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# Biogas Plants as a Tool for Supporting Sustainable Tourism: Opportunities and Challenges in the Context of the Slovak Republic

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## Abstract
This study investigates the application of biogas technologies as strategic tools to facilitate sustainable tourism development within the Slovak Republic, integrating key principles of the circular economy, climate neutrality, and regional socioeconomic advancement. It specifically focuses on the feasibility of incorporating biogas installations into existing tourism infrastructures, particularly in regions characterised by substantial production of biodegradable waste. The research delineates pertinent environmental, economic, and regulatory challenges encountered in deploying biogas and biomethane systems in tourism-centric areas by employing a comprehensive analysis encompassing contemporary datasets, relevant case studies, and established international methodologies. Moreover, the study articulates detailed policy-oriented recommendations for governmental entities, regional administrations, and private sector stakeholders to foster enhanced synergy between renewable energy initiatives and tourism development. The study's significance lies predominantly in its interdisciplinary framework, which systematically integrates perspectives from energy management, environmental governance, and tourism studies. Additionally, it contributes an innovative conceptualisation linking renewable energy utilisation directly to tourism, thereby proposing a robust new paradigm for the evolution of climate-conscious and circular tourism practices.

## Keywords
biogas plants, sustainable tourism, circular economy, regional development, ecotourism

## Introduction

In recent decades, environmental sustainability has emerged as one of the fundamental priorities of socioeconomic development, a trend increasingly reflected in the tourism sector. Sustainable tourism has gradually been established as a pivotal component of global efforts to mitigate adverse environmental impacts while enhancing the economic resilience of regions (Chiwaridza, 2024; Gandhi et al., 2019). Within this framework, technologies based on renewable energy sources have garnered growing attention, among which biogas, produced through the anaerobic digestion of biomass and biodegradable waste, stands out as particularly promising (Barbot et al., 2015; EBA, 2024). Biogas plants are currently positioned not only as instruments for achieving climate neutrality and reducing greenhouse gas emissions but also as strategic assets for regional development, especially in rural and less economically developed areas. Despite their multifaceted benefits, their potential contribution to the tourism industry remains vastly underutilised. This is noteworthy given that international research highlights several advantages of integrating biogas technologies into tourism infrastructure. These include enhancing the energy self-sufficiency of accommodation facilities, improving waste management practices, and offering opportunities for environmental education within ecotourism (Gandhi et al., 2019; Chiwaridza, 2024).

This publication examines the potential of biogas technologies as a strategic instrument for advancing sustainable tourism development in the Slovak Republic. Special emphasis is placed on the interlinkages between the principles of circular economy, climate neutrality, and regional development, with an analysis of their practical applicability in areas characterised by high biodegradable waste generation. The research is grounded in the analysis of current data, case studies, and international approaches, which collectively facilitate the identification of key environmental, economic, and legislative challenges associated with deploying biogas and biomethane technologies in tourism destinations. In addition, the study highlights existing barriers, such as an ambiguous regulatory framework, limited awareness among key stakeholders, and insufficient coordination between actors in the energy and tourism sectors (EBA, 2024).

The primary aim of this study is to propose systemic recommendations for public policymakers, local governments, and private sector entities to support integrating biogas-based solutions into tourism development strategies. The publication adopts a transdisciplinary approach that bridges the domains of energy, environmental policy, and tourism management into a unified strategic framework. This framework not only addresses contemporary challenges but also contributes to the advancement of climate-responsible and circular tourism in alignment with the objectives of the European Union.

## Literature Review

The application of biogas plants as a tool for promoting sustainable tourism development finds a compelling example in a case study from Zimbabwe. Research conducted by Chiwaridza (2024) highlights the considerable potential of various waste-to-energy technologies, including biogas systems, to enhance energy self-sufficiency and environmental sustainability within the local tourism sector. The study identified positive correlations between utilising biogas and other waste-based renewable energy sources and advancing sustainable energy systems in tourism destinations. Similarly, in the context of the Slovak Republic, implementing biogas plants may contribute to the energy independence of accommodation and hospitality facilities and the enhanced attractiveness of destinations positioned as environmentally responsible and sustainable. The Zimbabwean experience underscores the importance of an integrated approach involving active cooperation among tourism stakeholders in deploying these technologies. When assessing the potential of biogas plants as a mechanism for supporting sustainable tourism in Slovakia, it is essential to draw upon international best practices. A case study from the hotel sector in Jaipur, India, presented by Gandhi et al. (2019), demonstrates the high potential of utilising food waste from hotels for biogas production. The study emphasises the necessity of rigorous waste segregation and estimates a theoretical biogas yield of approximately 0.66 $m^3$ per kilogram of organic material. These findings suggest significant environmental and economic benefits applicable within the Slovak context, where systematic support for the separation and processing of biodegradable waste generated in hospitality establishments could substantially enhance the sustainability and competitiveness of tourism destinations.

Literature increasingly addresses the energetic valorisation of biomass in the context of sustainable tourism. Balata and Tola (2018) analysed the potential use of Posidonia oceanica seagrass as a biogas feedstock in the tourist city of Alghero. The authors identified environmental and economic benefits of anaerobic digestion of this biomass, which typically accumulates on beaches and presents aesthetic and ecological challenges. They emphasised the necessity of a comprehensive approach considering regulatory barriers, technological optimisation, and mitigating the adverse ecological impacts of biomass harvesting. The utilisation of waste biomass in tourism-intensive regions is further examined in the study by Barbot et al. (2015), which explored biomethane production from beached macroalgae on the island of Rügen, Germany. The authors applied a thermo-acidic pretreatment to the algal biomass to optimise biogas production, achieving a 39% increase in methane yield. This process delivered renewable energy benefits and improved beach waste management, enhancing the destination's touristic appeal.

Wang et al. (2020) investigated the factors influencing farmers' acceptance of biogas technologies in Pakistan, underscoring the critical role of environmental awareness, personal norms, and perceived responsibility in the adoption of renewable energy solutions. The study further confirmed the strategic utility of social media in effectively raising environmental awareness and positively shaping attitudes toward biogas technologies. These findings suggest that in Slovakia, targeted communication strategies and active use of social media could play a pivotal role in overcoming implementation barriers and fostering broader acceptance of biogas solutions as part of sustainable tourism development strategies. The utilisation of biodegradable waste materials for biogas production in tourism is also of growing interest. Akimoto et al. (2024) examined the efficiency of co-digesting sewage sludge with lactic acid derived from hydrolysed polylactic acid (PLA) waste. The authors demonstrated the high efficacy of this process in biomethane generation and confirmed the technical feasibility of using PLA waste for energy recovery. This approach offers an effective waste management solution for tourism facilities that frequently use biodegradable materials, advancing tourism destinations' environmental and economic sustainability.

A study from southern Italy by Bux et al. (2023) highlights the substantial potential of biogas technologies to foster the sustainable development of rural tourism. The research explored biomethane and compost production through anaerobic digestion of organic waste in tourist rural municipalities, confirming this approach's economic, environmental, and social benefits, including reduced ecological burdens and enhanced local energy autonomy. The authors emphasised the necessity of infrastructure development for separate waste collection and treatment, recommendations highly relevant to the Slovak context. Honcharuk et al. (2024) stress the dual environmental and economic advantages of biogas and biomethane production from waste materials in the broader discourse on biogas technologies. Their study, based on case studies from Ukraine, illustrates the potential of these technologies to support local energy resilience and reduce greenhouse gas emissions, even under adverse geopolitical conditions. These insights are particularly pertinent for Slovakia, where integrating biogas systems into the tourism sector may represent a strategic path toward regional development and environmental sustainability.

The integration of biogas technologies in insular tourism contexts is exemplified in the case study conducted by Huber (2020) on Koh Rong Island, Cambodia. The author identified biogas systems as effective solutions to environmental issues stemming from inadequate waste management and high dependence on fossil fuels in tourism-intensive areas. The findings indicated that local biogas production from organic waste, when combined with photovoltaic systems, significantly reduced the island's ecological footprint, increased energy autonomy, and contributed to the overall sustainability of tourism. These findings hold relevance for Slovakia, especially in tourist regions facing similar environmental and energy-related challenges.

The potential for biomethane as an alternative transport fuel—a sector closely intertwined with tourism—was explored by Legena et al. (2021) in the context of Barbados. The study evaluated biomethane production via anaerobic digestion of rum distillery waste and Sargassum seaweed, demonstrating significant $CO_2$ emissions reduction and decreased reliance on fossil fuels. The authors highlighted environmental and economic benefits, including strengthened energy security and mitigation of adverse effects from seaweed on beach-based tourism.

It is also noted that the potential integration of biogas technologies into sustainable tourism strategies aligns with broader trends in expert decision-making and sustainable infrastructure planning. Research by Skare et al. (2023a) introduces a large-scale decision-making model that facilitates the evaluation of funding needs for regional tourism infrastructure development. Such models support the practical implementation of renewable energy technologies, including biogas, by aligning investment priorities with regional tourism demands and sustainable development goals.

In a related vein, Skare et al. (2023b) have explored the application of fuzzy logic in modelling tourist satisfaction, particularly in the context of accommodation establishments and visitor preferences by social class, offering insights that could inform demand forecasting for energy services in tourism facilities.

Further, Gavurová et al. (2022) developed expert risk assessment models within smart city components, underscoring the value of resilient infrastructure, especially in tourism-centric urban areas that require adaptable and sustainable energy systems. Additionally, Gavurová et al. (2023) demonstrated the utility of fuzzy decision support tools in prioritising public health-related projects. Similar logic can be extended to tourism-related environmental initiatives, including biogas deployment, where multi-criteria decision-making frameworks are essential for balancing ecological, social, and economic objectives.

Importantly, the integration of fuzzy multi-criteria models, as presented by Skare et al. (2024), reveals a structured approach to assessing sustainable tourism options across multiple dimensions. These methodologies provide a solid foundation for evaluating the viability of biogas technologies in tourism destinations, particularly when considering cross-border case studies.

Finally, a study from Ireland underscores the critical importance of well-structured policy and economic incentives for successfully implementing biogas technologies (Rajendran, 2019). The authors evaluated the economic viability of biomethane production from anaerobic digestion across various geographical and economic contexts, identifying optimal upgrading technologies, with water scrubbing emerging as the most cost-effective. The study also reviewed international policy instruments and recommended targeted subsidies and support

schemes that could be adapted to the Slovak context to promote the integration of biomethane into tourism-linked energy strategies.

**The Strategic Importance of Biogas and Biomethane for Energy Transition and Sustainable Tourism**

Biogas and biomethane are strategic renewable gases that mitigate greenhouse gas emissions across multiple sectors, including industry, transport, buildings, and agriculture. Due to their compatibility with existing gas infrastructure, these gases can be seamlessly integrated into energy systems without additional investments in distribution networks. Biomethane offers a stable and storable energy source, effectively complementing variable renewable sources such as solar and wind energy. Its domestic production and utilisation within the European Union (EU) also reduces dependency on imported natural gas, thereby enhancing the Union's energy sovereignty and systemic resilience. In 2023, biogas and biomethane production reached 22 billion cubic meters (bcm), accounting for approximately 7% of the EU's natural gas consumption. Moreover, producing these gases represents a cornerstone of the circular economy, transforming organic waste into renewable energy and digestate, which can be used as an organic fertiliser. This process supports decarbonising the energy sector and agriculture while promoting healthy soil ecosystems and enhancing biodiversity (EBA, 2024).

Europe currently holds the position of the world's leading producer of biogas and biomethane. In 2023 alone, biomethane production experienced a year-on-year growth of 21%, with installed capacity reaching 6.4 bcm per year. Biomethane consumption is primarily concentrated in the transport sector (23%), followed by buildings (17%), electricity generation (15%), and industry (13%). Furthermore, the industrial sector is a significant source of biogenic $CO_2$, which has growing applications in producing e-fuels, sustainable chemicals, and carbon capture and storage (CCS) technologies (EBA, 2025).

Biogas plants are modern energy facilities that utilise anaerobic digestion of biomass and biodegradable waste to produce biogas, primarily composed of methane ($CH_4$) and carbon dioxide ($CO_2$). The resulting biogas can be used as a fuel for electricity and heat generation or as a feedstock for biomethane upgrades. Upgraded biomethane can be injected into the gas grid or used as a renewable transport fuel in bio-CNG or bio-LNG. From an environmental perspective, biogas technology contributes to greenhouse gas emission reduction, promotes waste valorisation in line with circular economy principles, and facilitates decentralised renewable energy production. In the Slovak context, biogas plants significantly harness the energy potential of agricultural biomass, organic waste, and wastewater treatment byproducts (EBA, 2025).

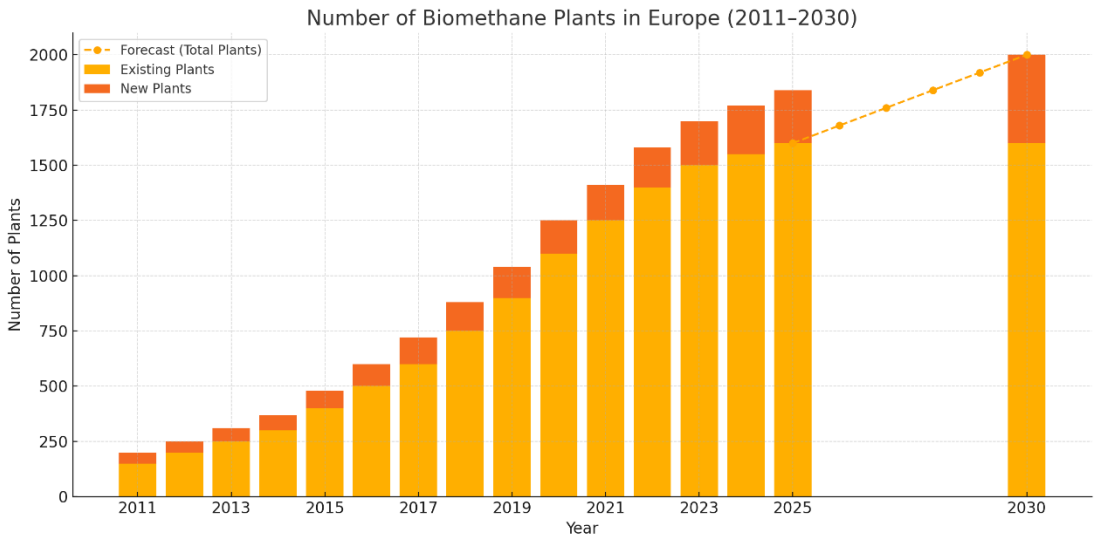


*Fig. 1 Number of Biomethane Plants in Europe (2011-2023). (EBA, 2025)*

According to data from the European Biogas Association (EBA), supplemented by forward-looking projections, a dynamic growth trajectory in the number of biomethane production facilities across Europe can be observed between 2011 and 2024. The total number of operational plants reached 1,548 by 2024, representing more than an eightfold increase compared to 2011 when only 182 facilities were reported. The most substantial year-on-year growth occurred between 2023 and 2024, highlighting intensified investments and accelerated technological development in renewable energy.

Figure 1 illustrates the development of biomethane production infrastructure in Europe from 2011 through 2030, offering an overview of existing and newly commissioned facilities and projections for their future expansion. The data suggest a sustained upward trend in the number of biomethane plants, reflecting the growing importance of renewable energy sources in the context of European Union climate policies and member states'

commitments to carbon footprint reduction. As depicted, the increase in newly constructed facilities has significantly contributed to the overall growth, particularly after 2020. This period aligns with increasing momentum toward economic decarbonisation and the transition to a circular economy. Projections to 2030 anticipate a marked rise in the total number of biomethane installations, primarily driven by the shift towards low-carbon energy systems and reinforced support for circular economy principles. This trajectory underscores the critical role of biomethane as a sustainable alternative energy source capable of enhancing energy security and environmental sustainability within the European region.

In addition to its environmental and energy contributions, biomethane infrastructure holds considerable potential in the context of sustainable tourism. Integrating biomethane plants into rural and ecologically valuable regions can foster local energy self-sufficiency, reduce greenhouse gas emissions, and serve as educational hubs for visitors and tourists. Agritourism enterprises, eco-farms, and environmentally conscious destinations may adopt biomethane facilities as exemplary of best practices, elevating environmental awareness among tourists and promoting positive perceptions of sustainable technologies. Moreover, localised energy production from biomethane reduces reliance on fossil fuels and enhances energy resilience in tourism-intensive regions. Within the European Green Deal framework and the climate neutrality targets set for 2050, the expansion of biomethane production represents a synergistic instrument that simultaneously advances energy system transformation and the development of environmentally responsible tourism.

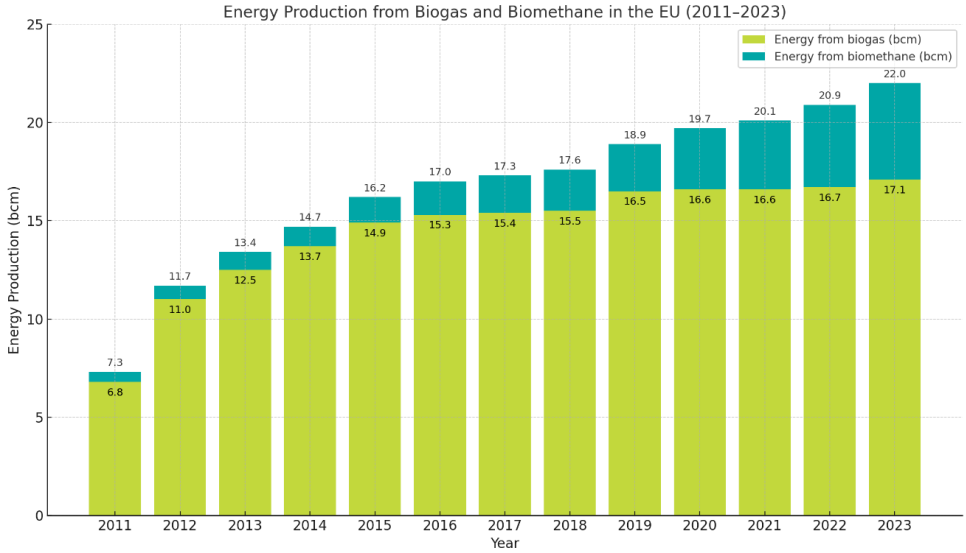


*Fig. 2 Energy Production from Biogas and Biomethane in the EU (2011-2023). (EBA, 2025)*

Figure 2 illustrates the evolution of energy production from biogas and biomethane in European Union member states from 2011 to 2023, expressed in billion cubic meters (bcm). The data reveal that biogas has remained the dominant renewable gas source throughout the observed period, with annual production stabilising at approximately 16–17 bcm since 2016. In contrast, biomethane production has steadily increased year-on-year from just 0.5 bcm in 2011 to 4.9 bcm in 2023. As of 2023, biomethane accounts for more than 22% of the EU's renewable gaseous fuel output. This trend highlights the rapid deployment of biogas upgrading technologies to produce biomethane, which is fully compatible with existing gas infrastructure and suitable for direct application in the gas grid, transportation, and power generation sectors. The increasing share of biomethane production supports the EU's decarbonisation and energy independence objectives, positioning biomethane as a key instrument for substituting fossil natural gas in alignment with the REPowerEU initiative.

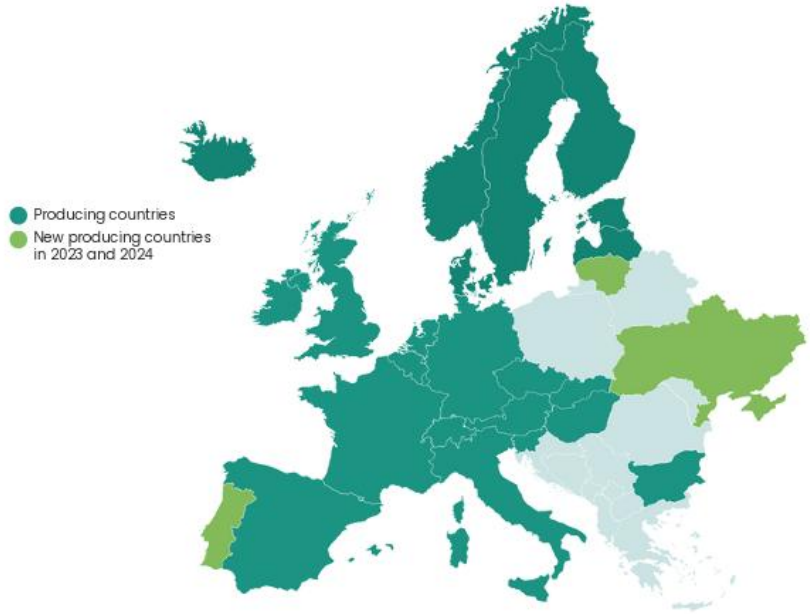


*Fig. 3 Geographic distribution of biomethane-producing countries in Europe, including new producers in 2023 and 2024. (EBA, 2025)*

Figure 3 presents a geographical overview of European countries engaged in biomethane production. Countries with established biomethane output are marked in dark green, whereas light green highlights new entrants that commenced production in 2023 and 2024. The visualisation reveals that biomethane production is widespread across most Western and Northern Europe. At the same time, emerging activities are increasingly evident in Eastern and Southeastern European countries—including Lithuania, Ukraine, Moldova, Portugal, and Albania. This development reflects a growing interest in decentralised renewable energy systems and a strategic effort to reduce dependency on imported fossil fuels. Newly acceded EU Member States and regional partner countries are thus entering a dynamic segment of the energy sector, which plays a pivotal role in advancing the transition towards a climate-neutral Europe by 2050.

The mutual synergy between renewable energy sources (RES) and the tourism sector has become a subject of increasing scientific interest. Research indicates that tourist destinations incorporating renewable energy technologies enhance their competitiveness, reduce operational costs, and attract a growing segment of environmentally conscious visitors (Ellabban et al., 2014).

Biogas plants—particularly on a small, regional scale—can provide clean energy for tourism facilities and are integral components of educational initiatives within ecotourism. Integrating biogas technologies into agritourism in rural and agricultural areas can foster income diversification, promote more efficient use of local resources, and strengthen energy autonomy. These systems also enable the practical implementation of circular economy principles by valorising organic waste streams (e.g., kitchen and green waste) and returning nutrients to the soil through the application of digestate.

Biogas and biomethane systems have the potential to operate not only as part of the energy infrastructure but also as key instruments in the advancement of sustainable tourism. Their deployment aligns with the ecological certification standards of tourism accommodations, such as eco-agritourism and sustainability-oriented rural guesthouses. These technologies can enable energy self-sufficiency for hospitality facilities, particularly in remote or protected areas, while simultaneously reducing the carbon footprint of operators in the HORECA (Hotel, Restaurant, Catering) sector. Moreover, such installations can function as educational and visitor centres, providing the public with hands-on exposure to sustainable waste and energy management models. In doing so, they contribute to regional development by strengthening destinations' environmental identities and fostering a green tourism brand. While precise statistical data on the number of biogas facilities utilised in tourism remains limited, numerous examples from countries such as Germany, Austria, and Italy confirm a growing interest in integrating renewable energy into tourism products.

## Biogas Potential of Slovakia in the Context of Tourism and Biowaste

As a member of the European Union, the Slovak Republic is well-positioned to actively contribute to the ongoing energy transition, particularly by developing regional biogas plants, which may serve as essential components of local circular bioeconomy systems. In recent decades, Slovakia has experienced a gradual increase in biogas plants (BGPS), utilising diverse biomass types for biogas production. According to data from 2011,

approximately 30 biogas plants were operational in the country, with a total installed electrical capacity of around 26 MW, accounting for roughly 0.4% of Slovakia's overall installed power generation capacity. These plants primarily processed maise silage (approximately 80%), while the remainder comprised cattle manure and slurry. By 2024, the number of registered biogas plants had risen to 83, of which 79 were agricultural-based, 4 were waste-based, and 1 facility was upgraded for biomethane production. Biogas plants are strategically located near sources of organic feedstock—such as livestock manure, silage, and biowaste—and are often situated in municipalities with a well-developed agricultural sector or food-processing industry. In subsequent years, the biogas sector experienced further development; however, recent statistics indicate a deceleration in growth (SBA, 2025).

Many biogas plants face economic challenges, particularly due to changes in legislation and shifts in renewable energy support schemes. Despite these constraints, there remains significant potential for optimising the operation of existing facilities and expanding their integration into emerging domains such as sustainable tourism. As a multisectoral industry, tourism generates a wide array of waste streams, among which biodegradable waste constitutes a significant proportion (Skare et al., 2023c). The Slovak Republic primarily includes biowaste from accommodation and food service establishments, recreational resorts, mountain lodges, campsites, and agritourism facilities. This type of biowaste—comprising mainly food leftovers, kitchen waste, grass clippings, leaves, and other forms of organic matter—represents a valuable feedstock for anaerobic digestion and subsequent biogas production.

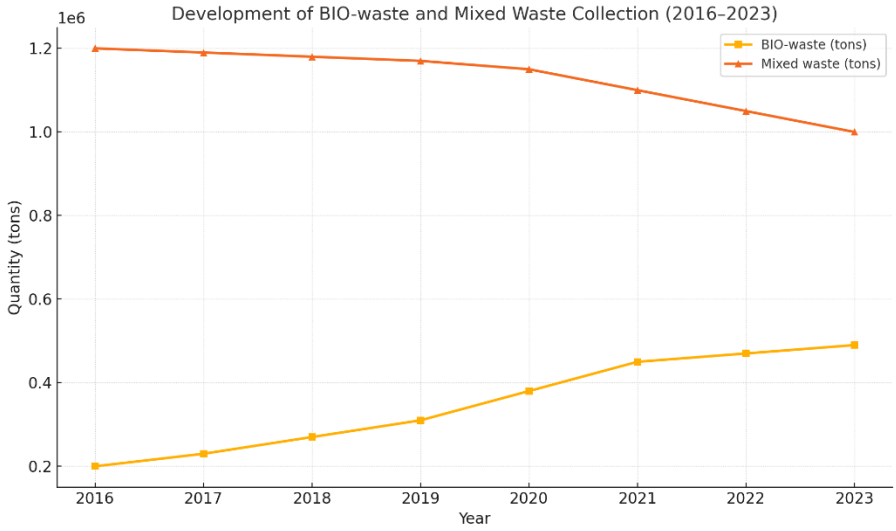


*Fig. 4 Development of BIO-waste and Mixed Waste Collection (2016-2023). (Statistical Office of the Slovak Republic, 2025)*

Figure 4 depicts the development in biodegradable municipal waste (BMW) volumes and mixed municipal waste in the Slovak Republic from 2016 to 2023. The data indicates a gradual and consistent increase in the quantity of BMW, which can be attributed to improvements in separate collection infrastructure and heightened environmental awareness among the population. Simultaneously, a gradual decline in the generation of mixed municipal waste is observed, signalling a shift toward a circular economy model. This trend is particularly relevant in biogas plant development, as these facilities offer an efficient solution for the energy recovery of BMW. The growing availability of organic waste creates favourable conditions for expanding the capacity of existing facilities or constructing new biogas plants, including areas with developed tourism infrastructure. Integrating such plants can significantly contribute to the decarbonisation-related infrastructure, enhance local energy self-sufficiency, and reduce environmental burdens in tourism-intensive regions. The findings further underscore the need for continued optimisation of waste collection systems and strengthening cooperation among municipalities, the private sector, and waste valorisation. Such collaboration is essential to maximising the potential of BMW as a resource for advancing the sustainable development of regions.

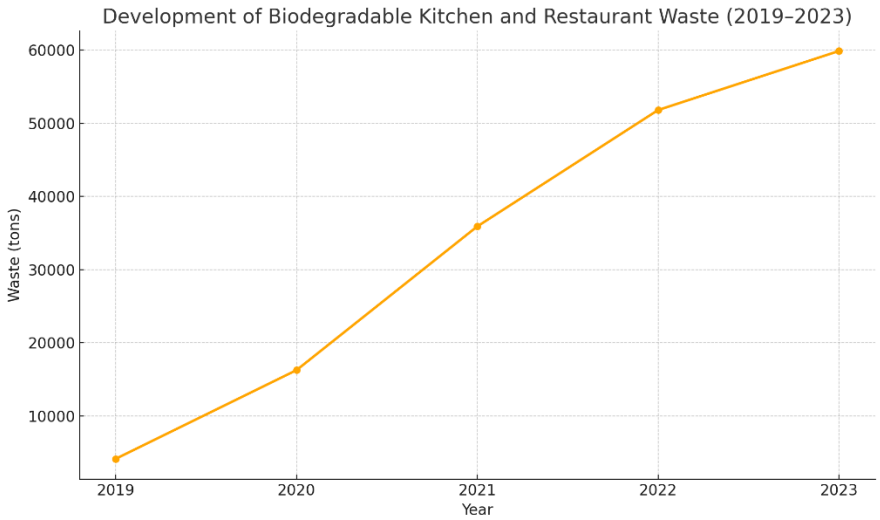


*Fig. 5 Development of Biodegradable Kitchen and Restaurant Waste (2019-2023). (Statistical Office of the Slovak Republic, 2025)*

Figure 5 illustrates the development in the volume of biodegradable kitchen and restaurant waste in Slovakia between 2019 and 2023. Available data indicate a substantial and continuous increase in this waste stream, with year-on-year growth, particularly from 2020 to 2023, reflecting intensified separate collection efforts and improved record-keeping within the municipal and commercial waste management sectors. In 2019, approximately 4,156 tonnes of such waste were recorded, whereas by 2023, the amount had exceeded 59,800 tonnes. This more than fourteen-fold increase over five years reflects both growing pressure for environmentally sustainable waste treatment in the HORECA sector (hotels, restaurants, catering) and the implementation of EU directives on biowaste and circular economy principles.

The findings suggest that increasing kitchen and restaurant waste volumes significantly supports the development of separate collection systems for biodegradable municipal waste (BMW). These fractions represent an important input material for biogas plants, thereby enhancing the potential for energy recovery from waste and generating renewable energy sources. This trend is in alignment with the objectives of sustainable development. It provides a practical foundation for applying circular economy models, particularly in high organic waste generation sectors. The growing volume of biodegradable waste underscores this material stream's substantial, still underutilised, energy potential. Its processing through anaerobic digestion can substantially contribute to renewable energy production, reducing greenhouse gas emissions and promoting regional circular economy systems. In the context of tourism, this type of waste constitutes a key biomass resource, especially in areas with a high density of food service and accommodation facilities. As such, this trend reinforces the need to develop further infrastructure for biowaste collection, separation, and energy recovery and to support the integration of biogas plants into local sustainable waste management systems.

Slovakia, as a country with diverse natural landscapes and marked seasonality in tourism, possesses a regionally differentiated potential for biomass generation. The highest potential is concentrated in areas subject to intense tourist activity, such as the High and Low Tatras, Liptov, Orava, Slovenský raj (Slovak Paradise), the Pieniny region, and the Little and White Carpathians—areas characterised by well-developed forms of rural and environmentally oriented tourism. In addition to year-round operations, temporary seasonal tourism, such as summer festivals, winter ski seasons, and various cultural events, also serves as a significant source of biomass, often generating large quantities of biowaste over short periods. Despite its relevance, the energy potential of this biowaste stream remains largely untapped. Several systemic barriers contribute to this situation, including a lack of targeted biowaste separation practices in smaller tourist establishments, inadequate logistical infrastructure for collection and transport, and weak coordination between tourism stakeholders and energy operators managing biogas facilities. Nevertheless, opportunities exist to enhance this potential by deploying decentralised biogas systems capable of processing biowaste directly at the generation site. This model is well-suited for remote or mountainous regions, where waste transport presents logistical and environmental challenges.

From an environmental perspective, treating biowaste through anaerobic digestion represents an ecologically preferred valorisation pathway, as it significantly reduces greenhouse gas emissions compared to conventional landfilling or incineration methods. The resulting digestate can be applied as an organic fertiliser within regional agricultural cycles, fulfilling the circular economy's core principles (Seyboth et al., 2008). Based on the above, it can be concluded that the tourism sector in Slovakia possesses a substantial, yet currently underexploited, biomass potential that could be effectively converted into renewable energy through the expansion of biogas technologies. However, realising this potential requires a coordinated approach encompassing legislative adjustments, public

financial support, and active collaboration among the tourism sector, municipal stakeholders, and energy providers.

## Challenges and Opportunities in the Development of Biogas Plants in Slovakia

Implementing biogas technologies under the conditions of the Slovak Republic represents a significant instrument for promoting the circular economy and the energy transformation of regions. However, it currently faces several systemic challenges. Despite 106 operational biogas plants in Slovakia, rising input costs have led to the temporary shutdown of 22 facilities. One of the principal barriers lies in the insufficient integration of biogas plants into the local economic and social ecosystems, particularly their limited linkage with communities and business entities active in the tourism sector. Legislative and administrative burdens also pose significant obstacles, complicating not only the permitting process and the connection of facilities to the distribution network but also the implementation of smaller, decentralised energy solutions. Legal ambiguities surrounding the management of biodegradable waste, including bio-waste generated by tourism-related establishments, further hinder effective deployment.

From an economic standpoint, high capital expenditures required for constructing and modernising biogas plants, coupled with uncertainties regarding long-term financial support and investment return, constitute key challenges. Technical constraints are especially evident in the underdeveloped infrastructure for the separate collection and logistics of bio-waste from tourism facilities. Additionally, there is a marked absence of support for innovative business models that could integrate the energy and tourism sectors, undermining the potential for regionally based sustainable development. Public awareness and promotional efforts regarding biogas solutions' environmental and economic benefits are also insufficient, limiting broader societal acceptance and uptake. A promising pathway under current conditions is the transformation of existing biogas facilities into biomethane production units, which could be directly connected to the national gas infrastructure. This model allows for a higher market price comparable to natural gas and enables the sale of guarantees of origin, valued between €25 and €100 per MWh, depending on the source and type of feedstock used (SPNZ, 2024). In alignment with European Union legislative mandates aimed at increasing the share of renewable energy in electricity and heat production, biomethane presents a realistic solution for achieving climate targets (European Commission, 2018). Despite this potential, only one biomethane facility is currently operational in Slovakia—in Jelšava. The transition to biomethane, however, is not universally applicable, as many existing biogas plants are not situated near gas infrastructure and would, therefore, require costly compression or liquefaction technologies and subsequent tank-based distribution.

From the perspective of environmental policy, the Slovak Republic has adopted an ambitious objective to reduce the amount of biodegradable waste in mixed municipal waste by 60% by 2025, compared to 2016 levels, as outlined in the National Waste Prevention Programme for 2019–2025 (MoE SR, 2024). This objective will be monitored through three indicators: the total quantity of separately collected biodegradable municipal waste (BMW), its share in mixed municipal waste, and the number of municipalities promoting domestic and community composting. According to the Ministry of Environment's assessment from autumn 2024, the first indicator shows a positive trend, with 461,960 tonnes collected in 2023, marking an increase of nearly 180% compared to 2016 (MoE SR, 2024). This progress is attributed to legislative changes, particularly eliminating exemptions from the obligation to separately collect kitchen waste starting in 2021, with full enforcement in 2023, except for municipalities where all households demonstrably compost.

However, the second indicator, the share of BMW in mixed municipal waste, cannot yet be reliably evaluated, as no representative waste composition analyses have been conducted despite the approval of the relevant methodology in 2020. Data are similarly lacking for the third indicator—the expansion of community composting. The absence of statistically substantiated data limits the objective assessment of progress toward strategic environmental policy goals. It highlights the need for improvements in data management, policy evaluation, and feedback mechanisms.

Despite these challenges, biogas technologies have substantial potential as part of regional energy transition strategies focused on sustainable tourism development. Energy self-sufficiency of tourism facilities through biogas utilisation can significantly reduce operational costs and carbon footprints. Moreover, it supports circular economic principles, as biological waste from hospitality and accommodation services can be efficiently converted into renewable energy and high-quality organic fertiliser (digestate) suitable for agricultural use. A further development opportunity lies in promoting ecotourism, where the application of ecological solutions becomes part of a region's marketing identity and provides a platform for educating visitors about environmental innovations.

For these reasons, it is essential not only to strengthen political and financial support for the implementation of biogas solutions through national and European strategic instruments, such as the National Integrated Energy and Climate Plan, but also to foster cross-sectoral collaboration between municipalities, energy sector stakeholders, and tourism industry actors. A combination of legislative reform, infrastructure investment, support

for technological innovation, and systematic data collection represents a key prerequisite for Slovakia's transition to a low-carbon and circular economy, in which biogas and biomethane technologies play an integrative role.

## Discussion

The discussion, grounded in the conducted analysis and literature review, confirms that biogas plants (BGPs) represent not only a technologically mature solution but also an environmentally and economically beneficial tool for advancing the sustainability of tourism. Numerous international studies (Yang et al., 2019; Salama & Abdelsalam, 2020; Vaskina et al., 2025; Kucher et al., 2022; Muthu et al., 2023; Idzikowski et al., 2024; Muchele et al., 2025) have empirically demonstrated that integrating BGPs into tourism infrastructure can generate synergistic effects, reducing environmental burdens, improving the energy autonomy of facilities, and diversifying local economies.

Despite these benefits, the potential of BGPs within the Slovak tourism sector remains significantly underutilised. Although the country operates over 100 biogas installations (SPNZ, 2024), rising input costs and the discontinuation of state subsidies have resulted in economic instability among operators. While the technological shift toward biomethane production is feasible, it requires substantial investments in system upgrades and connection to gas infrastructure, which is not uniformly available across all regions (EBA, 2024). Legal complexity and the lack of clear regulatory guidelines regarding bio-waste management in the HORECA sector also present further obstacles to successfully implementing such projects (MoE SR, 2024).

International experience suggests that the successful deployment of renewable energy technologies—including biogas plants—depends not only on techno-economic factors but also on the social positioning of stakeholders and how they construct their roles within the energy transition. The study by Vogler and Kump (2023), analysing energy communities (ECS) in Austria, identified four stakeholder archetypes—grassroots, local hero, technocentric, and entrepreneurial—each embodying different interpretations of sustainability goals and varying degrees of commitment to systemic transformation. These insights are equally relevant in the Slovak context, where the success of integrating biogas technologies into tourism may vary significantly depending on the motivations of local actors. As in Austria, stakeholder attitudes in Slovakia range from transformational (grassroots) to pragmatic, profit-oriented perspectives (entrepreneurial). This diversity underscores the need for a nuanced engagement strategy with communities and stakeholders from the earliest stages of BGP project planning.

An important contribution to this study is the identification of the risks associated with inflated expectations on the part of policymakers. While it is often assumed that energy communities will naturally fulfil transformative roles, stakeholders' real motivations are typically a mixture of environmental, economic, personal, and even hedonic drivers. In tourism, hospitality operators may be driven less by ecological responsibility than by cost reduction or marketing considerations. Based on these findings, proposed models for BGP deployment in tourism areas are recommended to acknowledge stakeholders' social and value diversity fully. Supporting mechanisms should be tailored to enable each stakeholder type to find its place within the system through financial incentives, educational campaigns, or participatory planning processes.

Discussions around the role of BGPS in sustainable tourism must also account for broader socio-political contexts influencing the implementation of renewable technologies. Leopold et al. (2024) highlight that energy system transformation in Europe is not only a technical or environmental process but also generates significant social tensions. These tensions often arise from the unequal distribution of benefits and burdens, low levels of public participation, and inadequate representation of vulnerable groups in decision-making. Such "eco-social conflicts" may surface in tourism-intensive regions where BGP projects are introduced without adequate dialogue among local authorities, residents, and businesses. Applying these principles to the Slovak context suggests that the success of biogas projects in the tourism sector will depend on economic efficiency and the ability to engage local communities and design inclusive governance mechanisms perceived as fair. A case from the French Upper Rhine illustrates that resistance to renewable energy projects frequently stems from feelings of marginalisation and lack of control over top-down decision-making—sentiments that may similarly emerge in Slovak regions with limited civic participation. Leopold et al. (2024) also point to the divergent motivations among actors. While some view biogas technologies as a pathway to environmental responsibility, others assess them solely through financial cost and personal convenience. These perspectives must be integrated into the design of community-based models, enabling local populations' direct or indirect financial participation, such as through energy cooperatives or shared ownership schemes.

From an environmental standpoint, existing studies confirm that anaerobic digestion has a substantially lower carbon footprint than traditional waste management methods (Seyboth et al., 2012; Ferdes et al., 2022). These authors emphasise that waste generated by hotels, restaurants, and other food service establishments constitutes a rich and stable substrate suitable for biogas production. This approach aligns fully with the circular economic principles and supports environmentally and economically sustainable practices in tourism destinations. Furthermore, digestate production as a byproduct offers ecologically viable solutions for local agriculture. This aspect is particularly significant in rural or protected tourism areas, as it facilitates closed-loop material cycling.

In Slovakia, it would be advisable to introduce targeted collection systems for food waste from accommodation and dining facilities and to process it centrally or decentrally via BGPs. Equally important is the education and motivation of tourism service providers to actively participate in the collection and separation of biodegradable waste. Such efforts can be complemented by educational ecotourism programs that demonstrate to visitors how waste is transformed into energy, thereby enhancing environmental awareness and the destination's attractiveness. An additional dimension introduced to the discussion is visitor experience—BGPs can become integral components of educational tourism, as demonstrated in case studies by Huber (2020) and Kucher et al. (2022), where such facilities are part of guided tours or ecological workshops. These tourism formats not only increase environmental awareness but also strengthen the local identity of destinations.

In summary, the Slovak context presents an opportunity for a hybrid approach that encompasses technological adaptation of existing facilities, reform of the legal framework for bio-waste, development of regional partnerships, and environmental education. To ensure that BGPs become an integral part of the green transformation of tourism, it is imperative to remove systemic barriers and support pilot initiatives that can serve as scalable models for other regions.

## Conclusion

The findings and analysis presented in this study confirm that biogas plants represent a viable and systemic instrument for supporting the transformation of the tourism sector towards a low-carbon and circular economy. Their integration into regional and local structures—particularly in areas with a high concentration of tourism-related operations—offers the potential not only for the environmentally sound valorisation of biowaste but also for strengthening energy self-sufficiency, diversifying income streams for local communities and reinforcing the ecological identity of tourism destinations. Despite the technological maturity and existing legislative frameworks, deploying biogas and biomethane plants within Slovak tourism continues to face several systemic barriers. These include economic uncertainty related to the phasing out of state subsidies, regulatory ambiguities surrounding the management of biodegradable waste generated by the HORECA sector, and infrastructural limitations regarding technological accessibility. Another significant challenge is the lack of alignment between energy-related projects and strategic tourism planning, which undermines the potential for synergistic development.

Based on the conducted analyses, international case studies, and current trends in renewable energy, it can be concluded that integrating biogas and biomethane technologies into tourism infrastructure represents a strategic opportunity for sustainable regional development. Their implementation directly supports the Slovak Republic's environmental objectives, contributes to carbon footprint reduction, and enables the effective recovery of biodegradable waste from tourism facilities. However, to fully harness this potential, it is essential to eliminate the existing barriers and adopt targeted measures at the public policy and regional planning levels. Key actions include simplifying permitting procedures for small-scale installations, supporting investments in biomethane technologies, establishing a clear legal framework for the hygienic and lawful treatment of bio-waste, promoting public-private partnerships, introducing certification schemes for ecotourism facilities, improving data collection on waste streams, and implementing educational programs for the public. These measures form the basis for the systematic integration of biogas energy into the sustainable development of regions. Thus, biogas technologies can substantially contribute to achieving climate policy goals and shaping a modern paradigm of circular tourism.

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