Assessment of the energy potential of unused biomass in Bulgaria with emphasis on the Northeastern region

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Abstract. This study explores the availability of biomass in Bulgaria, with a focus on the portion that remains unused and its potential for energy production. The analysis is based on statistical data covering the main sources of biomass, including agricultural, forest, and agro-industrial residues, and applies commonly used assessment approaches such as residue-to-product ratios, utilization factors, and lower heating value calculations to estimate the available energy potential. The results show that Bulgaria has a total biomass potential of about 17.5 Mt/year, of which approximately 35–45% is not utilized, equal to around 6.0–7.0 Mt/year. The largest share of this unused resource comes from agricultural residues. In energy terms, this corresponds to an estimated potential of about 26 TWh/year, which could contribute significantly to the country's energy demand. Particular attention is given to the Northeastern region of Bulgaria, where biomass resources are highly concentrated and largely underutilized. The study also discusses the main challenges limiting biomass use, such as logistical difficulties, economic constraints, and technological limitations. Overall, the findings highlight the need for better infrastructure, wider adoption of modern technologies, and supportive policies to unlock the full potential of biomass as a sustainable energy source.

1 Introduction

Biomass is widely recognized as one of the most accessible renewable energy sources, with a strong potential to support the transition toward a low-carbon energy system. Its ability to be produced and utilized locally makes it particularly valuable for enhancing energy independence and strengthening the resilience of regional energy systems. At the same time, a considerable share of available biomass remains either unused or inefficiently utilized, which limits its overall contribution to the energy sector. This issue is especially pronounced in regions with intensive agricultural and forestry activities, where large quantities of plant and wood residues with significant energy potential are generated [1-2].

In Bulgaria, biomass availability is closely linked to the structure of the agricultural sector and the presence of forest resources. Agricultural production generates substantial

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amounts of residues every year, including cereal straw, corn stalks, and sunflower husks, complemented by forest residues and by-products from agro-industrial processes. However, a significant portion of this resource is not effectively utilized. In many cases, residues remain in the fields, are not collected, or are used in ways that do not fully exploit their energy value, resulting in a loss of potential energy resources [3-5]. This highlights the need for more efficient management practices and improved utilization strategies.

Recent research has emphasized the growing importance of biomass within the European energy system, particularly in countries with well-developed agricultural sectors [1-2]. Various studies have assessed biomass availability and energy potential using statistical methods, residue-to-product ratios, and spatial analysis approaches [6-13]. These analyses consistently indicate that a substantial fraction of residual biomass remains unused, mainly due to logistical, economic, and environmental limitations. In this context, agricultural residues are often identified as one of the most promising resources for increasing the share of renewable energy, especially in decentralized energy systems.

At the same time, a significant body of research has focused on technological pathways for biomass conversion, including combustion, gasification, and combined heat and power (CHP) systems. These technologies have demonstrated considerable potential for improving energy efficiency and reducing greenhouse gas emissions [10,12]. However, most studies tend to concentrate on technological performance, while less attention is given to the detailed quantification of unused biomass resources, particularly at national and regional levels.

In the case of Bulgaria, existing research is primarily oriented toward biomass conversion technologies and energy efficiency improvements [4]. Nevertheless, comprehensive and up-to-date assessments of unused biomass potential remain limited, especially when considering regional characteristics. This creates a clear need for more detailed analyses that account not only for the quantity of available biomass, but also for the practical constraints related to its collection, transport, and utilization.

The Northeastern region of Bulgaria, including the districts of Varna, Dobrich, Shumen, and Targovishte, is characterized by intensive agricultural production and a high concentration of cereal and oilseed crops. As a result, the region generates large quantities of agricultural residues, a significant portion of which remains unused. Although this creates favorable conditions for energy utilization, the lack of well-developed logistics and the limited implementation of modern processing technologies continue to hinder the efficient use of this resource [3-5]. Addressing these limitations could substantially improve biomass valorization in the region.

The aim of the present study is to assess the quantity of unused biomass and its energy potential in Bulgaria, with a particular focus on the Northeastern region. The analysis is based on statistical data and established methodologies for evaluating plant residues, while also considering the key factors limiting their effective utilization. This approach enables a more realistic estimation of available resources and their potential contribution to energy production, while identifying the main barriers to their practical application.

2 Methodology and results

Biomass, as a resource, is closely linked to the structure of agriculture, where cereal and oilseed crops predominate. As a result, significant quantities of residues are generated annually, including wheat straw, corn stalks, sunflower husks, forest residues, and by-products from the wood-processing and food industries [6].

The assessment of biomass quantity is carried out using the “residue-to-product ratio” (RPR), which makes it possible to determine the relationship between the yield of the main crop and the generated plant residues. In this way, results can be compared across different

crops and production conditions. However, not all of the generated biomass is available for energy use. A portion of the residues remains in the field to maintain soil fertility or is used for other agricultural and industrial purposes. Therefore, only a certain share of the total biomass can be considered technically and economically available for energy production. This must be taken into account when estimating the realistic energy potential.

The analysis introduces the concept of a "utilization factor," which accounts for the portion of biomass that is actually used. The remaining share is considered a resource with potential for energy applications that remains untapped. This potential is determined based on the lower heating value of the respective types of biomass, considering their specific physicochemical properties. This approach allows for a quantitative assessment of unused biomass and an analysis of its potential for decentralized energy production. At the same time, it highlights the gap between the theoretically available resource and its actual use, which is mainly due to logistical, technological, and economic constraints. Addressing these limitations could significantly increase the effective use of biomass resources. Furthermore, improving infrastructure and adopting modern conversion technologies can enhance the efficiency of biomass utilization. This would support the development of more sustainable and locally based energy systems.

The assessment of available and unused biomass in Bulgaria shows that the country has a significant biomass resource, a large portion of which remains unused and represents unrealized energy potential [2]. This indicates considerable opportunities for improving its utilization in the energy sector. Better management and strategic use of this resource could contribute to increasing the share of renewable energy in the country.

2.1 Methodology

The assessment of biomass potential in Bulgaria is based on statistical data related to agricultural production, forestry activities, and agro-industrial residues. The evaluation follows commonly applied approaches used in biomass resource assessment studies.

The quantity of generated biomass residues was estimated using the residue-to-product ratio (RPR), which defines the relationship between the amount of primary agricultural production and the corresponding generated residues:

$$B = P*RPR \tag{1}$$

where:
B is the amount of generated biomass residues (t/year),
P is the annual production of the main crop (t/year),
RPR is the residue-to-product ratio.
Since not all generated biomass can be used for energy purposes, a utilization factor was introduced in order to estimate the quantity of unused biomass:

$$B_{unused} = B*(1-k_u) \tag{2}$$

where: B_{unused} represents the unused biomass potential (t/year), k_u is the utilization factor.

The energy potential of unused biomass was determined based on the lower heating value (LHV) of the corresponding biomass type:

$$E = B*LHV \tag{3}$$

where E is the theoretical energy potential, LHV is the lower heating value of the biomass (MJ/kg).

The obtained results were converted into annual energy potential expressed in PJ/year and TWh/year in order to allow comparison with national energy consumption indicators.

2.2 Quantitative assessment of the biomass resources

The quantitative assessment of biomass shows that the country has potential mainly derived from agricultural, forestry, and agro-industrial sources [7]. The analysis is based on the yields of the main crops (Table 1).

Table 1. Quantitative distribution of biomass in Bulgaria [7].

Type of biomass	Total amount (Mt/yr)	Share (%)	Main sources
Agricultural	11.5	65	Wheat, corn, sunflower
Forest	3.5	20	Logging, forest residues
Agro-industrial	2.5	15	Processing of agricultural product
Total	17.5	100	-

The data clearly indicate a strong dominance of agricultural biomass (Figure 1), which accounts for approximately two-thirds of the total resource. This is an expected outcome, considering the large share of arable land and the intensive nature of agricultural production in Bulgaria. As a result, crop residues such as wheat straw, corn stalks, and sunflower husks form the backbone of the country's biomass potential. Forest biomass ranks second, contributing around 20% of the total. Its potential is relatively stable over time; however, it is constrained by sustainable forest management practices, environmental regulations, and accessibility. A notable portion of this resource remains underutilized, particularly in remote or difficult-to-access areas where collection and transportation are economically challenging. Although agro-industrial biomass represents the smallest share, it plays a significant role due to its high concentration and relatively well-developed supply chains. Residues from food processing and wood industries are often generated at centralized locations, making them easier to collect, process, and convert into energy. This makes agro-industrial biomass especially suitable for the implementation of efficient, small-scale, and decentralized energy systems.

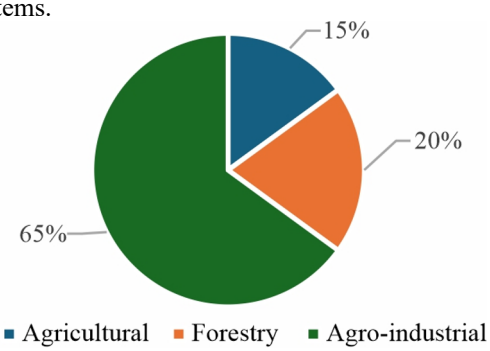

Fig. 1. Share of biomass types.

The total amount of biomass, estimated at 17.5 million tons per year, indicates that Bulgaria possesses a significant resource which, if managed effectively, could play an important role in the energy sector [8].

2.3 Assessment of unused biomass

The assessment of unused biomass (Table 2) is a key component of the analysis, as it defines the actual potential for additional energy utilization beyond what is currently exploited [7]. The results indicate that approximately 35–45% of the total biomass remains unused, which corresponds to about 6.0–7.0 million tons per year. This represents a considerable reserve that could be mobilized for energy production under appropriate conditions. The largest share of unused biomass is found in agricultural residues. This is mainly due to their dispersed distribution, seasonal generation, and the necessity to retain a portion in the fields to preserve soil fertility and prevent degradation. Additionally, challenges related to collection, storage, and transportation further limit their effective utilization. In the case of forest biomass, the proportion of unused resources is lower, but still significant in absolute terms. This is particularly evident in mountainous and remote areas, where difficult terrain and limited infrastructure hinder access and increase operational costs. Agro-industrial biomass exhibits the highest degree of utilization, owing to its concentrated generation and more efficient supply chains. Nevertheless, even in this category, a fraction remains untapped due to technological limitations or economic constraints. Overall, these findings highlight a substantial opportunity to enhance biomass utilization through improved logistics, advanced processing technologies, and better resource management strategies.

Table 2. Assessment of unused biomass in Bulgaria.

Type of biomass	Total amount (Mt/yr)	Utilization Factor (%)	Unused biomass (Mt/yr)	Share of unused biomass (%)
Agricultural	11.5	60	4.6	70
Forest	3.5	65	1.2	20
Agro-industrial	2.5	75	0.6	10
Total	17.5	-	6.4	100

The obtained results clearly show that the largest share of unused biomass potential is concentrated in the agricultural sector, which accounts for approximately two-thirds of the total unused biomass. This is mainly due to the dispersed nature of agricultural residues, their seasonal availability, and the requirement to leave part of them in the fields in order to maintain soil fertility and prevent degradation. In addition, insufficient infrastructure, as well as inefficient collection and transportation systems, further limit their effective utilization. Forest biomass ranks second in terms of unused resource volume. Although its relative share is smaller, the unused quantities remain significant in absolute terms. The main constraints are associated with difficult terrain, limited accessibility, and high harvesting and transportation costs, particularly in mountainous and remote areas. Furthermore, environmental regulations and sustainable forest management practices also restrict the extent of biomass extraction. Agro-industrial biomass exhibits the highest level of utilization due to its concentrated generation and more efficient logistics. However, despite this relatively high utilization rate, approximately 0.6 million tons per year remain unused, indicating additional potential for improving efficiency. This could be achieved through the implementation of advanced processing technologies and better integration into existing energy systems. Overall, these findings highlight significant opportunities to enhance biomass utilization across all sectors. Overcoming existing logistical, technological, and economic barriers could substantially increase the contribution of

biomass to energy production and support the transition toward a more sustainable and diversified energy system in Bulgaria [2, 7].

2.4 Energy potential

The assessment of the energy potential of unused biomass is a key stage of the analysis, as it allows for determining the actual contribution of these resources to the energy system. The data are examined in relation to the quantities of unused biomass and the characteristic values of the LHV for different types of materials (Table 3, Figure 2) [7]. Agricultural residues are characterized by an LHV in the range of 14–16 MJ/kg, depending on their moisture content and composition. Forest biomass generally exhibits slightly lower values (10–14 MJ/kg), while agro-industrial residues, such as sunflower husks, can reach 16–18 MJ/kg due to their lower moisture content and higher energy density [2, 7, 9]. This variation in heating values plays an important role in determining the overall energy potential and efficiency of biomass utilization. Therefore, both the quantity and quality of biomass must be considered when evaluating its contribution to energy production.

Table 3. Energy potential of unused biomass.

Type of biomass	Unused biomass (Mt/yr)	LHV MJ/kg	Energy (PJ/yr)	Energy (TWh/yr)
Agricultural	4.6	15	69	19.2
Forest	1.2	12	14.4	4.0
Agro-industrial	0.6	17	10.2	2.8
Total	6.4	-	93.6	26.0

The results show that the total energy potential of unused biomass in Bulgaria amounts to approximately 26 TWh per year, representing a significant resource in the context of national energy consumption. The largest contribution comes from agricultural biomass, which accounts for over 70% of the total energy potential due to the large available quantities.

Forest biomass contributes around 4 TWh per year, with its importance determined not only by its quantity but also by its fuel characteristics, such as relatively stable quality and suitability for combustion.

When compared to the national electricity consumption, which is approximately 35–40 TWh per year, unused biomass could theoretically cover a portion of the country's energy needs. This highlights its role as a strategic resource for the development of decentralized energy systems and combined heat and power (CHP) generation [2].

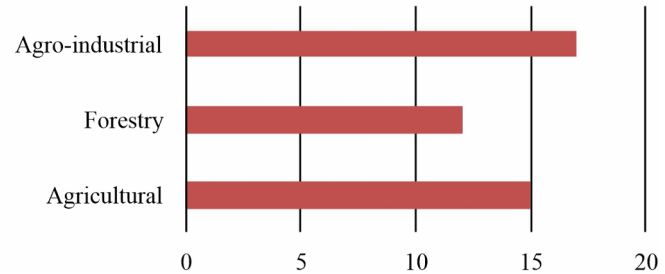

Fig. 2. LHV of biomass.

2.5 Northeastern Bulgaria

The Northeastern region of Bulgaria (Varna, Dobrich, Shumen, and Targovishte districts) is characterized by highly developed agriculture and a strong concentration of cereal and oilseed crops. This defines it as a key area for the generation of agricultural biomass and, consequently, as a region with high potential for the energy utilization of unused resources. The region accounts for approximately 25–30% of the total agricultural biomass in the country, corresponding to about 2.8–3.5 million tons per year. A significant portion of this resource remains unused, with the analysis indicating values of around 1.2–1.6 million tons per year. The energy potential of this unused biomass is estimated at approximately 5–6 TWh per year. This creates favorable conditions for the development of decentralized energy systems, including small-scale biomass-based combined heat and power (CHP) plants [1,7]. In addition, the relatively well-developed agricultural infrastructure and proximity to processing facilities further support the efficient collection and utilization of biomass in the region. However, challenges related to logistics, seasonal availability, and investment costs still need to be addressed. Overcoming these barriers could significantly enhance the role of Northeastern Bulgaria as a leading region in biomass-based energy production and contribute to regional economic development and energy security (Table 4.).

Table 4. Assessment of biomass potential in the Northeastern region.

Indicator	Value
Total amount (Mt/yr)	2.8-3.5
Unused biomass (Mt/yr)	1.2-1.6
Share of national resources (%)	25-30
Share of unused biomass (%)	40-45
Energy potential (TWh/yr)	5.6

It is particularly important that the concentration of this resource within a relatively small part of the country allows for a more efficient organization of logistics processes, reducing transportation costs and improving the economic efficiency of its utilization [8].

2.6 Analysis of the reasons for underutilization

Despite the availability of large quantities of biomass in Bulgaria, the data show that a significant portion remains unused. This is mainly due to the interaction of technological, economic, and organizational factors that limit its efficient utilization [1,10].

One of the main limiting factors is logistics. Agricultural residues are spatially dispersed and generated seasonally, which makes their collection, transportation, and storage more difficult. This, in turn, leads to increased costs and reduced economic efficiency. In many cases, the lack of well-developed supply chains and storage infrastructure further complicates the consistent use of biomass as an energy resource. From an economic perspective, biomass often struggles to compete with conventional energy sources, especially in the absence of financial incentives or regulatory support. This limits investments in biomass utilization technologies and slows down the implementation of innovative solutions. Market uncertainty and fluctuating energy prices also contribute to the

reluctance of investors to engage in biomass-based projects. From a technological point of view, there are also constraints related to the efficiency and reliability of existing biomass conversion systems. Processes such as combustion, gasification, and pyrolysis require specific operating conditions and proper fuel preparation, which increases system complexity. In addition, the variability in biomass quality can negatively affect the performance and lifespan of the equipment. Finally, agronomic requirements also influence the level of biomass utilization. A portion of plant residues must be left on the field to maintain soil fertility and prevent erosion. This limits the maximum amount of biomass that can be used for energy purposes. Furthermore, environmental considerations and sustainability criteria impose additional restrictions on biomass extraction.

Overall, these factors demonstrate that improving biomass utilization requires an integrated approach, combining technological innovation, economic support mechanisms, and effective resource management strategies (Figure 3).

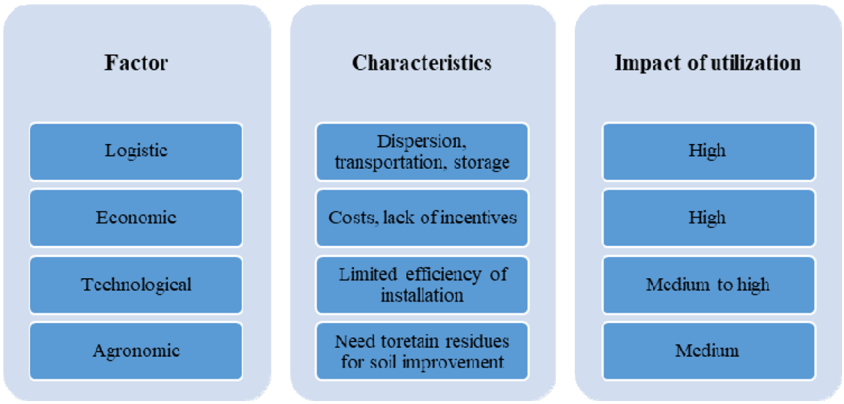

Fig. 3. Main factors limiting biomass utilization.

The analysis shows that logistical and economic factors have the strongest influence on unused biomass potential. Technological limitations can be overcome through the implementation of modern energy systems, including high-efficiency boilers, gasification installations, and cogeneration solutions. At the same time, agronomic requirements impose the need for a sustainable approach, seeking a balance between energy utilization and the preservation of soil quality [11–13]. Furthermore, integrated policies and targeted support measures are essential to facilitate the wider adoption of biomass technologies and improve overall resource efficiency.

Northeastern Bulgaria can be considered a pilot region for the implementation of integrated biomass utilization solutions, which could subsequently be applied in other parts of the country.

3 Conclusion

The present study provides an analysis and assessment of unused biomass in Bulgaria in 2024, with a focus on its potential for energy utilization. The results indicate that the country possesses a significant biomass resource, a large portion of which remains unused despite the availability of appropriate technological solutions. The data show that approximately 6–8 million tons of biomass per year are not utilized, corresponding to an energy potential of about 25–30 TWh per year. The largest contribution to this unused resource comes from agricultural residues, while forest and agro-industrial biomass are relatively better utilized. The obtained results indicate that Bulgaria has considerable

untapped biomass potential, particularly in the agricultural sector, which could be effectively integrated into the energy system through improved management and modern technologies. The regional analysis of Northeastern Bulgaria identifies it as an area with a high concentration of unused biomass, creating favorable conditions for the development of decentralized energy systems. However, the results clearly show that the main limitations are not related to resource availability, but rather to its effective management. Among the key barriers are logistical challenges, economic constraints, and the insufficient implementation of modern biomass conversion technologies. This highlights the need for the development of appropriate infrastructure, the introduction of economic incentives, and the adoption of innovative energy solutions. Addressing these issues would enable more efficient utilization of the available biomass and support regional energy sustainability and economic development.

Unused biomass represents a reliable source for the production of thermal and electrical energy, especially when high-efficiency technologies such as cogeneration are applied. In this context, its utilization can contribute both to improving energy efficiency and to reducing carbon emissions. Furthermore, integrating biomass into the energy system supports the transition toward more sustainable and low-carbon energy solutions, while also enhancing energy security at the local and national levels.

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References

1. S.B. Mubareka, A. Renner, R. Acosta Naranjo, T. Armada Brás, J.I. Barredo Cano et al., EU biomass supply, uses, governance and regenerative actions – 10-year anniversary edition (Publications Office of the European Union, Luxembourg, 2025). https://doi.org/10.2760/6511190
2. *EU biomass flows – Update 2022*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2760/082220
3. V. Avitabile, R. Pilli, M. Migliavacca, G. Duveiller, A. Camia, V. Blujdea, R. Adolt, I. Alberdi, S. Barreiro, S. Bender et al., Harmonised statistics and maps of forest biomass and increment in Europe. Sci. Data 11, **274** (2024). https://doi.org/10.1038/s41597-024-02740-1
4. A. Terziev, M. Ivanov, M. Vassilev, B. Stankov, Technical and economic analysis of a specific spruce wood material drying process. E3S Web Conf. **608**, 01016 (2025). https://doi.org/10.1051/e3sconf/202560801016
5. Ö. Ertuğrul, G. Özgünaltay Ertuğrul, A. Degirmencioglu, S. Kadirova, Analyzing sustainable cotton production in Türkiye through the water–energy–carbon nexus framework. Sci. Rep. **16**, 41947 (2026). https://doi.org/10.1038/s41598-026-41947-9
6. V. Motola, N. Scarlat, O. Hurtig, M. Buffi, A. Georgakaki, S. Letout, A. Mountraki, R. Salvucci, A. Schmitz, Clean Energy Technology Observatory: Bioenergy in the European Union – 2023 status report on technology development, trends, value chains and markets (Publications Office of the European Union, Luxembourg, 2023). https://doi.org/10.2760/327569
7. Eurostat, Agriculture, forestry and fishery statistics (2024)
8. Ministry of Energy of the Republic of Bulgaria, Ministry of Environment and Water, Integrated National Energy and Climate Plan of the Republic of Bulgaria – updated 2024 (Sofia, 2024)

9. Y. Xie, H. Yan, C. Dong, J. Xue, J. Zhang, X. Hu, Research on the LHV prediction for biomass fuel based on near-infrared spectroscopy and local model strategy. Biomass Bioenergy (2025), 108832. https://doi.org/10.1016/j.biombioe.2025.108832
10. S. Jeong, H. Lee, Y. Joo, N. Kim, S. Hwangbo, Sustainable ammonia production from unused biomass: Green hydrogen generation and supply chain optimization in South Korea. Int. J. Hydrogen Energy (2025). https://doi.org/10.1016/j.ijhydene.2025.06.114
11. Y. Ju, D.-y. Ryu, D.-Y. Kim, E. Lee, K.H. Jang, D. Kim, Grouping of unused agricultural by-product biomass for fuel conversion in South Korea through multivariate analysis. Waste Manag. **177**, 86 – 94, (2024). https://doi.org/10.1016/j.wasman.2024.01.005
12. A. Pfeifer, D.F. Dominković, B. Ćosić, N. Duić, Economic feasibility of CHP facilities fueled by biomass from unused agriculture land: Case of Croatia. Energy Convers. Manag. **125**, 222–229 (2016). https://doi.org/10.1016/j.enconman.2016.04.090
13. N. Greggio, E. Balugani, C. Carlini, A. Contin, N. Labartino, R. Porcelli, M. Quaranta, S. Righi, L. Vogli, D. Marazza, Theoretical and unused potential for residual biomasses in the Emilia Romagna Region (Italy) through a revised and portable framework for their categorization. Renew. Sustain. Energy Rev. **114**, 109332 (2019). https://doi.org/10.1016/j.rser.2019.06.019