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LEVERAGING THE TRIPLE - LAYER BUSINESS MODEL CANVAS FOR THE TRANSPORT-RELATED BIOMETHANE INDUSTRY

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Abstract

The European transport sector is undergoing a profound transformation toward sustainability, driven by the need to decarbonize mobility and align with the EU's Fit for 55 and Renewable Energy Directive (RED III) targets. Within this context, biomethane has emerged as a promising renewable alternative fuel, offering significant greenhouse gas reduction potential and compatibility with existing natural gas (NG) infrastructure. This paper investigates the application of the Triple - Layer Business Model Canvas (TLBMC) as a multidimensional analytical framework for the Croatian biomethane industry, with a particular focus on road transport applications and national support schemes. By extending the traditional Business Model Canvas to include environmental and social layers alongside the economic dimension, the study captures the complex interdependencies between sustainability goals, stakeholder engagement, and market viability. A comparative assessment with the Hungarian biomethane sector is conducted to identify differences in policy design, incentive structures, and institutional support mechanisms influencing business model development. The research employs a qualitative methodology combining policy analysis, stakeholder mapping, and business model synthesis to highlight key enablers and barriers to biomethane market integration in both countries. The findings reveal structural, financial, and institutional conditions that influence the scalability of biomethane production, grid injection, and fuel utilization in the transport sector. Targeted support schemes, investment incentives, and cross-sectoral collaborations can accelerate market maturity, indicating that business models integrate environmental performance and social value creation from the outset. This study provides actionable insights into how governments and private actors can codevelop robust, inclusive, and future-proof business models for biomethane in road transport. The outcomes inform national energy and transport strategies, contributing to the broader European decarbonization agenda and advancing the discourse on sustainable business model innovation in the bioenergy domain. The results identify early market risks arising from policy sequencing and highlight the critical role of demand-side instruments in converting biomethane supply ambitions into effective transport uptake.

Keywords: greenhouse gas reduction, renewable fuels, biogas and biomethane, market acceleration strategy, triple - layer business model canvas (TLBMC)

1 Introduction

The European transport sector is in the midst of an accelerated transition toward low-carbon mobility under the European Green Deal, the Fit for 55 legislative package, and the recast Renewable Energy Directive (RED III).

RED III increases the 2030 transport ambition to either 29% renewable energy in transport or a 14.5% reduction in greenhouse gas (GHG) intensity, in addition to strengthening the sustainability criteria for bioenergy and biofuels and creating clear demand for renewable fuels, including biomethane [1]. Similarly, the EU's policy emphasis on security of supply after the 2022 energy crisis further reinforced a structural shift toward domestically produced, infrastructure-compatible renewable fuels in road transport [2]. Within this policy context, biomethane has emerged as a practical decarbonization option for hard-to-electrify segments, such as transport, by leveraging existing gas grids, CNG/LNG refueling stations and mature vehicle technologies. According to the latest European Biomethane Map [3], the number of operational biomethane plants in Europe will increase from 1, 548 in 2024 to 1, 678 in 2025. During this period, 165 new facilities were commissioned, including 56 that came online in the early months of 2025. This growth trend signals the continued strengthening of a sector positioned as a cornerstone of sustainable energy, with a rising share of transport end-use. The latest EBA datasets (2024–2025) also underscore the role of biomethane in energy security and GHG mitigation [4]. Biogas and biomethane now play a central role in integrated energy systems, linking agriculture, waste-to-energy processes, and combined heat-and-power (CHP) production. By converting agricultural residues, livestock manure, and organic waste into energy, these systems significantly reduce GHG emissions and promote circularity [5]. Research by Nahwani et al. [6] highlights how agro-industrial facilities can leverage onsite biogas plants not only for energy supply but also for integrated waste treatment and carbon reduction, yielding closed-loop benefits and attractive returns on investment. This aligns with Mehdizadeh et al. [7] findings that integrated approaches, e.g. machine learning-optimized processes, circular design principles and participatory policy frameworks, enable firms to broaden their portfolios, innovate operational models, and meet national and EU decarbonization targets.

Croatia is aligning with this trajectory through its updated climate-energy governance: the Low-Carbon Development Strategy (to 2030/2050) [8] and the updated National Energy and Climate Plan (NECP) [9] process, whereas Croatia's National Policy Framework on alternative fuels provides the enabling basis for gaseous fuels in transport [10]. More recently, the government reaffirmed its commitment to accelerate the green transition and decarbonize the energy system, indicating a potential wave of grid-connected biomethane with potential transport [11]. To interpret these dynamics systematically, our paper adopts the Triple Layer Business Model Canvas (TLBMC) as an integrative analytical framework. The TLBMC, conducted by Joyce and Paquin [12] extends the classic Business Model Canvas with environmental (life-cycle) and social layers, enabling the analysis of horizontal (within layers) and vertical coherence (across layers). Recent applications in energy systems research demonstrate TLBMC's suitability for multi-actor, multi-value contexts – identifying reporting gaps and innovation levers in sustainable energy business models [13, 14], yet research applying TLBMC specifically to transport-oriented biomethane markets at the national level remains limited. This represents a clear research gap for Croatia, where market formation, policy instruments, and stakeholder alignments are still co-evolving under RED III. Given the transport-oriented scope of this study, the economic layer of the TLBMC provides the most relevant analytical perspective and is therefore prioritized in this research. This focus is warranted by the sector's pronounced profitability orientation, where the adoption of renewable fuels such as biomethane is contingent upon their economic competitiveness relative to that of fossil alternatives. While environmental dimensions have been extensively addressed in the literature, the integration of the social layer – although conceptually important – will be reserved for future research because of space constraints.

Before the economic layer of the TLBMC is applied, we focus on Croatia's transportrelated biomethane opportunity and develop a comparative perspective with Hungary, a neighboring member state with ambitious biomethane market developments [15]. Survey evidence from Hungary's gas distributor system operator (FGSZ) signals sizeable 2030 biomethane injection and consumption interest (≈255 million (mn) m^3 and 190 mn m^3, respectively) [16], highlighting both supply potential and market demand for certified renewable gas, including in transport applications. This contrast – Croatia's recent governance updates versus Hungary's rapid policy push – offers a useful comparative lens on how support scheme design, gridinjection regulation, and stakeholder coordination shape transportoriented biomethane business models in Central and Southeastern Europe. Therefore, the relevant research questions can be formulated as follows:

- Q1: What are the main characteristics of biomethane production in Croatia and Hungary?
- Q2: What are the key differences in policy design, incentive structures, and regulatory frameworks between Croatia and Hungary?
- Q3: How can the results of the analysis of biomethane production in Croatia and Hungary be integrated into the TLBMC model?

The objective of this research is to develop an analytical framework for evaluating the regulatory structures and strategic orientations governing transport-related biomethane deployment in Croatia and Hungary, with the aim of identifying interdependencies and coherence among key influencing factors. On the basis of this analysis, this study proposes evidence-based recommendations for future policy and strategic measures that can effectively accelerate biomethane adoption in national transport sectors.
This paper is organized as follows: section 1 introduces the European policy context for transport-related biomethane and defines the research questions and objectives; section 2 outlines the methodological approach and reviews the key characteristics of biogas and biomethane production, with particular attention to policy frameworks and support schemes; section 3 presents the empirical results of the comparative analysis of biomethane production, infrastructure, and transport-related policy instruments in Croatia and Hungary; and section 4 discusses the findings, identifies key market risks and policy implications, and concludes with limitations and directions for future research.

2 Materials and methods

As a circular bioeconomic solution, biogas systems exemplify the circular bioeconomy by converting organic residues – such as agricultural waste, animal byproducts, and sewage sludge – into renewable energy. Through anaerobic digestion, biomass decomposes in oxygen-free conditions, producing a gas mixture rich in methane (45–85%) and carbon dioxide (25–50%) [4]. When upgraded, biogas becomes biomethane, a renewable substitute for NG valuable for decarbonizing transport. Compressed or liquified biomethane can fuel CNG and LNG vehicles, offering an immediate low-carbon solution for heavy-duty and long-haul segments while leveraging existing gas infrastructure [5]. Its integration into transport networks represents a critical pathway for meeting EU climate targets and reducing reliance on fossil fuels. To characterize biomethane consumption in Croatia and Hungary, a comprehensive review of biomethane strategies and policies and access to a robust database containing relevant statistical indicators for production and utilization were essential. The collection of relevant datasets provides reliable measurements of biogas and biomethane use, including transport-specific data relevant to this research. Additional insights were obtained from biogas projects and scientific publications. Given the relatively immature biomethane markets in the countries analyzed, recent national data on production and utilization are often limited.

By evaluating the biogas strategy and policies, facilitating a structured analysis and comparing biogas policies and support schemes, a comprehensive literature review was conducted. This review focused on the key dimensions and characteristics of existing strategies, regulatory frameworks, and incentive mechanisms at both the European and national levels. Based on these insights, an analytical framework was implemented to enable a systematic comparison of biomethane utilization in the transport sector, aligning patterns with policy instruments and support schemes. The key insights derived from strategies and support schemes were organized according to the categories of the analytical framework. During the development of the analytical framework, the approach of our previous study [27] served as a reference point. As a result, the following categories were implemented for policy evaluation:
- the biomethane production support scheme type
- main legislatives and policies
- fuel supplier subsidies
- fiscal incentives demand side
- other types of support and influencing factors.

This research seeks to refine the evaluation process of product-related environmental policy documents and infrastructure development while identifying the underlying drivers reflected in the biomethane application in the transport sector (figure 1).

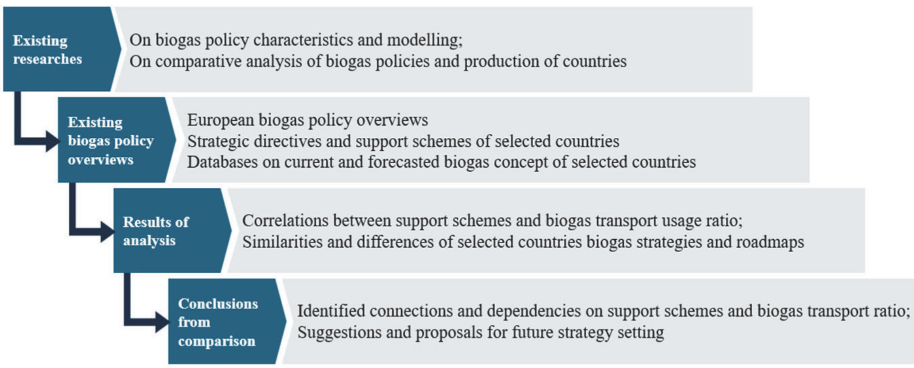

Figure 1 Flowchart of the analysis steps (own edition)

3 Results

3.1 Characteristics of biomethane consumption in Croatia and Hungary

Croatia is producing ~0.11 billion cubic meters (bcm) of biogas, accounting for 4.1% of the national NG supply, with 99% of the output used for electricity generation in CHP plants [17], and it has an estimated biomethane potential of 0.23 bcm, which is sufficient to replace approximately 5% of current NG imports (figure 2) Croatia has 42 biogas plants [18]; however, no biomethane production or transport-related consumption was recorded, with limited infrastructure and three CNG stations nationwide (figure 3) [19]. Based on these characteristics, strategic opportunities could include upgrading existing CHP plants and extending the filling station network. In contrast, Hungary is pursuing an ambitious scale-up aiming to triple biogas production from the current 200 mn m^3 to 600 mn m^3 annually by 2030, with biomethane output projected at 184–200 mn m^3 instead of the current 5 mn m^3 [21], signalling a strategic shift toward transport decarbonization (figure 2). Infrastructure readiness is advancing, with 17 CNG stations and growing interest in biofuel-driven fleets (figure 3) [16].

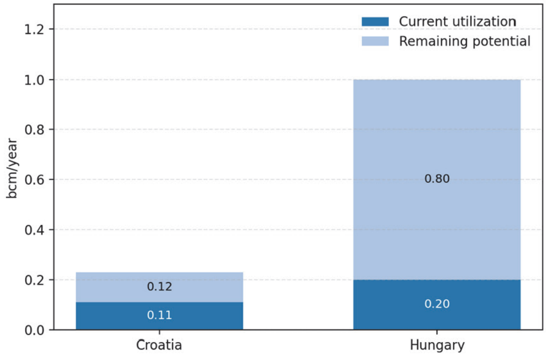

Figure 2 Current and estimated bcm biogas production of Croatia and Hungary (own edition) [19]

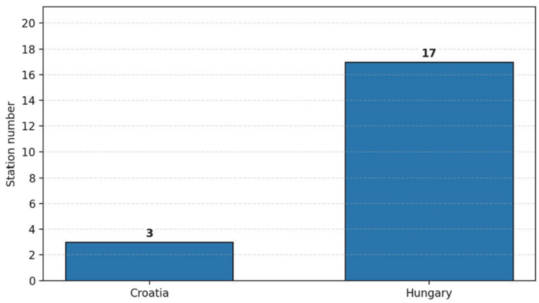

Figure 3 Operating CNG filling stations of Croatia and Hungary (own edition) [30, 31]

3.2 Policy formulation

In Croatia, biogas production has historically focused on electricity and heat generation, with no recorded biomethane production. A strategic shift began in 2025 by establishing a new support mechanism as a direct grant scheme, the €30 million State Aid Scheme for Supporting the Production of Biomethane [22, 26]. The scheme is projected to enable an annual production of approximately 0.004 bcm of biomethane [23]. Moreover, Croatia's biomethane-related legal environment is shaped by several key policies, including the Final Updated National Energy and Climate Plan (NECP) 2021–2030, the Gas Market Act, and the Transport Biofuel Act. Despite these frameworks, no specific incentives are available for fuel suppliers, and the fiscal environment offers no excise tax relief, VAT reduction, or vehicle-related tax benefits for biomethane or biomethane-powered vehicles. Similarly, no subsidies are provided for CNG or bioCNG vehicles, limiting demand-side stimulation. Additional indirect support comes from the Environmental Protection and Energy Efficiency Fund, which provides grants for waste management infrastructure, renewable electricity projects, educational initiatives, and energy-efficiency development. Although not biomethane specific, these instruments may influence the broader conditions for potential biogas and biomethane investments. Hungary operationalized a comprehensive biogas/biomethane investment support scheme under the Jedlik Ányos Energy Program in 2025, allocating €100 mn non-refundable grants to upgrade existing plants and develop new capacity across the full value chain [20].

The call ring is approximately €45 mn for small-scale units (<500 m^3/h), with typical grant amounts ranging from €0.5–12.5 mn (and €0.25–2 mn for small-scale modernization). Applications opened in 2025 and will close in 2026 (or until funds are exhausted). Policy targets presented by the Ministry of Energy supported by a GO system administered aligned with EECS standards to enable cross-border certificate trade. The program complements Hungary's updated NECP (2024) and REPowerEU framework [24, 25].

3.3 Integrating consumption and policy insights into the TLBMC

From a TLBMC perspective, the economic layer in both countries currently dominates; environmental value is created but not fully monetized without GOs, tax alignment, and procurement signals, while the social layer is currently under-reported and therefore remains out of our assessment. Our results (see table 1) suggest that co-developed policies - CAPEX + GOs + demand-side drivers + distributing infrastructure - can lock-in vertical coherence (economic–environmental–social) and horizontal fit (policy–infrastructure–market), improving the bankability and scalability of transport-oriented biomethane business models in Croatia and Hungary. In addition to our two-country focus, recent European evidence shows that blended approaches - CAPEX grants + OPEX/tax reductions + demand side incentives consistently increase installed capacity and fuel use. The EBA's 2024–2025 datasets [4] record a rapid expansion of biomethane plants and a rising share injected into grids, whereas the Guidehouse's Gas for Climate Report [19] emphasises that policy stability and end-use signals substantially lower investment risk and accelerate transport uptake. These insights support our recommendation to sequence Hungary's and Croatia's policies toward demand-relevant measures once more plants are online.

Table 1 Inputs for the TLBMC of the biogas-related elements in Croatia and Hungary

<table>
<tr><th>Elements</th><th>Croatia</th><th>Hungary</th></tr>
<tr><td colspan="3">Economic layer</td></tr>
<tr><td>Value proposition</td><td colspan="2">Renewable, infrastructure-compatible transport fuel (future)
Supports national/EU decarbonization goals
Potential replacement for imported NG</td></tr>
<tr><td>Customer segments</td><td colspan="2">CNG fleet operators
Export buyers using GOs
Fuel suppliers interested in renewable gas uptake</td></tr>
<tr><td>Customer relationships</td><td rowspan="2">No biomethane producing currently</td><td>Biomethane is exported</td></tr>
<tr><td>Channels</td><td>Grid injection and established CNG network (17 stations)
Export channels enabled by GO</td></tr>
<tr><td>Key activities</td><td>Biomethane upgrade project development
Infrastructure expansion</td><td>Large-scale production increase</td></tr>
<tr><td>Key resources</td><td colspan="2">Feedstock: agri residues, manure, organic waste etc.</td></tr>
<tr><td rowspan="2">Key partners</td><td>Ministry of Economy
Environmental Protection and Energy Efficiency Fund</td><td>Ministry of Energy
(Jedlik Ányos Program)</td></tr>
<tr><td colspan="2">Feedstock partners
CHP plant operators
Grid operators</td></tr>
</table>

Table 1 Inputs for the TLBMC of the biogas-related elements in Croatia and Hungary - continuation

Elements	Croatia	Hungary
Cost structure	CAPEX for plant upgrading & plant setup	
	Infrastucture expansion cost	
Revenue streams	Electricity & heat generation	Electricity & heat generation, biomethane sales
	Environmental layer	
Materials	Agri residues, manure, organic waste etc.	
Production	0.11 bcm biogas	200 mn m3 biogas, 5mn m3 biomethane
Supply & Outsourcing	N/A	
Distribution	Limited, 3 CNG station	Wider, 17 CNG station GO system for export
Use Phase	N/A	
End-of-Life	N/A	
Functional Value	Substantial GHG reduction potential. Compatible with existing gas and vehicle infrastructure	
Environmental Impacts	Contribution to energy security; methane/odour reduction Circularity benefits via waste-to-energy	
Resource Efficiency	N/A	

4 Conclusion

Our comparison confirms that Croatia and Hungary are positioned very differently on the biomethane learning curve. Croatia remains in the early-stage: recording no biomethane output and operating with three CNG stations – a configuration that naturally limits transport uptake and viable business models in the short term. In contrast, Hungary has coupled clear 2030 volume targets with a sizeable CAPEX grant window and a functioning GO regime - a triple signal to investors, gas system operators, and potential transport users. Both countries currently prioritize supplyside levers over transport demand creation. Croatia's State Aid scheme for supporting the production of biomethane moves the country from vision to bankable projects but (thus far) omits explicit demandside triggers for vehicle uptake or fuel switching. Hungary's Jedlik Ányos Energy Program follows the same sequence: build capacity, then unlock uses. This is in line with many EU member states where earlystage policy focuses on plant conversion and grid connection before the introduction of transportoriented incentives.

For both systems, the risk is an early "supply-without-offtake" gap unless public fleets, logistics corridors, or fuelsupplier obligations are mobilized in parallel. Hungary's GO system reduces market risk for project developers and opens a pathway to book-and-claim demand (including transport use via certificates of origin) even before domestic tax breaks arrive. Our review revealed no comparable, operational GO framework publicly documented for Croatia; given Croatia's current absence of biomethane output, the lack of GOs is not yet binding, but it will become a bottleneck as the first plant commission. Hence, early adoption of such a system should be a priority. Our paper provides a structured, policy-focused comparative framework that helps policymakers, regulators, and market actors identify early market gaps and design coherent support instruments to translate biomethane supply ambitions into viable, demand-driven transport markets over time.

Current research faces two main limitations: as Croatia currently has no recorded biomethane use in transport, the analysis relies on inferred policy effects rather than observable market behavior; therefore, several elements of the TLBMC cannot yet be meaningfully assessed. Moreover, in Hungary, transport consumption remains nascent despite strong policy commitments, so conclusions reflect anticipated rather than realized fuelswitching outcomes. Future research should revisit analyzed countries, enabling empirical evaluation of demand patterns and full TLBMC assessment. Future studies should analyze actual fleet uptake and fuel switching once purchase incentives or supplier obligations take effect, providing evidence on the real market impact of current policy instruments.

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