény! (Part 1). *Erdő-mező online*. (Instead of waiting for a miracle, one possible solution – our future is the industrial tree plantation!) http://erdo-mezo.hu/2016/02/07/csodavaras-helyett-egy-lehetseges-megoldas-jovonk-az-iparifa-ultetveny-1-resz/.

[40] Jose, S. (ed.) (2010). *Agroforestry for Ecosystem Services and Environmental Benefits*. Springer Kiadó, http://www.tankonyvtar.hu/hu/tartalom/tamop425/0027_BTRI13/ch01s02.html.

[41] Kumar, B. M., Nair, P. K. R. (eds.): *Carbon Sequestration Potential of Agroforestry System*. Springer Netherlands, Amsterdam.

[42] Clausen, C. A., Smith, R. L. (1998). CCA removal from treated wood by chemical, mechanical, and microbial processing. *Proceedings of the 4th International Wood Preservation Symposium*, The Challenge-Safety and Environment. https://www.fpl.fs.fed.us/documnts/pdf1998/claus98b.pdf.

[43] Clausen, C. (2004). Improving the two-step remediation process for CCA-treated wood. Part I. Evaluating oxalic acid extraction. *Waste Management*, 24 (4), pp. 401–40.

[44] Sierra-Alvarez, R. (2009). Removal of copper, chromium and arsenic from preservative-treated wood by chemical extraction-fungal bioleaching. Waste *Manag.*, 29 (6), pp. 1885–1891.

[45] AGROCROP. Project proposal webpage, https://sites.google.com/site/agrobenkcrop/services.

[46] AGFORWARD. Project webpage, https://www.agforward.eu/index.php/en/home-redirect.html.

[47] AFINET. Project webpage, https://euraf.isa.utl.pt/afinet