ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society

Ecocycles, Vol. 8, No. 1, pp. 16-26 (2022)
DOI: 10.19040/ecocycles.v8i1.217

RESEARCH ARTICLE

Bioenergy potential of agricultural phytomass production in Slovakia

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Abstract – Biomass is a highly versatile renewable energy source used on a global scale. The paper discusses the current state of biomass energy use in the EU and Slovakia. Residual biomass was found as a key feedstock for the European bioeconomy. Slovakia is one of the most forested and rural countries in the EU. Therefore, biomass energy has the highest technical potential from all renewables in Slovakia. The main objective of the paper was to evaluate the phytomass production of the selected crops and their energy potential in individual self-governing regions of Slovakia. It is focused on the production of usable post-harvest residues theoretically used for energy purposes from the following studied main crops: wheat, rye, oats, barley, maize, potatoes, oilseed rape and sugar beet. The results show the estimated production of usable post-harvest residues of the selected crops and their energy potential in individual self-governing regions in Slovakia in 2019. The total production of usable post-harvest residues from the studied crops was 4,854,017 t and their estimated energy potential was 68 PJ. This amount of energy would cover 10% of the total energy consumption in Slovakia. The top three productive crops were maize, wheat and sugar beet. Maize had the highest energy potential of 28.1 PJ, followed by wheat at 19 PJ and sugar beet at 14.2 PJ. The highest yields of post-harvest residues, as well as energy potential, was found in the Nitra region.

Keywords – biomass, crop, energy potential, post-harvest residue, Slovakia

Received: January 1, 2022 Accepted: January 19, 2022

INTRODUCTION

The European Union faces several energy challenges such as increasing dependence on energy import, insufficient diversification, high and volatile energy prices, rising global energy demand, security risks and uncertainties affecting the producing and transit countries, growing threats from climate change and slow progress in energy efficiency (Ciucci, 2020). The EU energy policy focuses on a set of measures aimed at achieving an integrated energy market, security of energy supply and a sustainable energy sector (Pacesila et al., 2016). A comprehensive integrated climate and energy policy was adopted by the European Council on 24 October 2014 and revised in December 2018. It aims to reduce greenhouse gas emissions by at least 40% by 2030 compared to 1990 levels, to increase the share of renewable energy sources (RES) in energy consumption to 32% and to increase energy efficiency by 32.5% (Ciucci, 2020). The EU is still heavily dependent on fossil fuels, however, gradual decarbonisation has been observed. In 2018, the EU's energy mix mainly consisted of five different sources: oil products (36%), natural gas (21%), solid fossil fuels (15%), renewable energy (15%) and nuclear energy (13%). The shares of different energy sources in total available energy vary considerably between the Member States (EEA, 2018; Eurostat, 2020). The share of RES was about 19.7% in the EU-27 in 2019. That represents an increase of more than 7 percentual points from 12.6% in 2009 (Eurostat, 2021a).

The global primary energy consumption was 584,000 PJ (petajoules) in 2019. Fossil fuels constituted 84.3%. Almost 16% came from low-carbon sources (combined nuclear energy and RES). Nuclear energy accounted for 4.3% and RES for 11.4% of the total primary energy consumption. If the traditional biomass is excluded, hydropower is the most prominent RES with 6.4%. Wind represents 2.2% and solar energy 1.1%, however, both sources are growing quickly (Ritchie and Roser, 2020).

The global installed capacity of renewable energy increased by more than 200 gigawatts (mostly photovoltaics) in 2019 compared to 2018. Wind and solar energy have become mainstream sources of electricity and are increasingly cost-competitive with fossil fuel power plants. Solar and wind energy rose by 1,300 PJ and 1,500 PJ, respectively in 2020. As governments around the world introduced a lockdown in 2020 to slow the spread of the new coronavirus, the energy demand has fallen. Global electricity demand fell by 2.5% in the first quarter of 2020, and demand for coal and oil fell by almost 8% and 5%, respectively. Renewable energy sources were the only source of electricity that saw an increase during this period (BP, 2021; REN21, 2020; REN21, 2019).

Residual biomass was found as a key feedstock for the European bioeconomy. It was estimated that biomass residues (from agriculture, forestry, urban greenery management and food waste) have a theoretical potential of 8500 PJ y^{-1}. It corresponds to the whole annual (2015) primary energy consumption of Italy and Belgium combined. Straw (3800 PJ y^{-1}) and forestry residues (3200 PJ y^{-1}) were the top-two contributors (Hamelin et al., 2019).

Worldwide, the total biomass supply from agriculture and forestry is estimated at 11.9B tons of dry matter annually, of which 61% is produced by agriculture (crops account for 47% and residues harvested above ground for 14 %) and 39% by forestry. Approximately 55% of biomass is used for feed and food products, followed by bioenergy (27%), and biomaterials (8%). Other uses and losses account for 10%. Agricultural crops are primarily used for food and feed (87 %). The energy use represents about 8.5 % (Popp et al., 2021).

Slovakia had committed to providing 14% of the gross final energy consumption from RES by 2020. The target was met in 2019 when the share of RES was 16.9% (EEA, 2021; Eurostat, 2021b). The total energy generation from RES was approximately 25.2 PJ (7 TWh) in Slovakia in 2020. Hydropower generates the most energy from all RES in Slovakia, representing about 17.1 PJ (57% of all RES). Solar energy accounted for almost 2.2 PJ, wind energy is negligible. Other RES (mainly biomass) represented up to 7.5 PJ (Ritchie and Roser, 2020).

Slovakia, together with Finland, are the most forested and at the same time the most rural countries in the EU. The conditions predestine it to the economic as well as progressive use of the country's natural potential. Except for the primary function of agriculture to provide food, the agricultural outputs can be used for energy purposes. It was integrated into the strategic and legislative materials of the EU as well as Slovakia (Hecl and Tóth, 2020). It is stated that biomass has the greatest technical potential of all RES (120,300 TJ, or 33,400 GWh) in Slovakia (Majlingová et al. 2019; MESR, 2007)

Increasing the share of renewable energy sources and the use of low-productive agricultural land for the cultivation of energy crops results in a significant increase in the potential of energy-efficient biomass for heat and energy production in Slovakia (Majlingová et al., 2019). However, the use of energy crops must not jeopardize food and feed production, the regeneration of soil fertility and sustainable land use. In terms of food security, it was estimated that approximately 1,050,000 ha of arable land is sufficient (approximately 78% of the total arable land area) for the population of Slovakia (MARDSR, 2009). The main crops (wheat, rye, barley, oats, maize, potatoes, oilseed rape and sugar beet) are currently the largest source of biomass produced in Slovakia. It is biomass produced as a by-product or waste in the form of straw and residues. Another source of biomass consists of residues from the pruning of fruit trees and vines, hay from permanent grasslands and wood from shrubs (Hecl and Tóth, 2020; Kanianska, 2016).

The article aims to estimate the energy potential of the agricultural phytomass (straw and residues) produced by the selected crops. The goal is to highlight the potential of crop residuals as a cheap and readily available energy source that has not been used in full potential and should be implemented in national and regional strategies of sustainable natural resource utilization.

MATERIALS AND METHODS

Selected crops, study area and data sources

The main crops grown in Slovakia in 2019 selected in the research included wheat, barley, oat, rye, maize, potatoes, oilseed rape and sugar beet. Wheat, barley, oat and rye are referred to as basic cereals.

The energy potential of the selected crops was studied in the whole territory of Slovakia and compared among all self-governing regions: Bratislava (BA), Trnava (TT), Trenčín (TN), Nitra (NR), Banská Bystrica (BB), Žilina (ZA), Poprad (PO) and Košice (KE).

Statistical data from the Geodesy, Cartography and Cadastre Authority of the Slovak Republic (GCCA, 2020) were used to determine the amount of phytomass produced on agricultural land in individual regions as well as for the whole of Slovakia.

The statistical data on crop production to determine the amount of phytomass produced by selected crops were obtained from the Statistical Office of the Slovak Republic (SOSR, 2020).

Energy potential of the post-harvest residues

To determine the energy potential of the phytomass of the selected crops, the amount of the above-ground post-harvest crop residues were taken into account. Available post-harvest residues, usable post-harvest residues and annual energy potential from the usable residues were calculated based on conversion coefficients. The calculations were based on Kanianska (2016). The available post-harvest residues (APHR), representing residues that are not used for human consumption are calculated as follows:

$$\text{APHR (kg)} = \text{primary crop harvest (kg)} \times \text{harvest index} \quad (1)$$

The harvest index (factor) is the share of primary crop harvest of total aboveground plant biomass, and the grain (product) to straw (residue) ratio. Residue-to-product ratios are widely used to estimate the amount of crop residues and thus their theoretical potential for alternative use (Haase et al., 2016; Scarlat et al., 2010). However, it was reported that this estimation approach might be unreliable and would highly benefit from additional experimental research (Karan and Hamelin, 2021).

Usable post-harvest residues (UPHR) are usually used as bedding material in livestock husbandry, however, they can also be used as feed, for energy production or as industrial raw material. In this paper, they represent residues that can be used for energy purposes. UPHR is calculated as follows:

$$\text{UPHR (kg)} = \text{APHR (kg)} \times \text{recovery rate} \quad (2)$$

The recovery rate is the actual fraction of the available post-harvest residues that will be harvested and further used. The harvest index and recovery rate for the selected crops used in Europe are shown in Tab. 1.

Tab. 1 Harvest indices and utilization coefficients of the selected crops (Eurostat, 2009; Kanianska, 2016)

Crop	Harvest index	Recovery rate
wheat	1	0.7
barley, rye, oat	1.2	0.7
maize	1.2	0.9
oilseed rape	1.9	0.7
sugar beet	0.7	0.9
potato	0.4	0.36

The calculation of the annual energy potential (EP) of post-harvest residues of the selected crops was based on a calorific value of 14 MJ/kg (Galvánek, 2020):

$$\text{EP (MJ)} = \text{UPHR (kg)} \times \text{calorific value [MJ/kg]} \quad (3)$$

Processing and evaluation of the data

The resulting findings presented as maps were processed in the QGIS (version 3.16.3) (QGIS Development Team, 2021). The digital relief model of the country was obtained from the European Environment Agency data (EEA, 2017). The map of the land use was created based on CORINE Land Cover. It is part of the Copernicus program coordinated by the EEA (Copernicus Program, 2019). Individual CORINE land cover classes were simplified to level 1 classes representing artificial surfaces (AS), agricultural areas (AA), forest and seminatural areas (FSA), wetland (W) and water bodies (WB).

RESULTS

Land cover of Slovakia

The whole territory of Slovakia covers 4,903,600 ha. Agricultural areas represent approximately 47.2%. They are closely followed by forest and seminatural areas (46%) (Fig. 1). Arable land accounted for almost 60% of the agricultural areas in 2019. Therefore, when it comes to biomass production available for energy purposes, arable land has the highest potential. The region with the largest area of agricultural land is the Nitra region (75.6%). Agricultural land covered 464,225 ha in the Nitra region in 2019, of which 404,949 ha was arable land. Another region with a high share of arable land is Trnava (73%). Agricultural land represented 287,598 ha and arable land was 258,002 ha in the Trnava region.

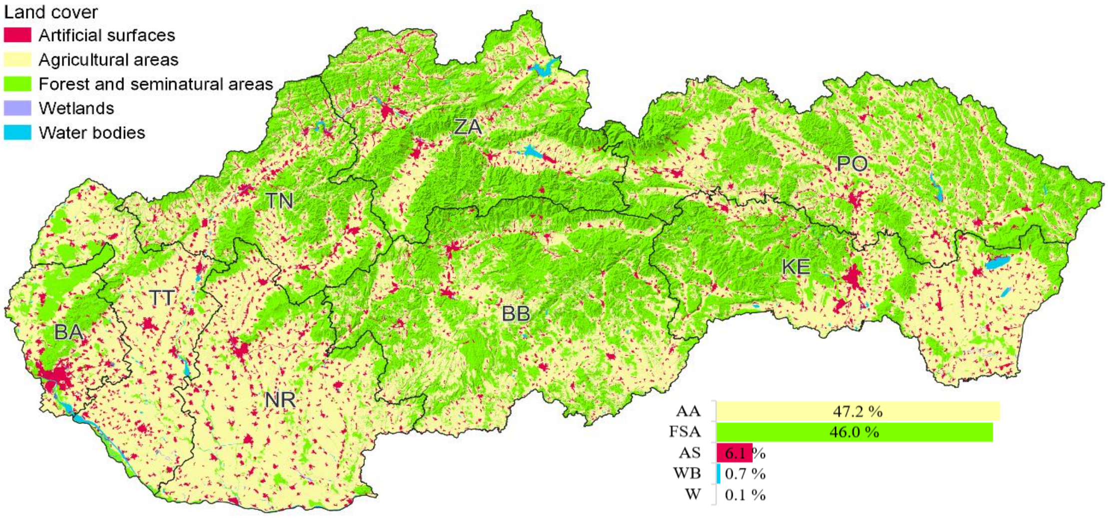

Fig. 1. Land cover in Slovakia.

Evaluation of usable post-harvest residues of the selected crops in Slovakia

The total yield of the selected crops was approximately 8,780,228 t in Slovakia in 2019. These crops were grown on an area of 1,493,710 ha. The highest primary yield was produced by wheat (1,939,133 t), maize (1,444,812 t) and sugar beet (1,243,135 t). These three crops provided also the highest theoretical amount of usable post-harvest residues (Fig. 2). In total, the estimated usable post-harvest residues of the selected crops were 4,854,017 t.

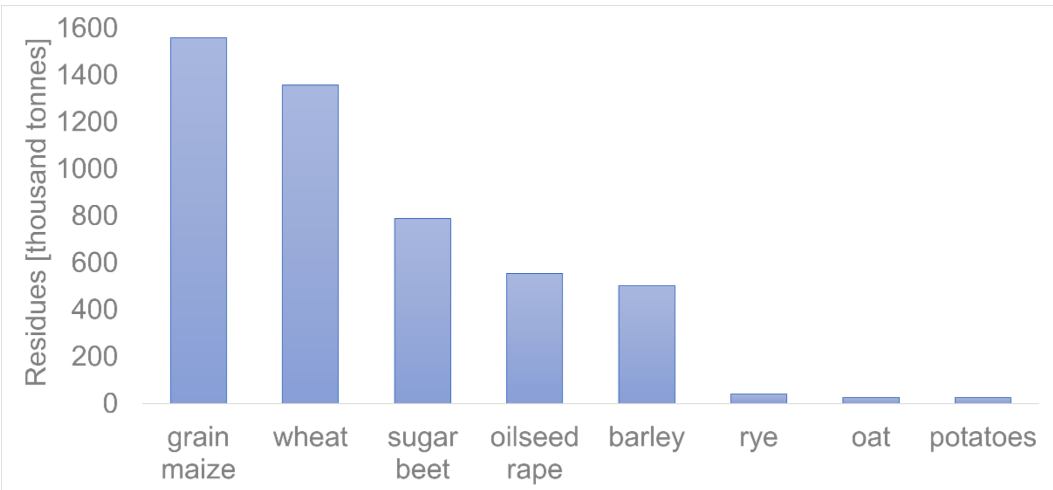

Fig. 2. Usable post-harvest residues of the selected crops in Slovakia in 2019.

The total yield of basic cereals (wheat, barley, rye and oat) grown on 559,180 ha of arable land was 2,619,283 t in 2019. It was both the highest yield and the largest growing area compared to other crops.

The estimated total production of usable post-harvest residues of basic cereals was 1,928,719 t. The highest production of the basic cereals residues was achieved in the Nitra region (697,540 t), followed by the Trnava region (385,940 t) and the Košice region (262,357 t) (Fig. 3). The yield of the residues per hectare ranged from 2.7 t ha^{-1} (Prešov region) to 3.9 t ha^{-1} (Nitra region).

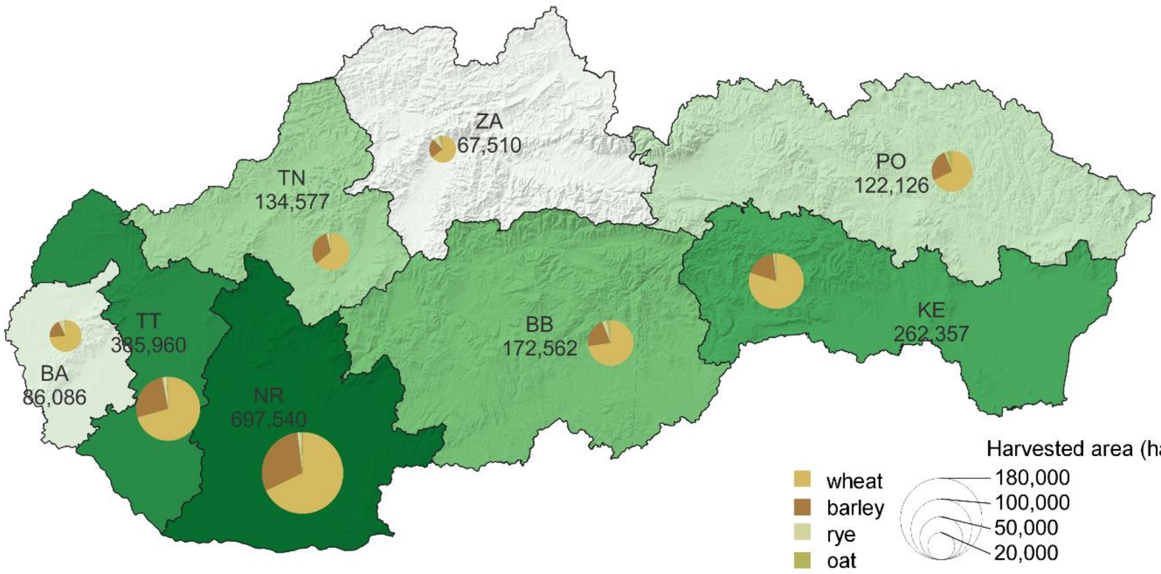

Fig. 3. Usable post-harvest residues of basic cereals (t) and the harvested area in 2019.

Maize was grown on 197,244 ha in 2019. The estimated total amount of maize residues was 1,560,397 t. The highest maize residue production was reached in the Nitra region (1,018,548 t) (Fig. 4) which was 65% of the total maize residue biomass. Wheat and maize are the region's largest agricultural commodities. The yield of maize residues per hectare ranged from 6.7 t ha^{-1} (Prešov region) to 8.6 t ha^{-1} (Košice region).

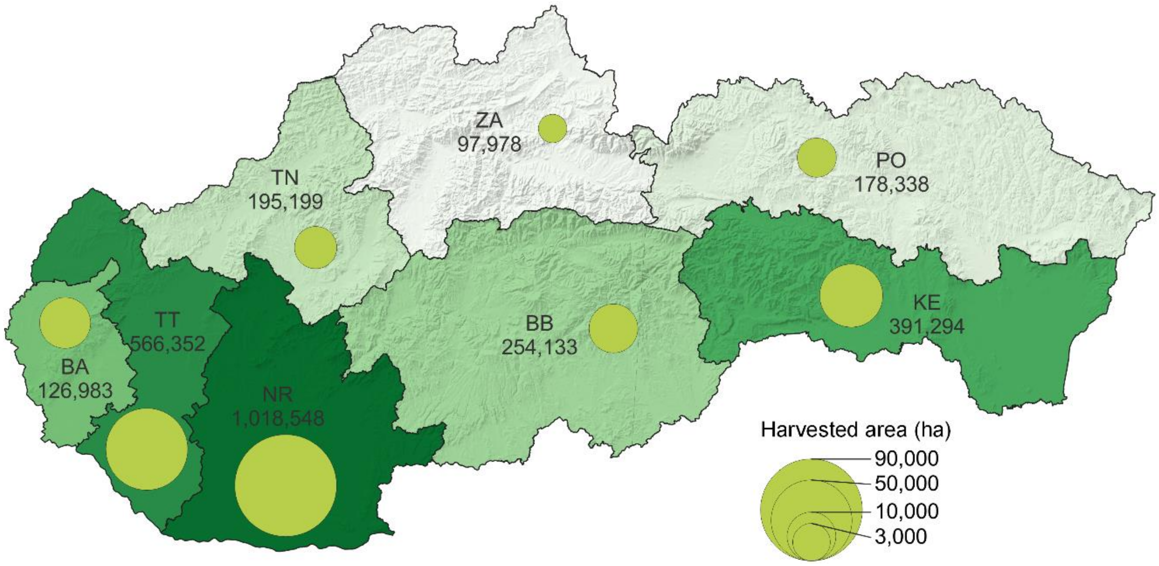

Fig. 4. Usable maize post-harvest residues (t) and the harvested area in 2019.

Sugar beet was grown on an area of 21,720 ha with a total primary yield of 1,251,665 t in 2019. The data on the sugar beet production was not available for the Žilina and Košice regions and it was not grown in the Prešov region in 2019. The estimated total yield of sugar beet usable post-harvest residues was 783,175 t. The Nitra region was the largest producer of sugar beet residues (322,353 t). The Trnava and Trenčín regions had the second and third largest residue production (290,746 t and 115,649 t), respectively (Fig.5). The yield of the residues per hectare ranged from 25.1 t ha^{-1} (Banská Bystrica region) to 38.5 t ha^{-1} (Trnava region).

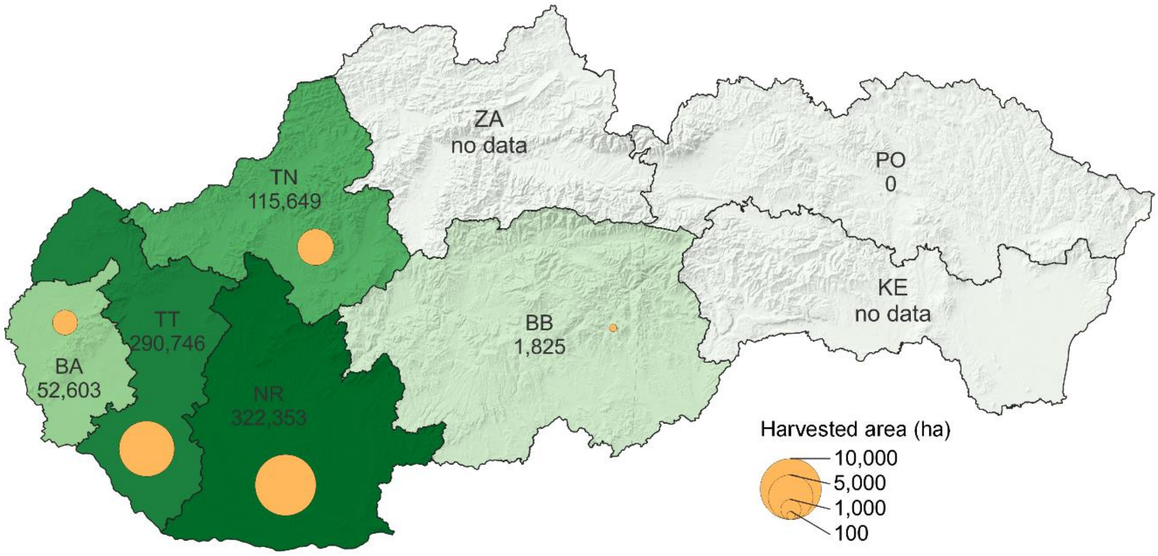

Fig. 5. Usable sugar beet post-harvest residues (t) and the harvested area in 2019

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Oilseed rape was grown on 147,000 ha and the total primary yield was almost 418,000 t in 2019.

The total yield of oilseed rape usable post-harvest residues was 555,457 t. The highest production of the residues was found in the Nitra region (219,292 t) followed by the Trnava region (114,648 t) and the Košice region (77,130 t) (Fig. 6). Similarly to basic cereals and maize, these regions had the highest harvested areas of rapeseed oil. The yield of the residues per hectare ranged from 2.9 t ha^{-1} (Prešov region) to 4,1 t ha^{-1} (Nitra region).

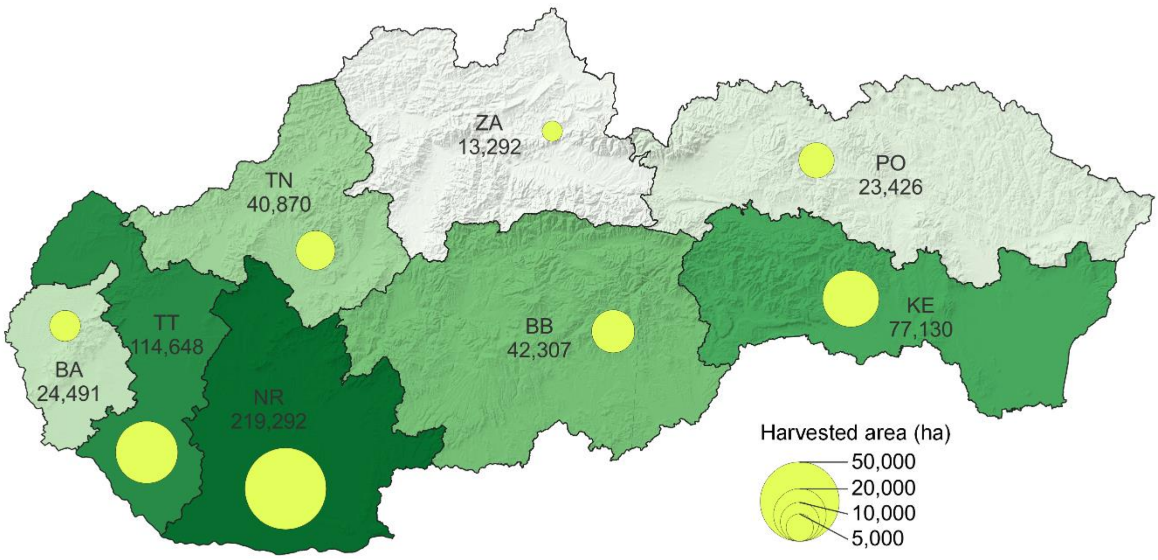

Fig. 6 Usable oilseed rape post-harvest residues (t) and the harvested area in 2019.

The total primary potato production reached 182,421 t on an area of 8,191 ha in 2019. The estimated total production of potato post-harvest usable residues was 26,269 t. The highest potato residue production was found in the Prešov region (6,281 t), the Bratislava region (5,840 t) and the Trnava region (5,711 t) (Fig. 7). The potato residue production per hectare was the lowest in the Banská Bystrica region (1.8 t ha^{-1}) and the highest in the Trnava region (4.8 t ha^{-1}).

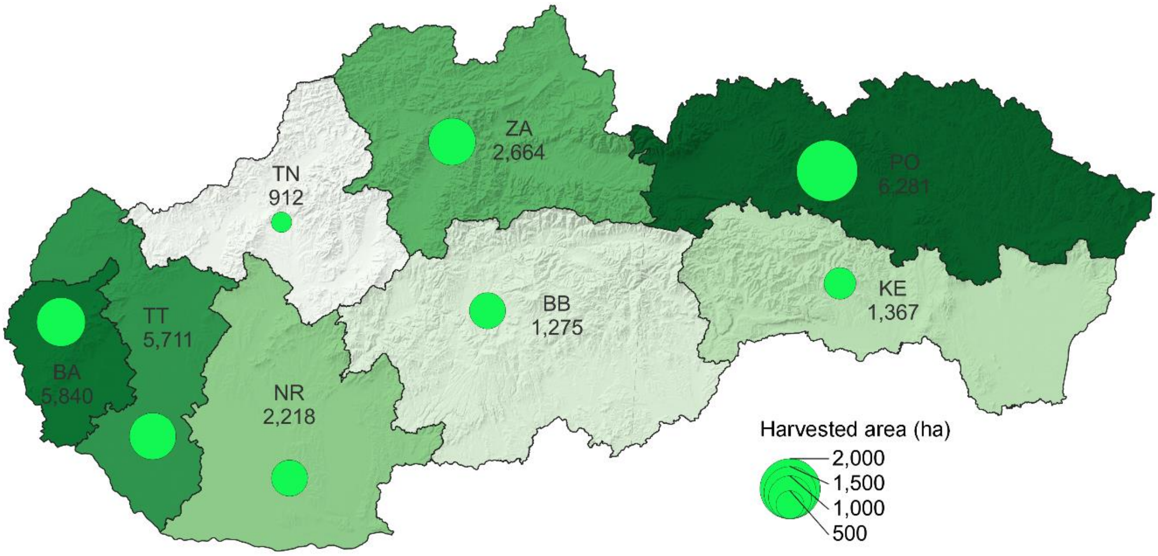

Fig. 7. Usable potato post-harvest residues (t) and the harvested area in 2019.

Evaluation of the energy potential of the selected crop residues

The total energy potential of the selected crop residues was estimated at approximately 68 PJ in 2019. The highest energy potential was achieved by maize (21.8 PJ), wheat (19 PJ) and sugar beet (11.4 PJ).

The highest energy potential was in the Nitra region (27.37 PJ). It was followed by the Trnava region (17.01 PJ) and the Košice region (7.73 PJ). The lowest energy potential (1.19 PJ) was found in the Žilina Region (Fig. 8).)

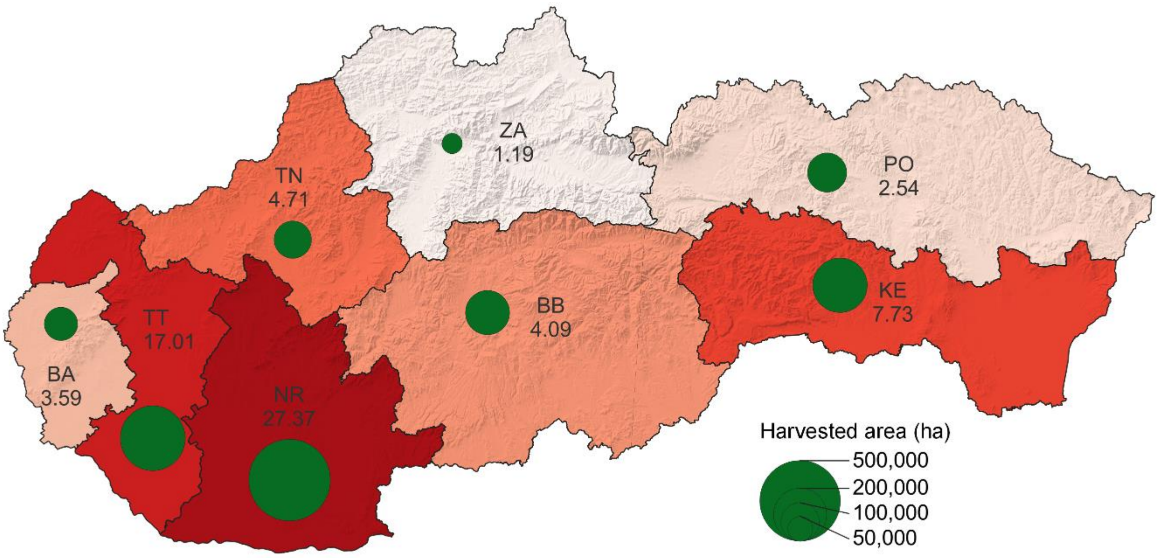

Fig. 8. Total energy potential (PJ) of the studied crops and their harvested area in 2019.

Discussion

One of the EU energy policies is to strongly support the development of RES that would lead to a very high share of RES in gross final energy consumption and electricity consumption reaching 75% and 97%, respectively in 2050 (EC, 2012). It would require, together with other scenarios, a large-scale mobilisation of Europe's biomass resources (Zappa et al., 2019). As already mentioned, biomass has the highest technical energy potential of all RES in Slovakia. A similar situation can be observed in the whole EU. About 59% of biomass produced in the EU is used for feed and food products. Biomass used for energy purposes represents 21 % and biomaterials such as wood products and wood pulp 20 % (Popp et al., 2021). The studied (main) crops (wheat, rye, barley, oat, maize, sugar beet, oilseed rape and potato) currently represent the largest source of produced agricultural phytomass in Slovakia (Hecl and Tóth, 2020).

The highest estimated post-harvest residues were obtained from the basic cereals compared to the other studied crops. The straw residues represent the third-highest residual biomass potential in EU-27 (plus Switzerland) with the production of 290 Mt. The highest production potential has manure (690 Mt) and the second forest residues (320 Mt). However, straw is estimated to have the highest energy potential of 3,800 PJ. Forest residues amounted to 3,200 PJ and manure to 560 PJ (Hamelin et al., 2019). According to Vilček (2013b), agricultural soils in Slovakia accumulate approximately 10,206 PJ of potential energy in total.

Based on the results, the most productive crop was maize with 1,560,397 t of the post-harvest residues in Slovakia in 2019. Maize is used widely for energy production as it is the predominant raw material for both the production of bioethanol and biogas production, with the highest yields in Europe (Skoufogianni et al., 2019).

Wheat was the second-highest productive crop (1,357,393 t). In the whole EU, wheat residue production represents about 149 Mt per year. Together with maize (80 Mt), they account for half of the total EU crop residue production (Camia et al., 2018).

The third-highest productive crop with 783,175 t of the post-harvest residues was sugar beet. It is mostly grown in the warm regions of Slovakia. Sugar beet is suitable for the production of ethanol due to its high sugar content. Its cultivation for ethanol production could become an alternative to declining sugar production. The disadvantages of sugar beet cultivation are the high demands on inputs, the occurrence of diseases and pests and the risk of soil erosion (Hanáčková et al., 2008).

Oilseed rape is the main oilseed crop used for energy purposes in Slovakia and Europe (Bajusová et al., 2019; USDA, 2020). However, its large production and the huge harvested area also raised concerns about the sustainable production of biofuel in the EU due to the increased simplicity of the agricultural landscape and resulting in increased use of synthetic insecticides (Ortega-Ramos et al., 2022). At present, oilseed rape is grown in all regions in Slovakia, from lowlands to mountain areas although, as seen in Fig. 6, its production dominates in the south.

The use of agricultural phytomass for energy purposes can also help in the reduction of greenhouse gas (GHG) emissions. The European Commission adopted a set of proposals to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels (EC, 2019). Weiser et al., 2014 estimated that energy use of straw residues could lead to a GHG emission reduction of 73.3–92.3% compared to fossil fuels.

The harvest indices and recovery rates used to calculate the amount of usable post-harvest residues of the studied crops can vary widely in the literature. In our study, we used the data provided by Eurostat (2009) and Kanianska (2016). However, according to a literature review by Scarlat et al. (2010) and Lal (2005), the harvest index (residue to crop production ratio) can range from 0.6 to 2.57 for wheat, from 0.82 to 2.5 for barley, up to 1.75 for rye, from 0.95 to 2 for oat, from 0.55 to 2 for maize, from 1.1 to 2 for oilseed rape, and the lower value both for sugar beet and potato is 0.2. Therefore, it can be stated that the value is very dependent on actual conditions and the region. The Decree of the Ministry of Agriculture of the Slovak Republic 338/2005 Coll. set a conversion coefficient for cereals (0.8), maize (1.2) and sugar beet (0.7). However, the Decree was issued 16 years ago and we have used more up to date sources.

We calculated the energy potential from all usable post-harvest residues. Some of these residues are also used as bedding material and feed or as industrial raw material (Eurostat, 2009; Kanianska, 2012), however, we did not take the other uses into account in our study. It means that the actual energy potential can be lower. The use of recovery rate is very important as part of the residues should be ploughed into the soil as a source of organic matter (carbon) and nutrients, especially potassium (Torma et al., 2018).

The Nitra region showed the highest energy potential compared to the other regions. It is also the most productive region in Slovakia when it comes to phytomass production in general (SSCRI, 2019). The region is located in the area with the highest bioenergy production precondition (22.2 MJ m^{-2}) (Vilček, 2013a).

In 2019, the total energy consumption was 658.8 PJ (183 TWh) in Slovakia (Ritchie and Roser, 2020). The estimated energy potential of the studied crops amounted to 68 PJ, which means that it would be able to cover about 10% of Slovakia's energy consumption in 2019.

Acknowledgements

The research was supported by the Agency for the Promotion of Research APVV-20-0076: Waste and Buildings – Modeling Efficiency of Alternative Opportunities for Public Authorities Cooperation, project SUMCULA (Sustainable Management of Cultural Landscapes): 2017-1-SE01-KA203-034570 and Grant Agency of the Slovak University of Agriculture GA SPU/2021/1: Phytoextraction of risk elements from soil substrates by selected species of fast-growing energy plants and their production potential.

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