Bioenergy and Biopesticides Production in Serbia

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The critical role of energy in contemporary life and the environmental challenges associated with its production imply the need for research and exploration of its novel resources, including biomass as a source of bioenergy. Along with the energy-related degradation of the environment, serious environmental issues arise from the use of pesticides in food production and plant breeding. This prompts the utilization of biomass in the production of biopesticides, offering a sustainable alternative to synthetic chemical pesticides.

Keywords: biofuels; biogas; biomass; biopesticides; biowaste; circular economy; invasive alien species; nature-based solutions; sustainable development goals

1. Introduction

Energy represents a primary need of a contemporary man, enabling the normal functioning of all aspects of life. Since the dawn of human civilization, people have adapted to different environmental conditions through the utilization of available natural resources for energy production. The industrialization and urbanization processes, combined with the continuous population growth, strongly affect the sector of energy production, which is reflected in the increasing exploitation of non-renewable energy sources [1]. Excessive energy consumption has led to serious environmental issues, such as global warming and climate change, as a result of greenhouse gas emissions from fossil fuel combustion, further causing the deterioration of both the environment and biodiversity [2]. The intense need for carbon-based fossil fuels has prompted many countries around the world to establish short-, medium-, and long-term systems aimed at transitioning to the use of renewable energy sources [3]. To adequately approach the preservation of the environment and natural resources, new technologies need to be accepted, which implies the development of the innovative concept of “green energy” [4][5]. The Global Renewable Energy Community announced that the amount of energy produced from renewable energy sources worldwide, such as hydropower, geothermal energy, wind energy and especially bioenergy, records a positive trend [2]. In the future, it is expected that renewable energy will play an essential role in the world’s energy supply, enabling the sustainable development of countries around the globe [6].

Biomass is a valuable source of raw material for the production of bioenergy, including biopower and biofuels [5]. Besides forests, agricultural plants, and newly introduced algaculture as a source of bioenergy, biomass encompasses different kinds of waste, such as biodegradable parts of by-products, waste or residues from agriculture (plant or animal origin), forestry and related industries, as well as biodegradable parts of industrial and municipal waste [7][8][9]. Unsustainable biowaste management practices are responsible for soil, groundwater and air pollution, with toxic compounds released into the environment, posing a serious threat to human health through the biological food chain [10]. Along with the energy-related environmental challenges, pesticides’ utilization in food production and plant breeding in general endangers sustainable development, jeopardizing environment preservation and human health improvement strategies. Biomass, except for its usage in bioenergy production, also offers numerous possibilities as a source of biopesticides. Biopesticides are pesticides of biological origin, developed from naturally occurring living organisms, mostly microorganisms (e.g., bacteria, fungi, and baciloviruses), animals (entomopathogenic nematodes), and plants. Biopesticides are alternatives to synthetic chemical pesticides and are key components of integrated pest management systems [10][11][12][13]. Biopesticides have several advantages over their synthetic chemical predecessors: they are usually less harmful, target-specific, effective in small quantities, decompose quickly, do not leave harmful residues in the environment and the development of resistance is less. To be accepted by producers, biopesticides must be as effective as the synthetic chemical pesticides they would replace [12].

The need for energy security paired with environmental degradation are the main issues associated with a linear economy based on conventional non-renewable energy sources [14][15][16][17]. The circular economy, unlike the linear economy,
represents a sustainable economic system in which economic growth is related to the reduced utilization of non-renewable resources [18].

The acquisition of bioproducts may be competitive with the food sector if food commodities are used as feedstock for bioenergy and biopesticides, or if the crops needed for production are cultivated on soil suitable for agricultural activities [19]. An additional problem that could arise from the increased bioproduct acquisition is the reduction of water availability for food production, as a larger amount of water is directed toward the manufacturing of bioproduct feedstock [20][21]. To address those essential questions while enabling the achievement of sustainable development goals set by Agenda 2030 [22], the approach to non-edible biomass sources as feedstock for bioenergy and biopesticide production must be altered [23].

The Republic of Serbia, a country situated in south-eastern Europe, does not fully utilize the possibilities regarding sustainable biomass usage due to many restraints. As candidates for joining the European Union, Serbia and other Balkan countries, have accepted the obligation to follow EU policies and programs, which implies that these countries need to introduce and intensify the production and use of renewable energy sources by 2030 [23][24]. The National Strategy for the Sustainable Use of Natural Resources and Goods highlights the main issues concerning the production and use of renewable energy, including the insufficient availability of technology, a lack of knowledge and professional skills to use necessary technologies, the undeveloped biomass market, the need for the introduction of measures for the purpose of biomass production monitoring, and the non-compliance of policies between the energy sector and other related sectors [25]. Although suitable for the production of bioproducts, in terms of feedstock availability [26], Serbia is not equipped with sufficiently developed capacities to achieve its full potential concerning nature-based solutions in this field. The low level of public awareness about the benefits related to renewable energy, a lack of financial resources and the absence of a legal framework, make it difficult for Serbia to properly approach the issues of sustainable development [27][28].

### 2. Biomass, Liquid Biofuels and Biogas

Bioenergy represents the largest renewable source of energy, based on several feedstock types. Mostly exploited feedstock includes residues from forestry (fuelwood, wood chips, sawdust), crops cultivated specifically for the purpose of energy production, wastes and agricultural residues (animal waste, paddy straw, rice husk), as well as some municipal solid waste partitions [29]. The overall energy demand records continuous growth, with a growth rate of 4% in 2021 in comparison with the pre-pandemic period, where modern renewables counted 8.8% in 2011, 11.7% in 2019 and 12.6% in 2021 of total energy consumption [30]. When compared to fossil fuels’ utilization of around 80% in overall consumption, renewables were responsible for the significantly lower share of energy, but the positive trend showed valuable improvement in renewable energy production. From the total share of renewable energy utilization, the same source reported that biofuels for transport participated with 1%, while biomass joined with the geothermal, ocean, solar and wind power participated with only 3%. In 2022, the biomass feedstock provided 2.4% of the overall generation of electricity [31].

The highest amount of the renewable energy produced in Serbia in the period 2017–2021 was utilized in the sectors of electricity and the sector of heating and cooling, while the sector of transport used less than 2% of renewable energy [32]. In the selected five-year period, the average renewable energy share in total energy consumption was 22.73%. From the total amount of energy used for heating and cooling purposes in 2021, 35.47% belonged to renewables.

The bioproducts acquisition from biomass is not a new process, but its use and application represent a major challenge for developing countries [33]. The increasing import of fossil fuels and the increasing demand for non-renewable energy sources in Serbia are considered the key reasons why it is necessary to invest in the development of renewable energy sources as well as in procedures for biowaste management [34]. The energy sector in Serbia is considered one of the most important and largest sectors of the country’s economy, but also very inefficient, as it is largely dependent on oil imports as its reserves of non-renewable energy sources are very limited [35]. Serbia’s energy dependency stands at 40%, which is deemed average when compared to other EU nations [36].

Biomass can be produced from edible and non-edible raw materials from the natural environment. In Serbia, agricultural edible crops such as sunflower, flax, soy and other crops are mainly used. Taking into account the factor of feedstock competition with food sector, non-conventional and non-edible oils have an advantage over edible oils when it comes to the production of bioenergy, and at the same time, they should represent a feedstock that has a high energy value [37].

Local governments and urban communities face mounting pressures to manage, collect, process, and dispose of waste appropriately in Serbian cities struggling to manage the effects of uncontrolled urbanization [38]. Because of that,
biodegradable waste as a biomass source remains unutilized, despite its potential in bioenergy production. Although Serbia has been in the process of joining the European Union for decades, developing an effective biowaste management system is essential, aligning with the broader societal and economic progress and in accordance with the European Union's renewable energy agenda. Today, the most common policy of waste management in Serbia is disposal in landfills or on free-untouched surfaces, which represents a huge danger to the environment in the form of gas emissions, CO₂ and CH₄ leakage and the production of wastewater. It is necessary to change this technology through sustainable practices to encourage development and reduce the harmful impact on the environment.

The development of biofuels markets, investment rates and the construction of new facilities is strongly affected by different factors, including policy uncertainty, competition for feedstock, crop productivity dependence on the weather conditions, competition of biofuels production with food production in terms of land and water resources, concerns about production impacts on environment. The production of liquid biofuels in the world was 162 billion liters in 2021, which corresponds to 3.6% of total energy consumption in the transport sector.

Biodiesel derived from biomass sources stands out as a promising alternative to petroleum diesel fuel. It represents a biodegradable, non-toxic, nearly sulfur-free, and non-aromatic fuel, originating from vegetable oils or animal fats. Globally, biodiesel has been gaining growing attention, serving either as a blending component or as a direct substitute for conventional diesel fuel in vehicle engines. Feedstock materials utilized in biodiesel production encompass various triglyceride-based substances, traditionally categorized into the following main groups: vegetable oils (including both edible and non-edible types), animal fats (such as chicken fat, pork lard, beef tallow, and poultry fat), waste oils (such as waste cooking oils or waste industrial oils), and algal oils.

The limited adoption of biodiesel as a replacement for fossil diesel is mainly attributed to its relatively higher production costs and the restricted availability of feedstock. In Serbia, sunflower, rapeseed and soybean are recognized as the most significant oilseed crops. According to Đurišić-Mladenović et al., if sunflower and/or rapeseed, along with waste cooking oils, are going to be the main sources of biodiesel production in Serbia, the annual biodiesel output has the potential to reach approximately 285,000 tons. This quantity would replace nearly 20% of the diesel fuel consumed in the transportation sector in Serbia. Alternatively, if soybean oil is considered the primary biodiesel feedstock, the substitution rate would be 10%.

The utilization of edible oils poses a challenge to global food production, which is further exacerbated by fertile soil scarcity. Therefore, there is a pressing need to explore biodiesel production from non-edible or lower-quality edible oils derived from existing urban and peri-urban greenery. Investigating these alternative sources could help address the conflict between biodiesel production and the demands of fertile soils for food production. A segment of agricultural waste biomass and used frying oil is identified as highly appropriate feedstock for biodiesel production, offering advantages from both environmental and economic standpoints. By utilizing these materials as feedstock, not only is the problem of waste disposal addressed, but it also reduces the demand for agricultural feedstock that could otherwise be utilized for food production. Recent studies by domestic researchers discussed some novel feedstock alternatives that could be introduced in Serbia for the purpose of bioenergy production, suggesting the non-edible species that are relatively easy to grow, that are characterized with intensive annual vegetative biomass growth, which production is more cost-effective or that are suitable even for degraded soils. The potential of the following species have been discussed: Phragmites australis, Miscanthus × giganteus, Beta vulgaris, Saccharum sp., Ricinus communis L. Prosopis sp., Arundo donax L., Thinoypyrum ponticum, Panicum virgatum. Current legislatives in Serbia do not recognize specifically the invasive alien species (IAS) as a source of biomass for liquid biofuels nor biogas production thus such feedstock could be assigned to the residuals from forestry or horticulture and biodegradable part of municipal waste. However, the potential of many IAS for bioenergy acquisition has been investigated and recognized by researchers in Serbia and worldwide, including species Koelreuteria paniculata, Reynoutria japonica, Ailanthus altissima, Paulownia tomentosa, Dichrostachys cinerea, Acacia Holosericea, etc. The process of biodiesel acquisition from invasive species in Serbia has been investigated and explained in the works of Ljubojević et al. and Tomić et al.

The fact that diesel vehicles will be banned in many European cities in the near future, decreased prices of used vehicles, which enabled citizens of Serbia to buy those cheaper vehicles, further increasing already high consumption of diesel fuel for transportation purposes. To address the negative environmental impacts of this trend, and decrease foreign trade deficit, Serbia has to find sustainable ways of imports' reduction, highlighting the need for domestic production of biofuels. The directive 2009/28/EC set a goal to achieve 10% of biofuels in petroleum fuels by the end of 2020. A previous directive implied 5.75% share of biofuels, including biodiesel and bioethanol, in total transport fuels, by the end of 2010.
This goal has led to several important investments in production of biodiesel in Serbia, where investors indeed believed that state will provide incentives and aid to overcome obstacles in production.

After the initial installation of biodiesel plants in Serbia, several government moves led to almost complete termination of production, including high excise taxes on biofuels, the absence of subsidies for production and transportation fuel marking regulations. Central Serbia currently has a modest share of approximately 2% of oil crops out of its total arable land area. This implies that a significant expansion in the cultivation of oil crops is more likely to occur in Central Serbia rather than in Vojvodina, where the cultivation potential has already been realized. The country encompasses around 4.2 million hectares of cultivable land, with an annual portion ranging from 170,000 to 200,000 hectares left unused. It was estimated that within a span of five to seven years, it is possible to produce enough feedstock for the production of 300,000 tons of biodiesel, utilizing 200,000 hectares of available land. The balance of biodiesel production and consumption in Serbia appears for the first time in 2021 in the data of the Statistical Office of the Republic of Serbia. The import of biodiesel in its pure form counted 1139 t, while 758 t of biodiesel fraction in blended biodiesel (biodiesel blended with fossil fuel) were exported, with no primary production of this form of biodiesel. Gross available energy of pure biodiesel was 28 TJ, but this biofuel was not utilized.

Although Serbia has basic prerequisites for the production of bioethanol, the level of industrial bioethanol production is very low. Bioethanol is mostly used for medical and pharmaceutical purposes, as well as in the production of alcoholic beverages. Serbia is not producing bioethanol as an energy source and in order to provide capacities for the production of bioethanol as a fuel, new capacities need to be constructed.

According to the Energy Development Strategy of the Republic of Serbia, the raw materials required for bioethanol production include cereals, millet, Jerusalem artichoke (topinambour), and potatoes. The primary source for bioethanol production is sugar beet molasses, but maize is presently the most appropriate as bioethanol feedstock in Serbia.

An estimate suggests that roughly 100,000 hectares of marginal land in the Republic of Serbia could be utilized for the cultivation of millet and Jerusalem artichoke, potentially leading to the production of around 3 million tons of ethanol per year. The utilization of field crops for biodiesel and bioethanol production has been consistently increasing until recently. Particularly noteworthy for cultivation, given their substantial energy potential, are prairie grass, reed canary grass, giant reed, and miscanthus. Alternative feedstocks not suitable for the food production are actively being sought.

Biogas is an another efficient renewable energy source that contributes to the reduction of greenhouse gas emissions and aids in waste disposal. Reducing the release of greenhouse gases into the atmosphere involves preventing methane emissions that occur naturally during the storage of substrates. Biogas is primarily composed of methane (\( \text{CH}_4 \)) within the range of 50–70%, along with carbon dioxide (\( \text{CO}_2 \)) at a concentration of 30–50%. It is predominantly utilized for the generation of heat and electricity. When upgraded to pure biomethane, it is employed as a vehicle fuel, serving as an alternative to fossil fuels. As a renewable energy source, biogas holds advantages over solar and wind energy due to its constant (and variable) energy generation and the potential for energy storage in the form of biomethane.

Biogas can be produced in different facilities like landfills, sewage treatment plants, or anaerobic digestion plants. The characteristics of biogas, such as its chemical composition, energy potential, and fuel properties, vary depending on where it originates. Various feedstocks can be utilized for biogas production, including agricultural products (such as energy crops) and by-products (like livestock manure and crop residues), industrial wastes and residues, municipal organic waste, among others.

The biogas sector exhibits considerable diversity across Europe, with well-developed systems in countries such as Germany, Denmark, Austria, and Sweden, followed by the Netherlands, France, Spain, Italy, the UK, and Belgium. The study conducted by Cvetković et al. showed that Serbia has a great potential for biogas production. There are 24 registered biogas power plants that commenced operations between 2011 and 2021, boasting a combined installed capacity of 9415 kW. The construction of 73 more biogas power plants is planned. The Energy Development Strategy until 2025 including projections up to 2030, foresees the construction of power plants with a cumulative capacity of up to 80 MW by the year 2030. The direct production of biogas from energy crops grown in agriculture presents the greatest potential for biogas production in Serbia. However, the official data on the raw material composition used in Serbian biogas power plants are currently unavailable. Given that natural gas consumption in Serbia amounts to 2.5 billion m\(^3\), these findings suggest a considerable opportunity for substituting natural gas. The estimated potential of biogas production from municipal solid waste in Serbia is 95.6 million m\(^3\) per year, equivalent to 49.72 ktoe, indicating that municipal solid waste could become a significant energy source for the Republic of Serbia. Dijatkov et al. argue...
that the utilization of municipal biodegradable waste as a substrate for biogas production will only become viable if there is a primary waste selection process in place.

According to Eurostat [22], the renewable energy share in total amount of energy, among Serbia and the neighboring countries differ significantly (Figure 1). Generally, the highest share in five-year period was recorded in Albania, Montenegro and Bosnia and Herzegovina. In 2022, the countries which participated with the share of energy from renewable resources around 40% were Albania and Montenegro, while share in Serbia reached more than 25%. Interestingly, Serbia showed higher or similar rates of renewable energy production, depending on the year, when compared with Slovenia, while these differences are even more prominent in comparison with Hungary. Such data indicate that the development of a country does not have to be directly correlated with the application of sustainable forms of energy.

Figure 1. Share of energy from renewable sources (% in Serbia and the neighboring countries of Western Balkan in a five-year period [22].

Figure 2 shows that in Serbia, the complete renewable energy available was near 3 million toe, which represent about half of the estimated total renewable energy potential of 5.65 million toe per year [63]. Among the selected neighboring countries of Serbia, Romania was characterized with the highest amount of energy from renewables in the five-year period, reaching about 6.5 million toe in 2021. Figure 3 shows complete energy balances (non-renewable plus renewable energy) per country in 2017–2021, showing the ratio between total and renewable energy in one year. From total energy produced, Serbia produced 25.58% renewable energy, being placed behind Albania, Montenegro, Bosnia and Herzegovina, and Croatia, which reached share higher than 30%. The National Renewable Energy Action Plan for the Republic of Serbia established a target to achieve a share of 27% of energy produced from renewable sources in relation to the total gross final energy consumed by 2020 [28]. Despite the numerous ambitious projections that Serbia would accomplish the planned goal, the target share was not achieved. In 2021, the share of renewable energy in total consumption was even lower than in 2020, after which the highest share was recorded in 2022 [27][29]. Bearing in mind that Serbia is aiming to further increase the share of renewable energy sources in the future, the goal is to provide more feedstock and develop capacities for the increased production [28].
3. Biopesticides

Biopesticides have emerged as a green tool in the era of sustainable agriculture and as suitable for the production of ‘organically produced food’ and ‘biologically based products’ [80]. Plants have developed many strategies to defend themselves from being assaulted by predators by developing compounds that are highly toxic to pests and/or phytopathogens [81]. Botanicals are biopesticides derived from different plant tissues or organs and can be used in different ways, mostly like different kind of extracts or essential oils. Some botanicals are highly effective against pest insects [81,82], plant pathogens [83,84] or other plants [85,86].

Currently, 68 biopesticide active substances are registered in the EU, while over 1000 biopesticide-based products are imported worldwide [86,87]. The development of biopesticides was recognized and defined by EU regulation (2009/128/EC) with the goal of promoting sustainable agriculture and mitigating the adverse effects of synthetic chemical pesticides on the environmental and human health [88]. However, only a few member countries have recognized biopesticides as a separate group of alternative pesticides, which has led to their reduced use due to a lack of awareness of their importance, effectiveness and environmental safety [89].

According to the official data, a total of 1215 plant protection products were registered on the market in Serbia in 2023, of which a total of 1.31% are biopesticides (biofungicides 0.74%, bioinsecticides 0.33%, bioacaricides 0.16% and other products based on biological substances 0.08%) [90]. Biopesticides occupy a small share with 16 registered products in the total market for plant protection in Serbia. In Serbia, the largest number of products based on biofungicides were registered in 2023, followed by bioinsecticides and bioacaricides, while no bioherbicides have yet been imported. The
The most commonly used biopesticides on the territory of Serbia, which are used as plant protection agents to combat invasive disease agents, are mainly microbiological and biochemical in nature. The utilization of these biopesticides is in accordance with the Law on Organic Agriculture. In their research, Golijan-Pantović and Sečanski [96] showed that biopesticides with microbiological effects containing bacteria such as *Bacillus subtilis* and *Bacillus thuringiensis* have great effectiveness in protecting and suppression of disease agents and pests. The bacterium *B. subtilis* has found the most effective when applied in biological protection and has the power to indirectly inhibit the growth and development of parasites. The bacterium *B. thuringiensis* is predominantly used in the control of harmful insects, having a great potential to control a wide range of pests, while it produces toxins that are harmless to humans and plants [96]. Some scientific papers note that 75% of biopesticides contain the Gram-positive bacterium *B. thuringiensis* in their composition [96]. The current status of biopesticides in Serbia is shown by biochemical research of biological pesticides containing plant extracts and essential oils. In their work on alternative sources of biopesticides, Šunjka and Mechora [95] stated that the application of essential oils can have a negative effect on plants if applied in high concentrations, although insecticides based on essential oils are less effective when applied in low concentrations. They also highlighted that plant extracts that have found application in the production of biopesticides offer an unlimited source of biodegradable, ecological and renewable resources as an innovative measure in the control of a large number of pests and diseases. In their work, Tanović et al. [96] demonstrated that 16 varieties of essential oils exhibited partial or complete inhibition of pathogenic mycelia growth under in vitro conditions. In research conducted by Golijan-Pantović and Sečanski [96], rosemary, pine, and orange essential oils exhibited the least potent effect, while basil, thyme, cinnamon, anise, geranium, and mint essential oils completely inhibited pathogen growth. The remaining essential oils demonstrated a reduction in fungal growth and suppression of invasive disease agents, are mainly microbiological and biochemical in nature. The utilization of these biopesticides is in accordance with the Law on Organic Agriculture. In their research, Golijan-Pantović and Sečanski [96] showed that biopesticides with microbiological effects containing bacteria such as *Bacillus subtilis* and *Bacillus thuringiensis* have great effectiveness in protecting and suppression of disease agents and pests. The bacterium *B. subtilis* has found the most effective when applied in biological protection and has the power to indirectly inhibit the growth and development of parasites. The bacterium *B. thuringiensis* is predominantly used in the control of harmful insects, having a great potential to control a wide range of pests, while it produces toxins that are harmless to humans and plants [96]. Some scientific papers note that 75% of biopesticides contain the Gram-positive bacterium *B. thuringiensis* in their composition [96]. The current status of biopesticides in Serbia is shown by biochemical research of biological pesticides containing plant extracts and essential oils. In their work on alternative sources of biopesticides, Šunjka and Mechora [95] stated that the application of essential oils can have a negative effect on plants if applied in high concentrations, although insecticides based on essential oils are less effective when applied in low concentrations. They also highlighted that plant extracts that have found application in the production of biopesticides offer an unlimited source of biodegradable, ecological and renewable resources as an innovative measure in the control of a large number of pests and diseases. In their work, Tanović et al. [96] demonstrated that 16 varieties of essential oils exhibited partial or complete inhibition of pathogenic mycelia growth under in vitro conditions. In research conducted by Golijan-Pantović and Sečanski [96], rosemary, pine, and orange essential oils exhibited the least potent effect, while basil, thyme, cinnamon, anise, geranium, and mint essential oils completely inhibited pathogen growth. The remaining essential oils demonstrated a reduction in fungal growth and development. Many studies suggest that in the coming years, the importance of biopesticides in agricultural practice will be equal to chemical pesticides and will become a dominant strategy for controlling and suppressing a large number of pests and diseases both in Serbia and around the world.

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