Chapter

Energy Potential of Biomass Sources in Slovakia

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Abstract

Renewable energy has provided many potential benefits, including a reduction in greenhouse gas (GHG) emissions, the diversification of energy supplies, and a reduced dependency on fossil fuel markets (oil and gas in particular). The growth of renewable energy sources (RES) may also have the potential to stimulate employment in the European Union (EU), through the creation of jobs in new green technologies. In this chapter, first, we introduce the information on renewable energy sources, their statistics, and legislation background in Slovakia. In more detail, we further introduce the information on forest and agricultural biomass as a renewable energy source. In the experimental part, we introduce two case studies—the assessment of the potential stock of woody biomass and the determination of energetic properties of woody biomass, i.e., selected fast-growing tree species based on the implementation of laboratory fire tests and calorimetric analyses.

Keywords: woody biomass, energy potential, stock, renewable energy source

1. General overview on renewable energy production in EU and in Slovakia

In general, renewable energy sources (RES) include wind power, solar power (thermal, photovoltaic, and concentrated), hydropower, tidal power, geothermal energy, ambient heat captured by heat pumps, biofuels, and the renewable part of waste.

Here we introduce the overview of statistics on renewable energy sources in the EU published by Eurostat [1].

The information presented here is based on data compiled in accordance with accounting rules set down in the Directive 2009/28/EC [2] on the promotion of the use of energy from renewable sources and calculated on the basis of energy statistics covered by Regulation 1099/2008 on energy statistics, most recently amended in November 2017 by Commission Regulation 2017/2010. The most recent data available on the share of energy from renewable sources are for the reference year 2017.

The primary production of renewable energy within the EU-28 in 2017 was 226.5 million tons of oil equivalent (toe). The quantity of renewable energy produced within the EU-28 increased overall by 64.0% between 2007 and 2017, equivalent to an average increase of 5.1% per year [1].

Among renewable energies, the most important source in the EU-28 was wood and other solid biofuels, accounting for 42.0% of primary renewable production in 2017 (**Figure 1**).

Wind power was, for the first time, the second most important contributor to the renewable energy mix (13.8% of the total), followed by hydropower (11.4%). Although their levels of production remained relatively low, there was a particularly rapid expansion in the output of biogas, liquid biofuels, and solar energy, which accounted, respectively, for a 7.4, 6.7, and 6.4% share of the EU-28's renewable energy produced in 2017. Ambient heat (captured by heat pumps) and geothermal energy accounted for 5.0 and 3.0% of the total, respectively, while renewable wastes increased to reach 4.4%. There are currently very low levels of tide, wave, and ocean energy production, with these technologies principally found in France and the United Kingdom [1].

In 2018, the share of energy from renewable sources in gross final energy consumption reached 18.0% in the European Union (EU), up from 17.5% in 2017 and more than double the share in 2004 (8.5%), the first year for which the data are available.

Gross final consumption of energy is defined in the Renewable Energy Directive 2009/28/EC [2] as the energy commodities delivered for energy purposes to industry, transport, households, services (including public services), agriculture, forestry, and fisheries, including the consumption of electricity and heat by the energy branch for electricity and heat production and including losses of electricity and heat in distribution and transmission [1].

The increase in the share of renewables is essential to reach the EU climate and energy goals. The EU's target is to reach 20% of its energy from renewable sources by 2020 and at least 32% by 2030.

The European Council endorsed a 2030 Framework for Energy and Climate for the Union based on four key Union-level targets: a reduction of at least 40% in economy-wide greenhouse gas (GHG) emissions; an indicative target of improvement in energy efficiency of at least 27%, to be reviewed by 2020 with a view to increasing the level to 30%; a share of renewable energy consumed in the Union of at least 27%; and electricity interconnection of at least 15%. It specified that the target for renewable energy is binding at Union level and that it will be fulfilled through Member States' contributions guided by the need to deliver collectively the Union target [3].

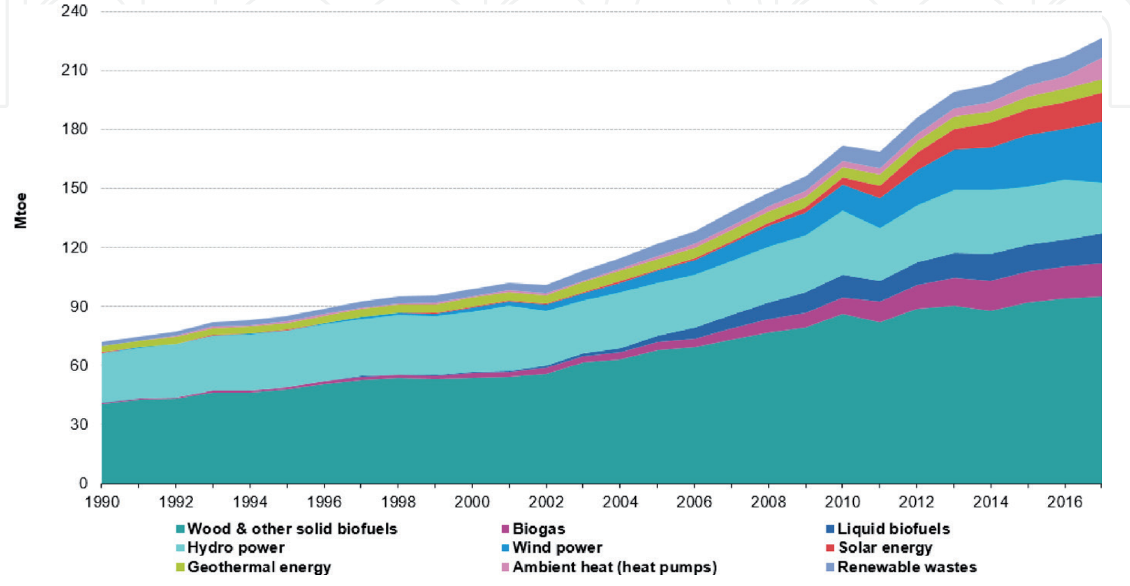

Figure 1.
Primary production of energy from renewable sources in EU-28 in period 1990–2017 (Source: Eurostat [1]).

A recast of Directive 2009/28/EC [2] of the European Parliament and of the Council has introduced a new, binding, renewable energy target for the Union for 2030 of at least 32%, including a provision for a review with a view to increasing the Union-level target by 2023. Amendments to Directive 2012/27/EU [4] of the European Parliament and of the Council have set the Union-level target for improvements in energy efficiency in 2030 to at least 32.5%, including a provision for a review with a view to increasing the Union-level targets.

This target is distributed between the EU Member States with national action plans designed to plot a pathway for the development of renewable energies in each of the Member States [5].

Among the 28 EU Member States, 12 Member States have already reached a share equal to or above their national 2020 binding targets: Bulgaria, Czechia, Denmark, Estonia, Greece, Croatia, Italy, Latvia, Lithuania, Cyprus, Finland, and Sweden. Four Member States are close to meet their targets (i.e., less than 1 percentage point (pp) away), nine are between 1 and 4 pp. away, while three are 4 or more pp. away from their targets [1].

The share of renewable energy in gross final energy consumption is identified as a key indicator for measuring progress under the Europe 2020 strategy for smart, sustainable, and inclusive growth. This indicator may be considered as an estimate for the purpose of monitoring Directive 2009/28/EC [2] on the promotion of the use of energy from renewable sources—however, the statistical system in some countries for specific renewable energy technologies is not yet fully developed to meet the requirements of this Directive.

Figure 2 shows the latest data available for the share of renewable energies in gross final energy consumption and the targets that have been set for 2020. The share of renewables in gross final energy consumption stood at 18% in the EU-28 in 2018, compared with 8.5% in 2004.

This positive development has been prompted by the legally binding targets for increasing the share of energy from renewable sources enacted by Directive 2009/28/EC [2] on the promotion of the use of energy from renewable sources.

The share of energy from renewable sources is divided into three different components: share in electricity, share in heating and cooling, and share in transport.

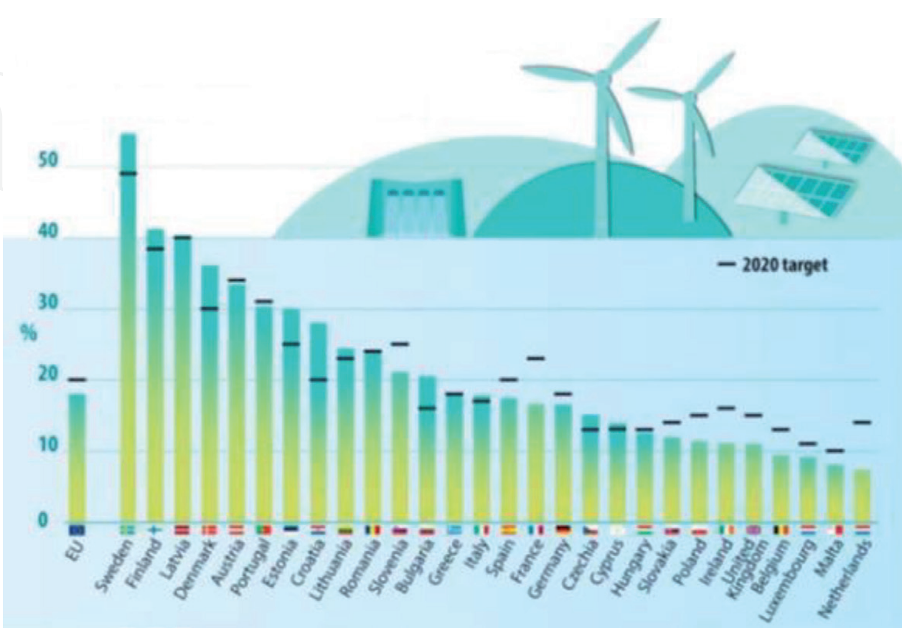

Figure 2.
Share of energy from renewable sources in in EU-28 in % of gross final energy consumption in 2018 (Source: Eurostat [1]).

While the EU as a whole is on course to meet its 2020 targets, some Member States will need to make additional efforts to meet their obligations as regards the two main targets: the overall share of energy from renewable sources in the gross final energy consumption and the specific share of energy from renewable sources in transport [1].

In 2017, electricity generation from renewable sources contributed more than one quarter (30.7%) to total EU-28 gross electricity consumption. Wind power was for the first time the most important source, followed closely by hydropower.

Renewable energy accounted for 19.5% of total energy used for heating and cooling in 2017. This was a significant increase from 10.4% in 2004. Increases in industrial sectors, services, and households (building sector) contributed to this growth [1].

But the Slovak Republic (SR) is moving away from its target for the share of renewable energy sources. This is set at 14% for 2020.

In 2017, however, Slovakia reached only 11.5%, while the share decreased for the second consecutive year. In 2016, it was 12%. In 2015, it was 12.9%. Slovakia returned statistically before 2014, when the share was 11.7% [1].

The share of energy from renewable sources in final energy consumption in the Slovak Republic in period 2004–2016 is shown in **Figure 3**.

The decrease in the share of renewable energy sources was caused by lower growth in the use of renewable energy sources than the growth in final energy consumption. The growth in electricity consumption and the significant increase in the use of motor fuels, which caused a dynamic increase in energy consumption, reflect the Slovak Republic's economic growth. In the long term, the Slovak Republic's priority is energy efficiency, which leads to a reduction in energy consumption and thus to savings in fossil fuels and greenhouse gas emissions.

At the same time, in 2017, the highest increase in energy consumption in Slovakia was recorded by 7% of all EU Member States. Slovak gross domestic product (GDP) increased this year by 3.2%. This means that the country is failing to separate energy consumption from economic growth and thus enhance energy efficiency.

Of all 28 EU Member States, in the share of renewable energy, the Slovak Republic ended in the ninth place backward.

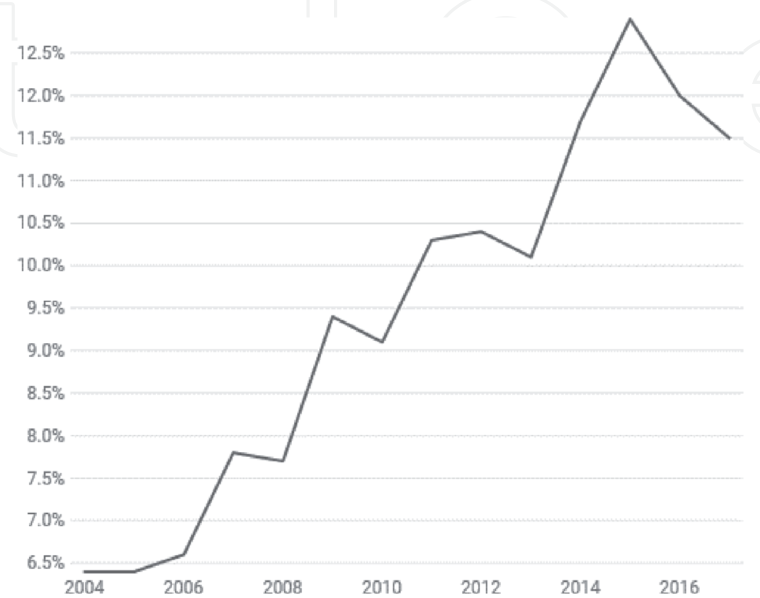

Figure 3.
Share of energy from renewable sources in final energy consumption in SR in period 2004–2016 (Source: Energie Portál [6]).

Year	Natural gas (GWh)	Biomass (Kt)	Coal (Kt)	Biogas (GWh)	Fuel oil (Kt)
2016	8514	1113	571	275	96
2017	8141	845	577	326	128
2018	8637	877	586	326	128

Table 1.
Renewable energy sources are used in addition to electricity production also for heat production (Source: URSO [7, 8]).

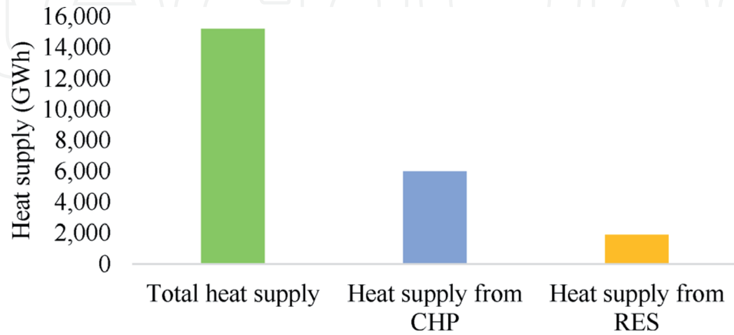

Figure 4.
Heat supply in SR in 2018 (Source: URSO [7, 8]).

According to the latest statistics of Eurostat [1], the Slovak Republic is the country with the highest year-on-year increase in final energy consumption—by 7%.

As energy consumption in the Slovak Republic is growing and renewable sources are not developing, their share inevitably decreases.

In the Slovak Republic, electricity from renewable sources is promoted through a fixed feed-in tariff. Energy companies are obliged to purchase and pay for electricity exported to the grid.

Renewable energy biomass must be given priority connection, and electricity from renewable sources must be given priority dispatch. The grid operator is obliged to extend the grid without discriminating against certain users.

Renewable energy sources are used in addition to electricity production also for heat production. URSO [7, 8] 2019 statistics show that in 2018 the most used fuel for heat production in Slovakia was natural gas. As can be seen from the data in **Table 1**, its use increased year-on-year most significantly from all fuels to around 8640 GWh.

The total volume of heat supply from renewable energy sources in 2018 was less than 2000 GWh according to data from the URSO Annual Report [7, 8]. From the combined heat and power (CHP) came 6000 GWh. The distribution of heat supply volume is visualized in **Figure 4**.

The support of heat from renewable energy sources mainly takes the form of financial support for investments in the Slovak Republic.

Further, we are focusing more on the legislation governing the use of renewable energy sources in Slovakia.

2. Legislation governing the use of renewable energy sources in Slovakia

In Slovakia, the primary legislation consists of Act of the National Council of the Slovak Republic No. 656/2004 Coll. Energy Act [9]. This Act defines the basic processes related to electricity and RES, as well as basic concepts, and performance of state administration. It also introduces conditions for issuing a license for electricity production from RES and conditions for the construction of energy facilities (including facilities for electricity production, when electricity is produced from RES). And also, the Act defines the rights and obligations of a producer of electricity from RES and rights and obligations of the transmission and distribution system operator to which the producer of the electricity from RES is connected and through which the transmission or distribution of electricity produced from RES is carried out to the final consumption point. Under this Act, support for RES is achieved through the priority access, connection, transmission, distribution, and supply of electricity produced from RES. However, the producer must respect the technical and commercial conditions of access and grid connection, which are specified in the tertiary legislation.

The secondary legislation consists of the Government Regulation No. 211/2010 [10], laying down the rules for the functioning of the electricity market and the Act no. 309/2009 Coll. [11] on the Promotion of Renewable Energy Sources and High Efficiency Cogeneration and on Amendments to Certain Acts.

Government Regulation No. 211/2010 [10] (Electricity Market Rules), by its very nature, supplements the "Energy Act" and specifies some of its provisions. These market rules lay down the conditions for connection, access, transmission, and distribution of electricity. It defines the criteria to connect the producer to the system, criteria to carry out the distribution of electricity produced also from RES, and the necessary contractual relations necessary for connecting the production equipment. The contractual relations named in the Market Rules are further specified in tertiary legislation. The electricity market rules further define and develop functional processes related to market participant deviation, registration of daily supply diagrams, etc.

The Act no. 309/2009 Coll. [11] specifies the method of support and conditions for the promotion of electricity production from renewable energy sources, electricity by high-efficiency cogeneration, and biomethane; rights and obligations of producers of electricity from renewable energy sources, electricity from cogeneration, electricity from high-efficiency cogeneration, and biomethane; the rights and obligations of other electricity and gas market participants; and the rights and obligations of the legal person or the natural person who places on the market fuels and other energy products used for transport purposes.

The tertiary legislation includes in particular rules of operation of the transmission system operator; operating rules of the distribution system operator; technical conditions of the transmission system operator; technical conditions of the distribution system operator; URSO decisions; and URSO Decree no. 2/2008 and its amendments[7, 8].

3. Biomass as a renewable source of energy

Biomass is one of the key renewable sources of energy that is produced from organic matter. It includes wood, agricultural crops and waste, and other "living" materials that can be used to produce heat and energy.

Dzurenda and Jandačka [12] define biomass as a matter of biological origin, which includes plant biomass grown in soil and water, animal biomass, production of animal origin, and organic waste.

Directive 2001/77/EC [13] defines the biomass as a biodegradable fraction of products, waste, and residues from agriculture (including vegetal and animal substances), forestry, and related industries, as well as the biodegradable fraction of industrial and municipal waste.

Lieskovský and Gejdoš [14] understand the term biomass as all living and organic matter in each system that was originated and developed as a product of life processes (development, growth, and reproduction) of living organisms. According to this definition, it provides a very wide range of its possible systematic sorting and distribution.

In terms of its origin, we can talk about plant biomass (phytomass), animal biomass (zoomass), and municipal and industrial waste. Dendromass is an organic matter of woody and shrubby plants consisting of wood, bark, and green matter [12]. Phytomass is a biomass of plant origin [15].

Regardless of source, biomass materials can be divided into two broad categories: woody and non-woody. Forests provide only woody materials; agriculture sources provide both woody and non-woody biomass for bioenergy production [16].

The choice of biomass (i.e., woody or herbaceous species) for energy production purposes depends upon the end-use, bio-conversion portion of interest, e.g., combustion, gasification, pyrolysis, fermentation, or mechanical extraction of oils.

Looking back at the recent past, also in the Slovak Republic, biomass for energy purposes was not an interesting topic until 2000. Traditionally, it was previously considered as an additional source of energy to meet local heating needs, mostly in areas without fossil fuel infrastructure. Until 1999, there was no domestic demand for forest fuel chips and their annual production ranged from 2000 to 3000 tons (i.e., 2–3 Kt) [17].

The pioneer in this area was Slovenské energetické strojárne (SES), a. s., Tlmače in Slovakia, which reconstructed the boiler room in 2001 and adapted the equipment for the combustion of chips. According to the TREND newspaper (published on April 11, 2003), at that time it was 20,000 tons of wood chips per year, covering the heating needs of buildings and part of the Lipník housing estate in Tlmače. The use of wood chips in SES Tlmače also solved to a large extent the problem of the Forest Enterprise Levice (LZ), who were looking for sales opportunities for not very attractive tree species such as Turkey oak (*Quercus cerris*) and black locust (*Robinia pseudoacacia*) at that time.

Since that time, much has changed in the timber market. The amount of logging in the Slovak forests has been increasing in the past 15 years. Planned and actual logging is increasing in Slovakia, particularly due to an increase in the share of stands of higher (ruby) age.

The unbalanced age structure in the forests of Slovakia causes cyclical changes also in the development of logging possibilities. It is anticipated that they will decline already around 2030 but depending on the extent of incidental felling [18].

In 2000, approximately 5.5 mil. m^3 of timber was logged, while it was more than 9.3 mil. m^3 in 2017. The trend of the decreasing quality of timber on the market and an increase in the share, especially of the fifth-grade timber assortments, is visible. To a large extent, wood degradation is also due to a high proportion of incidental felling, which regularly exceeds 50% (57% in 2015), with a significant proportion of felling being found in coniferous forests [19].

According to the document "Utilization of wood for energy purposes," the total consumption of solid wood fuel biomass (fuel wood, chips, fine-grained and lump residues after processing and handling of wood, briquettes, and pellets) amounted to 3.05 mil. tons (3.05 MMt) in 2017.

The key consumers of wood fuels, which are the dominant renewable energy source in Slovakia, are the wood processing and pulp and paper industry, the population, central heating sources, and the energy sector. The heat produced i s mainly used for heating and industrial purposes. The proportion of wood fuels in the total consumption of primary energy sources in the Slovak Republic was 1.9% [18].

The heat producers associated in the Slovak Association of Heat Producers (SZVT) heat 38 places together, for which approximately 257,000 tons of timber are used annually (i.e., 2.14% of harvested wood). If the heat producers only used branches and wood waste for heating, it would still not be even 10% of the total harvested wood plant.

Other nine electricity producers from biomass, who are not associated with the SZVT, utilize approximately 530,000 tons (530 Kt) of wood annually, i.e., approximately 4.17% of total timber harvesting. Indication of how much wood is used for individual heating of households is not available [20].

The decisive legal document for forest management in the Slovak Republic is the Act no. 326/2005 Coll. [21] on forests, as amended. The Act defines the areas of forest land and forest protection, professional and differentiated forest management, forest use, and the requirement of sustainable forest management.

The current forestry and agriculture legislation also addresses land use issues related to the sustainability of forest biomass (also dendromass) production and has a direct impact on its energy use [22].

Table 2 presents data representing the development in the dendromass stock specified for energy use.

The expected significant increase in the proportion of renewable energy sources and the use of underproductive agricultural land for the cultivation of energy stands results also in a significant increase in the potential of energy-efficient biomass to produce heat and energy in Slovakia. At the same time, it is possible to support further development of the fuel dendromass market. The amendment to the Act on forests introduced concepts such as energy stands and forest plantations. Energy stands are purpose-built forests with the aim of maximizing biomass production in the first 15 years, while also fulfilling other forest functions, especially soil conservation, erosion control, and partly landscape creation. Biomass produced in this way should be used mainly for energy production.

In energy stands and forest plantations, it is not possible to effectively use the management methods as in conventional forests. For example, it is unreasonable to require the provision of conventional management operations in such forest stand. For that reason, the application of the conventional stand management obligation is excluded in these cases. At the user's request, the stands can be reclassified to

Year	Forest chips[1]		Wood fuel and other[2]		Total	
	(Kt)	(TJ)	(Kt)	(TJ)	(Kt)	TJ
2017	580	5510	845	8028	1425	13,538
2016	610	5795	830	7885	1440	13,680
2015	615	5843	835	7933	1450	13,775
2013	620	5890	820	7790	1440	13,680
2010	250	2375	695	6602	945	8977
2005	120	1140	640	6080	760	7220
2000	5	48	471	4475	476	4522
1990	2	19	368	3496	370	3515

[1]*Wood chips and wood to produce wood chips*
[2]*Fuel wood and wood used for energy from waste, harvest residues, and dead trees*

Table 2.
Development of the dendromass stock for energy use (Source: NLC 1991–2018).

energy stands during the recovery of the Forest Management Program (PSL). In 2006, almost 550 ha of forest were reclassified this way in the OZ Levice (management unit of Forests Slovakia, S.E.). These were mostly the coppices of black locust (96.1%) and Turkey oak (1.2%). These coppices are restored by the clear cutting connected with the maximum utilization of the stump and root sprouting of the abovementioned tree species [23].

Current resources of wood on non-forest ground are mainly the tree stands on long-term unused agricultural land (so-called white areas), streamside stands, and trees in the open country, including linear planting vegetation, e.g., windbreaks and trees around roads.

Legislative conditions for planting fast-growing trees on agricultural land are determined directly by the Act no. 220/2004 Coll. [24] on the protection and use of agricultural land and by the amendment of Act no. 245/2003 Coll. on integrated pollution prevention and control and on amendments and supplements to certain acts.

For the purposes of this Act, fast-growing trees on agricultural land shall mean the plantation of fast-growing trees to produce wood biomass, on an area with extent more than 1000 m^2, for a maximum of 20 years.

The fast-growing tree species can be planted on agricultural land classified into the 5th to 9th quality group, according to the code of a certified soil-ecological unit used in Slovakia. Also they can be planted on agricultural land contaminated by dangerous substances, or on agricultural land classified into the 3rd or 4th quality group according to the code of a certified soil-ecological unit, or on agricultural land, which is located in a floodplain, that is wet or exposed to wind erosion. The plantations of fast-growing tree species cannot be established on areas situated in the 3rd to 5th degree of nature and landscape territorial preservation.

The tree stands on "white areas" formed mainly by succession of trees are located on an area of ca. 275,000 ha with a total wood supply of 36.6 MMm^3 (timber stock without bark).

The current stock of coniferous trees is 12.7 MMm^3, hard deciduous trees 9.1 MMm^3, and soft deciduous trees 14.8 MMm^3. The assortment structure of stands on "white areas" is represented by a higher proportion of fiber wood and wood for energy use than the stands on forest land. Due to their localization, stands on "white areas" are easily accessible, and terrain conditions enable the use of efficient timber logging technologies [25].

Another possibility of increasing biomass production is the plantation of fast-growing trees. The establishment of fast-growing tree plantations supports other unique and important environmental and ecological benefits that can provide enough raw material for the energy industry. At the same time, if certain decisions are considered in addition to production when planning a fast-growing tree plantation, they finally can have a positive impact on the landscape, biodiversity, soil, and water cycle in the ecosystem. The use of this method of targeted energy biomass extraction is a combination of forestry and agriculture and brings new opportunities supporting regional energy self-sufficiency.

With the increasing demands for biomass for energy purposes, the issues of production and targeted cultivation of fast-growing tree plantation (known also as short rotation coppice (SRC)) are becoming topical. In the future, demand for wood as a raw material for heating and electricity production is expected to increase. This increase will mainly be influenced by the situation on the fuel market and will be supported as a target of national and European energy policy. Energy chips from fast-growing tree species can thus make a significant contribution to the European targets related to increasing the proportion of renewable energy sources [23].

The most frequently planted tree species on plantations are various clones and varieties of poplar (*Populus* sp.) and willow (*Salix* sp.). Current legislation does not directly limit plantation owners and users to the use of a clone or varieties, but the cultivation of non-origin tree species is in violation of the Act no. 543/2002 Coll. [26] on nature and landscape. Appropriate selection considering habitat conditions is a prerequisite for meeting production expectations.

An important factor that can influence the future plantation of fast-growing trees is enough potential area for their establishment. The potential of plantation establishment is both on the forest and in the agricultural ground fund.

In 2017, the area of utilized agricultural land was 1,910,654 ha. The Slovak Republic accounts for 38.8% of agricultural land in the total land area [18]. In addition, the distribution of agricultural land in the Slovak Republic is also characterized by a high proportion of agricultural land in mountain and foothill areas with rugged terrain and unfavorable climatic conditions.

Under such conditions, intensive agricultural production is not efficient today. However, it creates the preconditions for the possibility of diversification of production, one alternative of which is the production of biomass for energy purposes.

In the medium-term horizon, energy stands is considered to be planted on an area of 30,000 ha. Their production of energy chips is accounted for 70% and fiber wood for 30 %, considering the 15-year-long rotation period (MP SR 2018) [18].

The possibilities of biomass to be used for energy purposes and its energy properties are studied by many experts worldwide. There is introduced brief review of the last research works in this field.

The worldwide research trends related to biomass as renewable energy derived from the analysis of the state of the research and trends in biomass for renewable energy from 1978 to 2018 were published by Perea-Moreno et al. [27]. Woch et al. [28] published a case study focusing evaluation of potential use of forest biomass for renewable energy based on systems approach. The ways to meet the future energy demands based on biotechnology and wood for energy purposes are described by Al-Ahmad [29]. Climate, economic, and environmental impacts of producing wood for bioenergy are introduced by Birdsey et al. [30]. Koponen et al. [31] published a study in which they tried to quantify the climate effects of bioenergy. Cordiner et al. [32] introduced results of biomass pyrolysis modeling at laboratory scale, which were further completed with their experimental validation. Kluts et al. [33] dealt with agriculture biomass sources. There are also several studies focusing on the determination of energetic parameters of biomass, e.g., [34–37].

4. Assessment of woody biomass stock in Slovak forests: case study 1

The geodatabase containing the data from the territory of the Slovak Republic (digital terrain model (DTM), settlements, district borders—producer and provider is the Topography Institute of the col. Jan Lipsky in Banska Bystrica) was added and preprocessed in ArcGIS for Desktop ver. 10.2. together with geodata on forest stand outlines and forest inventory database produced and provided by the Department of Forest Resources and Informatics of the National Forest Centre in Zvolen and containing the detailed description of the stands which is updated every 10 years.

For the needs of further analyses of the database, all the forest stands existing in the territory of the Slovak Republic were selected. Totally, there were 211,968 forest stands included in the analysis.

From the digital terrain model, and using the surface analyses tools in ArcGIS, a raster of terrain slopes in the ArcGIS environment, which was later used in the process of identifying available sources of woody biomass (dendromass) for energy use in forests of the Slovak Republic, was derived.

As the primary source of data for calculating the amount of dendromass is available, we used the data concerning the description of the basic parameters of forest stands, which are introduced in the database, which is used as the primary source of data for providing the spatial analyses in GIS environment. These data are the result of detailed surveys on forest which are provided for purposes of forest management plan elaboration.

As the basic parameters for the derivation of the total available dendromass stock, we used the data on the extent of area of forest land, timber stock, and the planned annual cutting. In addition, we also analyzed the age structure and forest category of the stands.

Not all dendromass is suitable for energy purposes. There were specified restriction criteria. The most restrictive criterion to identify the dendromass for energy purposes is terrain slope. Steep terrain is a limitation for deployment of majority of timber logging technologies used in Slovakia. That is the reason why the forest stands situated within terrain with slope of 50% and more were excluded.

There were also excluded forest stands classified as protection forests, where protection function is superior to productive function. There are also included stands assigned into the 5th degree (the highest) of nature preservation, which are mostly in the National Parks of the Slovak Republic.

The information on the category of forest and its nature protection level was obtained from a database containing basic parameters of forests, which we received from the Department of Forest Resources and Informatics, National Forest Centre. Those data were classified, and the unsuitable stands were excluded from further analyses.

Another criterion for excluding the stands unsuitable for energy purposes was the classification code of individual forest stands related to the "management set of forest types," which is used in the Slovak Republic. The management sets of forest types [38] were identified, which are naturally very low in nutrients (especially calcium, magnesium and potassium) or habitats with extreme texture, skeleton, water regime, as well as sites with an excess of certain nutrients, but a great lack of potassium and phosphorus. The forest stands belonging to those management sets of forest types were classified as unsuitable and were excluded from the analysis.

The results of the analyses are introduced in **Figure 5** and in **Table 3**. The information on potential woody biomass stock was derived from eight existing district (region) units in Slovakia.

The graphical output of the analysis is introduced in **Figure 5**.

In **Table 3**, the potential stock of woody biomass to be used for energy purposes in Slovakia, derived from eight existing districts in Slovakia based on pre-defined criteria, is introduced.

According to the data introduced in **Table 3**, we can state that the highest stock of woody biomass to be potentially used for energy purposes is in Banská Bystrica (24%) and Prešov (24%) districts (together 48% of the overall woody biomass stock).

Further, we introduce the approaches used to determine the energetic properties of selected fast-growing tree species which have potential to be planted for energy purposes in Slovakia.

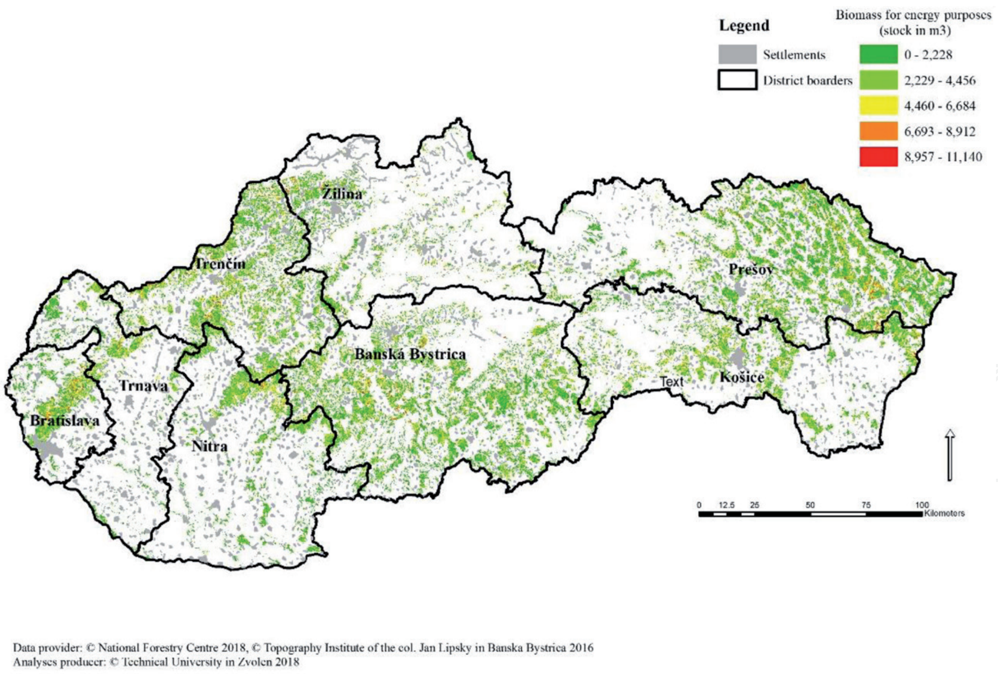

Figure 5.
Woody biomass stock in forests of the Slovak Republic (Source: Authors).

District	Biomass stock (m^3)	Number of forest stands	Stand extent (km^2)	District extent (km^2)
Bratislava	10,782,036	9955	418.0	2059.5
Trnava	10,034,628	11,109	414.3	4143.0
Trenčín	37,080,538	32,030	1336.8	4501.3
Žilina	16,716,540	19,726	590.0	6789.2
Nitra	15,183,661	15,200	732.2	6338.7
Banská Bystrica	53,848,038	54,345	2292.3	9450.5
Košice	25,116,195	19,536	1041.3	6749.2
Prešov	53,896,725	46,659	2307.5	8988.2
Total	222,658,361	208,560	9132	49,020

Table 3.
Woody biomass stock to be used for energy purposes in Slovakia.

5. Fire and energy properties of woody biomass: case study 2

To analyze the fire and energetic properties of selected species of woody biomass for energy production purposes, several standardized but also progressive analytical methods were used.

Three woody biomass species were tested: *Populus x euroamericana* clone MAX 4, *Salix viminalis* clone TORA, and *Paulownia tomentosa*.

To implement the laboratory fire tests, the samples of woody biomass species were represented by the blocks with dimensions of 50 × 40 × 20 mm in the case of mass loss testing and 20 × 20 × 10 mm in the case of spontaneous ignition temperature testing.

The samples of *Salix viminalis* clone TORA and *Populus x euroamericana* clone MAX 4 were taken from the existing plantations of the University Forest Enterprise of the Technical University in Zvolen territory.

The samples of *Paulownia tomentosa* were taken from the plantations belonging to the Agricultural Co-operative Dolné Saliby.

The following analyses were implemented: analyses of spontaneous ignition temperature; analyses of mass loss during sample thermal loading with radiant heat source; and gross calorific value, heating value, and ash content analyses.

5.1 Analyses of spontaneous ignition temperature and induction period of samples

In the laboratory fire tests, samples of woody species, i.e., blocks with dimensions of 50 × 40 × 20 mm for mass loss testing and 20 × 20 × 10 mm for spontaneous ignition temperature testing, were used.

Before the test, all the samples were conditioned according to the STN EN ISO 291 standard requirements. Totally, three samples of each woody biomass and herbaceous energy crops undergone testing.

To determine the temperature of spontaneous ignition, the incendiary hot-air oven (Setchkin furnace) was used, and the methodology for testing the spontaneous ignition temperature, according to the STN ISO 871 standard, was applied.

Those analyses were performed in the laboratories and use the research infrastructure of the Department of Fire Protection, Faculty of Wood Sciences and Technology, Technical University in Zvolen.

Table 4 shows an overview of the determined spontaneous ignition temperatures and induction periods reached by *Populus x euroamericana* clone MAX 4.

The lowest mean spontaneous ignition temperature value was recorded by *Salix viminalis* clone TORA (419.46°C), which was reached in 328.87 s from the start of the test. The results also showed that with increasing thermal loading (and higher spontaneous ignition temperature value), the samples were resistant to fire for a shorter time.

5.2 Analysis of mass loss during sample thermal loading with radiant heat source

To understanding the thermal decomposition process of all the samples tested during their burning, implementing thermal analyses, and studying the mass loss of the sample are recommended.

To study the mass loss of the samples, the nonstandard method of solid thermal properties testing was applied.

The samples of woody biomass and energy crops undergone thermal loading by a radiant heater with the power of 1000 W for a specific time, i.e., 10 min. The mass

Measurement no.	Spontaneous ignition temperature of *Populus* t (°C)	Spontaneous ignition temperature of *Salix* t (°C)	Spontaneous ignition temperature of *Paulownia* t (°C)
1.	424.92	412.65	420.10
2.	417.14	426.63	410.98
3.	419.69	419.09	441.87
Mean	420.58	419.46	424.32

Table 4.
Spontaneous ignition temperatures of woody biomass species.

loss of the samples (g) was measured for each 10-s interval. Totally, three samples of each woody biomass undergone testing.

Those analyses were performed in the laboratories and use the research infrastructure of the Department of Fire Protection, Faculty of Wood Sciences and Technology, Technical University in Zvolen.

The resulting courses of mass loss of the tested woody biomass species are introduced in **Figures 6–8**.

5.3 Gross calorific value, heating value, and ash content analyses

To calculate the heating value, it was necessary to determine the gross caloric value of the samples. The IKA C200 calorimeter was used to determine it. The procedure was conducted in correspondence with the standard STN ISO 1928:2003-07 Solid fuels. Determination of gross caloric value and calculation of heating value. In the test, the sample is burnt in a calorimetric bomb and filled with oxygen under the pressure of 3–5 MPa.

Based on the mathematical Eq. (1) introduced in the same standard, the heating values (KJ·kg^{-1}) of the samples were further calculated:

$$q_{v,net,m} = \left[q_{v,gr,d} - 206.0 \cdot w\,(H)_d\right] \cdot (1 - 0.01 \cdot M_T) - 23.5 \cdot M_T \qquad (1)$$

where $q_{v,net,m}$—heating value at constant volume and containing with water (kJ·kg^{-1}); $q_{v,gr,d}$—gross calorific value at constant volume without water content (kJ·kg^{-1}); $w(H)_d$—percentage of hydrogen (%); M_T—total water content of the fuel for which conversion is required - relative moisture (%).

In the calculations of heating value, the relative moisture content of 10% was used. Before the testing, the samples were dried at 103 ± 2°C to reach the moisture content of 0% and further conditioned in a desiccator at the temperature of 20 ± 1°C for 24 hrs. Three measurements were made for each sample. The results show the average value of those measurements.

The procedure for ash determination was based on the requirements of the standard STN ISO 1171:2003 (441378) Solid mineral fuels. Determination of ash. The principle of the method is the incineration of the sample, heated in air at a temperature of 815 °C ± 10 °C, for specified time interval and maintained at that above-mentioned constant temperature. For this purpose, the muffle furnace was used. The ash content was calculated from the weight of the residue after incineration.

Those analyses were performed at laboratories and use the research infrastructure of the Department of Forest Harvesting, Logistics and Ameliorations, Faculty of Forestry, Technical University in Zvolen.

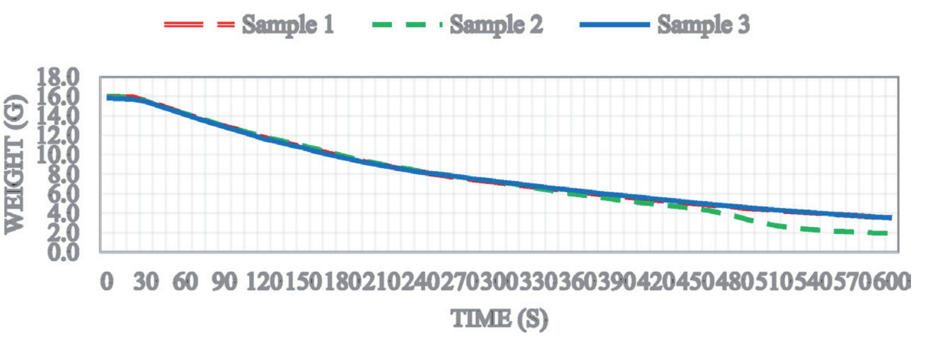

Figure 6.
Mass loss course of Populus x euroamericana *clone MAX 4 during the thermal loading.*

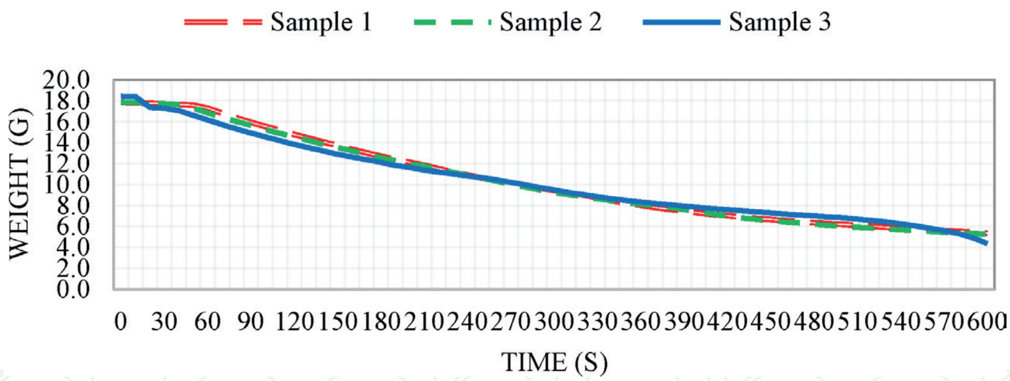

Figure 7.
Mass loss course of Salix viminalis *clone TORA during the thermal loading.*

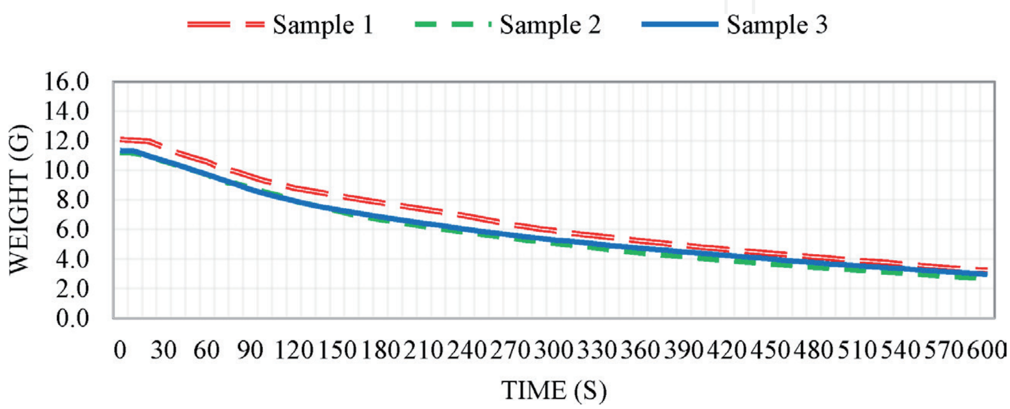

Figure 8
Mass loss course of Paulownia tomentosa *during the thermal loading.*

The highest energy potential expressed in terms of the highest gross calorific values (19.71 ± 0.18 MJ.kg^{-1}) as well as heating values was found in the case of *Paulownia tomentosa*.

The results of gross calorific value and heating value of all woody biomass species are introduced in **Table 5**.

The ash content analyses results are introduced in **Table 6**.

The highest ash content was achieved in *Populus x euroamericana* clone MAX 4, followed by *Salix viminalis* clone Tora and *Paulownia tomentosa* which showed the lowest value of ash content in the analyses.

The highest energy potential expressed in terms of the highest gross calorific values as well as heating values (at 10% moisture content) was recorded in the case of *Paulownia tomentosa* (19.71 ± 0.18 MJ·kg^{-1}; 16.40 ± 0.18 MJ·kg^{-1}). The lowest values of gross calorific values and heating were recorded in *Populus x euroamericana* clone MAX 4 (19.47 ± 0.29 MJ·kg^{-1}; 16.18 ± 0.29 MJ·kg^{-1}). The differences in values recorded in the tested samples of fast-growing tree species were very low. According

Sample	Gross calorific value (MJ·kg^{-1})	Heating value (MJ·kg^{-1})	Standard deviation
Populus x euroamericana clone MAX 4	19.47	16.18	0.29
Salix viminalis clone Tora	19.63	16.33	0.11
Paulownia tomentosa	19.71	16.40	0.18

Table 5.
Gross calorific value and heating value of tested woody biomass samples.

Sample	Ash content (w%)	Standard deviation
Populus x euroamericana clone MAX 4	2.58	0.24
Salix viminalis clone Tora	1.28	0.08
Paulownia tomentosa	0.75	0.05

Table 6.
Ash content of the woody biomass species.

to these finding, all the tested biomass species were considered suitable to be used for further energy use. However, *Paulownia tomentosa* seems to be the most suitable from calorific value and heating value point of view.

Heating value should be tightly connected also with elemental composition and affected by the variation in cell wall composition and ash. This fact was confirmed also by ash content analysis using the muffle furnace for ashing. The ash content of tested woody biomass species was in the range of 0.75–2.58 w%. The lowest values of ash content were recorded right in *Paulownia tomentosa* (0.75 ± 0.05 w%).

Similar results were achieved also by Yavorov et al. [37], who were engaged in determining the potential of fast-growing hardwood species from Bulgaria (*Paulownia elongata*, *Populus alba*, and *Salix viminalis* RUBRA), and Martinka et al. [39] who studied the calorific value and fire risk of selected fast-growing hardwood species (*Populus nigra x Populus maximowiczii*, *Salix alba* L.).

6. Conclusions

Climate change caused by increasing greenhouse gas emissions is among the most serious global threats. Therefore, many experts have been looking for ways to solve this problem for more than 20 years.

In recent years, in the world, the importance of the energy sector has increased, particularly in terms of sustainable development. The direction of energy sector development is slowly changing toward the use of environmentally friendly fuels and energy from renewable sources.

Slovakia as a country that is more than 90% dependent on imports of primary energy sources should have a primary interest to use its own, renewable energy sources.

Biomass is the largest renewable energy source in Slovakia. It consists of vegetable and animal origin materials suitable for energy use. Biomass is considered in terms of CO_2 biomass is a neutral fuel, because it shall release only as much of the CO_2 when burning as the plant has taken during its growing.

The Energy Policy of the Slovak Republic aims in increasing the share of renewable and secondary energy sources, which constitutes a significant portion of woody biomass (dendromass) produced in forestry, wood industry, and pulp and paper industries.

To identify the available sources of woody biomass or any kind of biomass, as the first step of any analysis concerning the possible location of any power plant using biomass for energy and heat production, it is recommended to deploy those tools allow processing the existing data on forest and agricultural land and different kinds of spatial analyses to get the required information. An approach that is used in Slovakia for this purpose is introduced.

To study the important characteristics for the biomass combustion process is possible through deployment of standardized and progressive nonstandardized laboratory fire tests and calorimetric and thermal analyses. Some of them were introduced in the framework of this chapter.

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Nomenclature

EU	European Union
RES	Renewable Energy Sources
URSO	Regulatory Office for Network Industries
MP SR	Ministry of Agriculture of the Slovak Republic
EC	European Commission
CHP	Combined Heat and Power
GDP	Gross Domestic Product
SR	Slovak Republic
DTM	Digital Terrain Model

Symbols

$q_{v,net,m}$	Heating value at constant volume and containing with water [kJ·kg^{-1}]
$q_{v,gr,d}$	Gross calorific value at constant volume without water content [kJ·kg^{-1}]
$w(H)_d$	Percentage of hydrogen [%]
t	Temperature [°C]

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