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Executive Summary

GreenMeUp – Green Biomethane Market Uptake is a Horizon Europe project that aims at providing a basis for policy-makers and stakeholders to develop more informed renewable energy policies and country-tailored market uptake measures, in order to improve and complement existing biomethane policy in Europe. Started in August 2022 and running until July 2025 the project involves fifteen partners from eleven European countries, aiming to significantly **accelerate biomethane's market uptake** across the European Union. Structured around **Market**, **Policy**, and **Society** pillars, the project's core mission is to **enhance biomethane deployment** by evaluating framework conditions in advanced and target European countries, fostering societal acceptance through science-based evidence, and designing tailored market uptake policies.

Biomethane is a fundamental component of Europe's energy transition, contributing to a net-zero energy system and circular economy. Current production stands at **3.5 bcm (37 TWh)** as of late 2023, with a potential to reach **167 bcm by 2050**, covering **35-62% of Europe's gas demand**. The REPowerEU plan specifically targets a tenfold increase to at least **35 bcm annually by 2030**. The project highlights the evolving feedstock usage, shifting from energy crops to agricultural residues, manure, and organic municipal solid waste, aligning with EU objectives.

While some **advanced European countries** such as Germany and Italy lead in biomethane production, **target countries** like the Czech Republic and Estonia are emerging, while others such as Greece, Poland, and parts of the Danube Region are still developing their biomethane sectors despite significant potential. The project emphasizes the critical role of stable and reliable **policy and financial support.** Regulatory frameworks in many target countries remain limited.

A comprehensive **SWOT analysis and PESTEL workshops** organized by GreenMeUp partners, identified common **challenges** including the lack of clear, long-term regulatory frameworks, high investment and grid connection costs, lengthy permitting processes, and low public awareness. Proposed **strategies** include establishing clear roadmaps, providing financial incentives (subsidies, grants, tax exemptions), improving infrastructure, harmonizing Guarantees of Origin (GOs), and promoting additional value streams from biomethane projects (e.g., bio-CO_2 commercialization, digestate valorization).

Public perception based on a survey, shows generally low awareness of biomethane, with common misconceptions persisting. While intentions to use biomethane-based

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fuels are moderate, price sensitivity is high. Acceptance of biomethane facilities increases with greater spatial distance

GreenMeUp project in a nutshell

The GreenMeUp, a Horizon Europe project running from 2022 to 2025, aims to significantly increase biomethane's market presence across the European Union. Its core mission is to enhance the overall deployment of biomethane throughout the Europe.

The concept of GreenMeUp is based and developed around three pillars: **Market**, **Policy**, and **Society**, applied consistently across advanced European countries, target European countries, and Mission Innovation countries. Beyond geographical considerations, it also addresses innovation and standardization, focusing on fostering biomethane production in less developed markets, increasing social acceptance through scientific evidence, and designing comprehensive market uptake measures.

GreenMeUp has several **specific objectives**:

- Evaluating framework conditions and market dynamics in 10 advanced European countries, where the biomethane sector is well developed and several Mission Innovation countries from outside Europe;
- Assessing these conditions in target countries, those with a low market development;
- Ensuring active stakeholder engagement and fostering societal acceptance using science-based evidence;
- Designing country-tailored market uptake policies ;
- Conducting vital dissemination, communication, and exploitation activities for project findings.

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1. Overview of Biomethane Production and Utilisation in Europe

Figure 1. Biometaan OÜ, agricultural plant, near the city of Tallin, Estonia
Source: ETA-Florence

Biomethane is a key renewable resource for Europe's energy transition, helping for a more sustainable future, reduce reliance on natural gas, and contribute to an integrated net-zero energy system and circular economy. Current biomethane production supplies **18.4 bcm** of renewable gas to Europe and could potentially reach up to **167 bcm by 2050**, covering **35-62%** of the whole continent's gas demand.

The project identified and quantified existing production and use routes, focusing on feedstock usage, anaerobic digestion, and gasification and then, investigated successful policies and market dynamics in advanced European countries, which account for **over 95%** of Europe's biomethane production, with the main aim of sharing best practices with target countries (1) (2) (3) (4). The analysis also extended to Mission Innovation countries such as Canada, China, India, and the USA.

Key regulations relevant for the sector were analysed, including: **EU Renewable Energy Directive (RED II/III)**, **Energy Taxation Directive (ETD), European Union Emissions**

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Trading System (EU ETS), **REPowerEU plan**, which specifically aims to increase biomethane production by 2030 to at least 35 bcm annually.

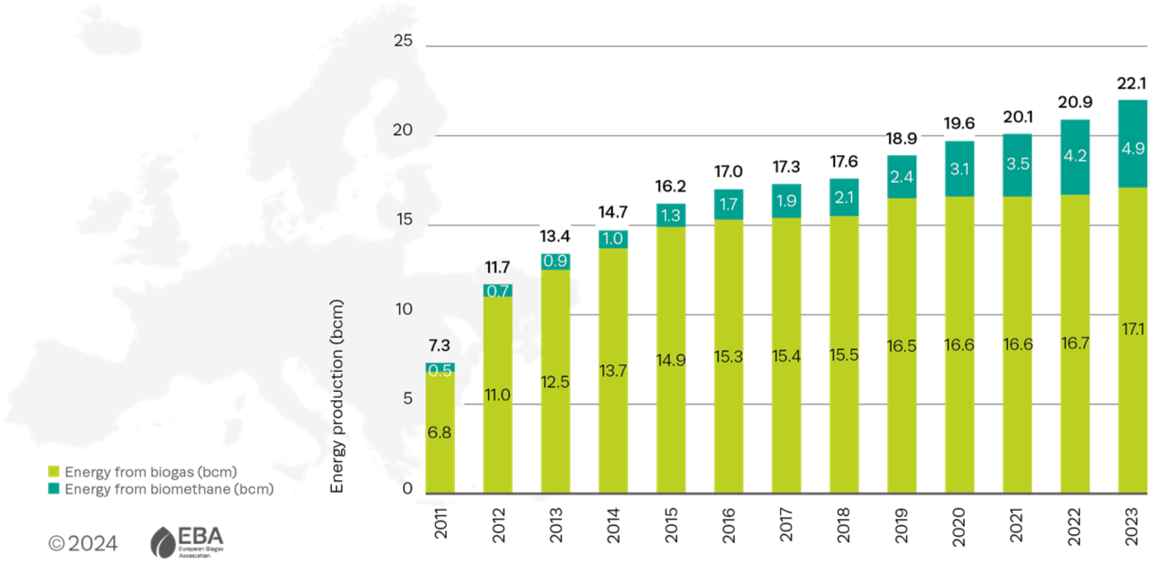

Figure 2. Combined Biomethane and Biogas production in Europe (bcm). Source: EBA Statistical Report

1.1. Production routes, end-uses and policy support

Biomethane is seen as **instrumental in shaping Europe's future energy mix**, significantly contributing to reducing reliance on natural gas and achieving a net-zero energy system. European biomethane production **increased by 20% in 2021**, with a record number of new plants commissioned, bringing the total to over 1,000 facilities across 22 countries (5).

The actual biogas production (and therefore that of **biomethane**) occurs through **anaerobic digestion of organic materials** (like agricultural waste or municipal solid waste) and **gasification of solid fuels**. After a purification process, biomethane achieves natural gas quality, enabling different end-uses across **transport (Bio-CNG, Bio-LNG), industry, power generation, and heating**.

Key supportive policies identified in advanced European countries include establishing a **national vision and clear targets**, providing **direct investment and production support** (e.g., Feed-in Tariffs), offering **indirect production support** (e.g., incentives for feedstock use and digestate valorization), and implementing **demand-side incentives** (e.g., tax

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reductions). **Regulations enabling market access**, such as the right to inject biomethane into gas grids and robust Guarantee of Origin systems, have been vital and the **EU's REPowerEU plan targets a twelve-fold increase in biomethane production by 2030** to ensure energy security (1).

2. Feedstock Supply Developments

Biomethane is a flexible, interchangeable substitute for fossil natural gas and a mature technology essential for achieving climate neutrality by 2050, with the potential to **reduce global greenhouse gas emissions by 10-13%**, and to achieve this objective, we must acquire a precise and detailed knowledge of feedstock availability, that is critical for verifying energy policy targets. The main types of feedstocks include livestock manure, with global **potential for 250-370 bcm of biomethane**, where anaerobic digestion mitigates methane emissions and produces nutrient-rich digestate (3) (6)

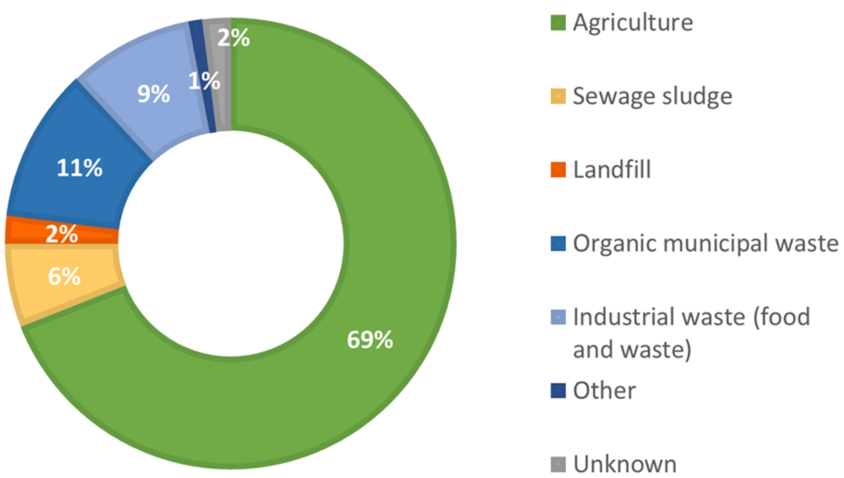

Figure 3. Biomethane production per type of feedstock (2023). Source: EBA Statistical Report 2024

Food waste and municipal solid waste, accounting for **a third of global food production** and **8% of anthropogenic GHG emissions** , have a **global biomethane potential of 85-100 bcm**, with separate collection being key to unlocking this potential; **industrial and sewage sludge, wastewaters** with high organic content, can produce **digestate rich in phosphorus**, making it a high potential soil amendment, with a **global biomethane potential estimated at 22-32 bcm**; **agricultural residues**, such as cereal straw and

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pruning, have a **global biomethane potential of 300-380 bcm**, with pre-treatment enabling their use despite lignin content challenges; **sequential cropping**, cultivating two or more crops in the same field over time, optimizes land use and could reach **46-185 bcm annually in Europe**; **cultivation in marginal and contaminated lands** addresses food vs. fuel competition and increases carbon stock.

2.1. Biomass availability and utilization

Europe's theoretical biomass potential from key sources like **livestock manure, food waste and whey** is consistent: while these feedstocks could theoretically produce over **23 billion cubic meters of biomethane annually**, getting closer to the EU's **35 billion cubic meter target for 2030**, underscoring the need for additional sources:

- **Cereal straw** is a significant supplementary source, potentially contributing over **16 billion cubic meters more biomethane;**
- **Sewage sludge** is another important feedstock with considerable biogas generation potential and no competitive uses;
- The valorization of **woody biomass through gasification and methanation** represents a mature technological pathway that will help Europe achieve its 2030 target.

3. Development of Standardisation Processes for Biomethane

European standards are an important step for giving a solid foundation to the single market, **enhancing competitiveness**, and streamlining international trade within the biomethane sector. **CEN** (European Committee for Standardisation) plays a key role, with its standards replacing 34 national ones and often being mandated by the European Commission to ensure compliance with EU legislation (7) (8).

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Table 1. European standards for biomethane.

CEN Working Group/Technical Committee	Name of relevant Standard	Description
SECT/SF GAS I/JWG GQS	Gas quality standard – EN 16726	This standard specifies gas quality characteristics, parameters and their limits, for gases classified as group H that are to be transmitted, injected into and from storages, distributed and utilized.
CEN/TC 408	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid EN16723-1 and EN 16723-2	Standardization of specifications for biomethane as fuel for engines and of biomethane for injection in the natural gas grid, including any necessary related methods of analysis and testing.
CEN/CLC/JTC14/WG5	Guarantees of origin related to energy -EN 16325	Standardization in the field of energy management within the energy transition framework in close coordination with CEN/CENELEC sectorial strategy
CEN/TC 223	Soil improvers and growing media - CEN/TS 17732:2022	standardization of two types of material used in agriculture. Compost and digestate properties when used in fertilizing products

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3.1. Key regulations for gas production and by-products quality

Standardization efforts and challenges include **Gas Quality Standards (EN 16726)**, which specify gas quality characteristics for injection into the natural gas grid, and in particular, is defining **oxygen limits** for biomethane injection due to different national standards, as elevated oxygen levels expose the grid to risks of corrosion, "black powder" formation, combustion, and microbial growth.

Biomethane for transport and grid Injection resulted in two standards:

- **EN 16723-1 for natural gas network injection;**
- **EN 16723-2 for automotive fuel specifications**,

They are addressing unique biomethane components like siloxanes, terpenes, and amines.

- **Guarantees of Origin (GOs) - EN 16325** are legally mandated by the **Renewable Energy Directive 2018/2001 (RED II)** for all renewable energy sources, including biomethane, proving the "renewable value" of gas and facilitating cross-border trade;
- **EN 16325** is being revised to cover GOs for various energy sources, but a lack of harmonization in GO content and a single cross-border transfer scheme remain challenges for a pan-European GO market;
- Soil improvers and growing media **(CEN/TC 223)** standardizes materials used in agriculture, including digestate, aligning with the **EU Fertilising Products Regulation (FPR)** to ensure quality and safety.

These standardization efforts aim to improve market access, ensure free trade, and enhance legal and technical security for biomethane applications.

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4. Midstream and Downstream Technological Developments for Biomethane Production and Offtake

This chapter outlines key advancements in renewable gas technologies, specifically focusing on biomethane ($bioCH_4$) and biohydrogen ($bioH_2$) production and their integration into existing energy systems. It details innovations in anaerobic digestion and CO_2 management, highlighting their role in greenhouse gas emission reduction and climate neutrality. The discussion further encompasses developments in sustainable bioenergy production, including biochar, sustainable aviation fuel (SAF), e-methane, and various biohydrogen pathways. The complexities and challenges associated with the large-scale introduction of biomethane into the European natural gas grid are also addressed. Finally, the importance of monitoring and mitigating fugitive methane emissions within the expanding biomethane industry is underscored, emphasizing sustainable practices for Europe's energy future (2) (9).

The future of the biogas industry anticipates **integration** with other renewable energy systems like wind and solar, hydrogen production, and a shift towards decentralized, localized energy production and cooperative farming models. **Enhanced biogas production** is influenced by several factors such as:

- substrate type;
- temperature;
- volumetric load;
- hydraulic retention time;
- pH;
- C/N ratio;
- substrate concentration;
- inoculants;
- mixing.

Feedstock diversification extends beyond traditional agricultural biomass and residues to include food waste, sewage sludge, industrial organic waste, and challenging lignocellulosic biomass, enabled by advanced pre-treatment techniques and **monitoring** and **optimization** include in-line monitoring systems that measure methane, CO_2, and humidity in real-time to optimize plant operations, reduce costs, and

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protect equipment. **Innovative additives** like carbon-encapsulated iron nanoparticles (OPS) can increase methane production by 20%, reduce hydrogen sulfide (H_2S) by up to 99%, and enhance digestate quality.

4.1. CO_2 management

Developments in CO_2 management highlight **biogenic CO_2 capture**, which occurs during biogas upgrading, from combined heat and power (CHP) plant flue gas, or during biohydrogen production, with biogas upgrading being the most accessible source of concentrated biogenic CO_2. **Advantages of biogenic CO_2** include high purity, absence of CO, very low NH_3/H_2S, non-toxic contaminants, local production, price stability, and synergistic contributions to the local bioeconomy. CO_2 capture technologies include mature options such as sorption (absorption, adsorption, e.g., amine scrubbing), membrane separation (dominant for new plants), and cryogenic separation. Utilisation Pathways are classified into direct use (e.g., beverage carbonation, urea production) and conversion pathways (e.g., methanol, construction materials).

Table 2. Theoretical potential of biogenic CO_2 from biogas.

Year	**Biogas and biomethane production in Europe**	**Theoretical potential of biogenic CO_2 from biogas**	**Equivalence**
2020	18 bcm	24 Mton	Equivalent of the GHG emissions of Croatia in 2020
2030	35 bcm	46 Mton	Equivalent of the GHG emissions of Sweden in 2020
2050	95 bcm	124 Mton	3% of EU-27 GHG emissions in 2020

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4.2. AD systems and potential integration technologies

Developments in **plant integration** with AD systems showcase slow pyrolysis plants, where slow pyrolysis processes are integrated with AD plants[1] to produce biochar from organic biomass, improving soil quality, sequestering carbon, and generating syngas for energy. **Downstream integration**, such as pyrolysis of solid digestate, increases product value and enables carbon removal certification, while **upstream integration** can increase buffer capacity, mitigate inhibition, support microbial growth, and enhance digestate quality.

Beyond just making and biochar, **treating them afterward can reduce ash**, giving us better products such as **biocoal for factories**. We're also seeing progress with **Sustainable Aviation Fuel (SAF)**: by using a process called **Fischer-Tropsch (FT) synthesis**, we can turn biomass into liquid fuels for planes, and this fuel is **approved and can be mixed in up to half** with regular jet fuel. Worth to be mentioned are the **E-Methane technologies**, which greatly increase the amount of biomethane we can obtain. This is done by combining carbon dioxide from biogas or gasification with green hydrogen or electricity, resulting very helpful in places having a lot of extra renewable electricity. Moreover, **biomethanol** is a sustainable alternative to traditional methanol derived from renewable sources, and biohydrogen is produced from biogenic sources through various processes.

[1] Pptx presentation from Andrea Maria Rizzo on behalf of RECORD for further information on integrating technologies

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4.3. Biomethane grid injection

Biomethane grid injection faces many **hurdles** to keep up with regulations for large-scale biomethane injection into the gas grid, including significant infrastructure modifications to accommodate injection points and ensure compatibility, and also the maintenance of **biomethane quality,** falling on individual producers at each injection point.

Grid interconnection can extend the user base and increase injection capacity but also entails high costs and prolonged permitting. Important is also monitoring and curbing fugitive methane emissions within the rapidly expanding biomethane industry, as methane leaks occur at various points, with digestate storage and post-treatment being major sources. Mitigating these emissions is crucial for achieving EU biomethane production targets, preventing direct production losses, and avoiding adverse environmental impacts. Plus, cost-efficient **technical and operational measures** are available, including installing gas-tight covers, optimizing process parameters, using enclosed flares, limiting methane slip, ensuring sufficient hydraulic residence time, implementing gas-tight digestate storage, and conducting regular leak detection and repair (LDAR) campaigns.

5. Current State of Biomethane in Europe and Target Countries

The European biomethane sector is now expanding rapidly, with a record **1,322 biomethane plants** operating across Europe **by the end of 2023**, producing **37 TWh or 3.5 bcm of biomethane**. Furthermore, there is a considerable shift from traditional biogas production to biomethane, particularly in 2022, representing a successful year for new biomethane plant operations, and **feedstock usage** is also **evolving**, with a progressive transition from dedicated energy crops towards agricultural residues, manure, and plant residues, and to a lesser extent, sewage sludge and organic municipal solid waste. This shift aligns with the EU objective to replace 35 bcm of natural gas imports from Russia with domestic biomethane production by 2030, a target requiring significant investment and efforts into the three main areas identified as crucial by the project: policy, market and society (10) (11).

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Across the European Union, countries face unique challenges and opportunities in biomethane production and deployment, including variations in biomass types, processing technologies, gas distribution and grid connection capabilities, end-use applications, policy targets, and financial mechanisms, and despite these differences, most EU Member States possess existing gas infrastructure and regulations crucial for biomethane deployment.

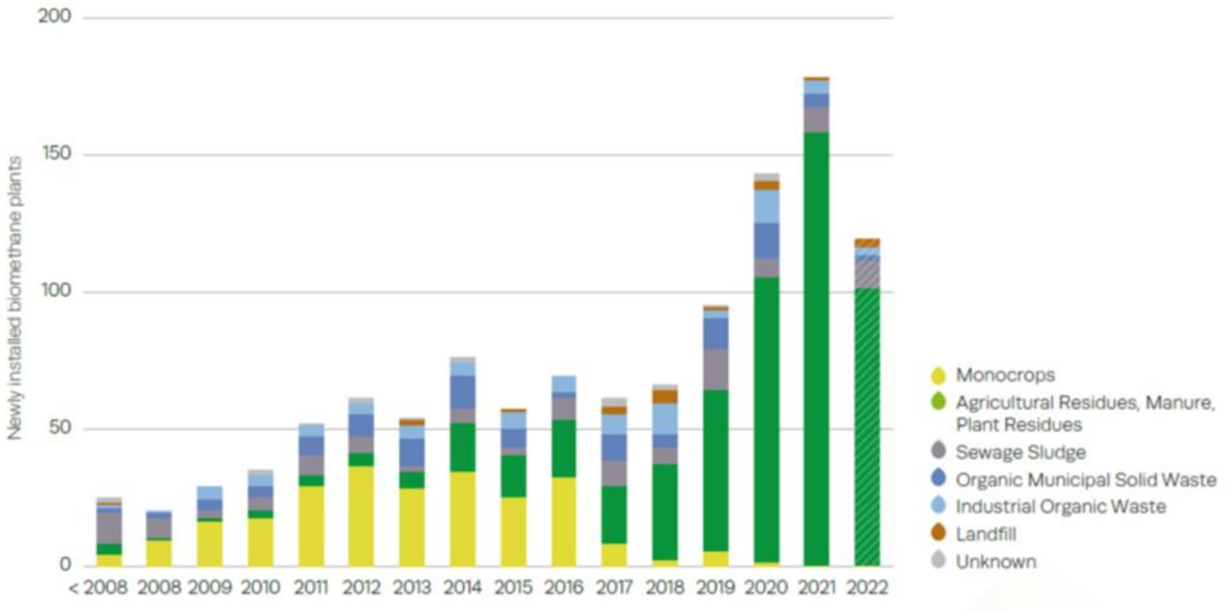

Figure 4. Total number of newly installed biomethane plants in Europe each year, 2008-2022, overall and per feedstock type (Source: EBA Statistical Report 2022)

Among the GreenMeUp target countries, **Czech Republic** and **Estonia** are currently leading in biomethane market development, and **Spain** follows with 5 biomethane plants producing 250 GWh in 2022. Regarding **Latvia**, it has one operational plant, while in contrast, **Greece**, **Poland**, and parts of the **Danube Region** (Hungary, Romania, and Serbia) have not yet established dedicated biomethane plants, despite possessing significant potential in agricultural resources and organic waste, which are the main feedstocks. Predominant production routes in all target countries refer to agricultural resources, primarily manure and agricultural residues, with municipal wastes holding a lower share.

6. Regulatory Landscape and Supportive Policies

The existence, stability, and reliability of **targeted policy** and **financial support** are key factors for biogas and biomethane development, regardless of market maturity. In target

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countries, **policy and regulatory frameworks are still limited**, mainly consisting of **National Energy and Climate Plans (NECPs)** and adjustments to the REPowerEU initiative (10).

6.1. Target countries

The following list wants to highlight what are the main updates on the political and financial sides for those countries where the biomethane sector is still under development, but showing a high potential:

- The **Czech Republic** provides direct and indirect investment support for biomethane plant construction and upgrade, along with "green bonuses" for biomethane production, and demand-side support includes green electricity purchase and recognition of Guarantees of Origin (GOs);
- In **Estonia**, government subsidies have covered biomethane production, biogas plant construction, filling station development, and the transition of public transport to compressed gas;
- **Spain** has launched an aid plan for biogas plants and developed a regulatory framework for grid injection;
- **Poland** offers financial support from various structural funds and EU programs for renewable energy projects, including biogas and biomethane, and has demand-side financial support for consumers of CNG/biomethane, LNG, and hydrogen used as transport fuel;
- In **Latvia**, **Greece**, and the **Danube Region countries** (Hungary, Romania, and Serbia), the regulatory framework and supportive policies are still under active development.

7. SWOT Analysis: Challenges, Opportunities, and Strategic Responses

The GreenMeUp project utilized **SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis** to identify factors affecting each target country's biomethane market, followed by a TOWS matrix to collaboratively formulate strategies, involving stakeholders from Policy, Market, and Society Hubs (12).

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A recurring common issue across target countries is the **lack of clear, supportive, and long-term regulatory frameworks**, hindering market development and investment. **Financial support** measures are crucial to reduce investment risks and ensure economic viability. Logistical challenges, such as feedstock supply chain management, high costs of grid connection, and lengthy permitting processes, are also prominent barriers and concerns about future market prices and demand for biomethane, particularly given competition from other technologies like hydrogen and electric fuels, must be addressed. As already stated along the different chapters, there is a recognized need to increase public awareness of biomethane's role in decarbonisation and to foster stakeholder engagement for greater acceptance.

Key strategies proposed by target countries and stakeholders include establishing clear and **comprehensive regulatory frameworks** (roadmaps and strategies) to provide long-term stability and certainty, including **binding targets** and **streamlined permitting processes**. **Financial support** and **incentives** (subsidies, grants, tax incentives) are fundamental aspects to ensure a stable return on investment and mitigate market price fluctuations. Implementing improvements **in infrastructure** and **technical support**, such as grid connections, filling stations, and reverse flow units, will reduce logistical and operational obstacles, and harmonizing registers within the EU (e.g., Guarantees of Origin) will enhance market stability and cross-border trade. Exploring and promoting additional value streams from biomethane projects, such as **bio-CO_2 commercialization**, **surplus heat utilization**, and **digestate valorization**, will enhance economic attractiveness and overall sustainability.

7.1. Country-specific insights and top strategies

In the following list, target countries recommendations and main objectives are summarised with their future plans:

- **Czech Republic** focuses on new operating and investment aids, updating the National Energy and Climate Plan (NECP), and converting existing biogas plants;
- **Estonia** aims to build biomethane injection facilities, expand its use into new areas like shipping, and develop subsidies for transport companies;
- **Spain** seeks to develop a realistic roadmap with clear biomethane targets, implement a consumption incentive system, and increase coordination among stakeholders;

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- **Latvia** prioritizes targeted investments and incentives, regulatory framework enhancement, and increasing awareness and education;
- **Poland** focuses on developing a biomethane strategy with clear targets, promoting transport sector decarbonisation, and introducing economic instruments;
- **Greece** emphasizes state support for biomethane plants, promotion of the natural gas market as the main carrier of biomethane, and maximum exploitation of theoretical biomethane potential;
- The **Danube Region** (Hungary, Romania, Serbia) aims to elaborate national action plans, corroborate regulatory frameworks for grid injection cost sharing, apply contracts for difference, strengthen knowledge of potentials, elaborate dedicated governmental roadmaps, set mandatory targets, perform comprehensive framework analyses, interlink decarbonisation and waste reduction targets, and define appropriate incentive schemes.

The **GreenMeUp** project's assessment of target countries (4) reveals a varied landscape of biomethane market development. **Czech Republic** and **Estonia** lead the way with well-developed markets, while **Spain** follows closely with several operational plants and **Latvia** is at an earlier stage with one operational plant. In contrast, **Greece**, **Poland**, and the **Danube Region**—comprising **Hungary**, **Romania**, and **Serbia**—have not yet established any biomethane plants, but this is poised to change, particularly in Greece, where new legislation anticipated by late 2025 is expected to catalyze investment.

Across all target countries, the **dominant production route for biomethane is the use of agricultural resources**, such as manure and agricultural residues, a trend projected to continue beyond 2030. This highlights a significant and readily available biomass potential. The **primary end-use for biomethane is consistently identified as transportation**, with power and heat generation making up a smaller share.

A critical factor driving biomethane development is the presence of stable and reliable **targeted policy and financial support**. Mature markets like the Czech Republic, Estonia, Spain, and Poland have implemented various support mechanisms, including direct investment and demand-side incentives, while in contrast, the **regulatory frameworks in Latvia, Greece, and the Danube Region are still evolving**, indicating a clear need for policy advancements to unlock their biomethane potential. The findings underscore that a combination of clear national targets, consistent feedstock availability, and robust policy frameworks is essential for fostering a thriving biomethane market.

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8. Stakeholder Engagement and Co-creation Actions

A strategic pillar of the GreenMeUp project is the engagement of **key stakeholders** through a **multi-actor approach**, involving market players, policy, and societal actors across the biomethane value chains.

This methodology aimed at establishing "Hubs" (13) (14) (15) within each target country—**Policy**, **Market**, and **Society** Hubs—which functioned as exchange platforms to boost (16) across various end sectors like heat, electricity, and transport. These dynamic groups allowed for membership changes to incorporate expertise or address specific plans affecting citizens or actors near production and transport facilities. This multi-actor engagement fosters co-creation activities, facilitating diverse perspectives and allowing stakeholders to provide input on defined plans.

The initial phase focused on establishing these hubs, with core objectives including **mapping relevant stakeholders** based on thematic interests and national agendas. The hubs serve as platforms for actors to contribute to the **analysis of national biomethane markets**, providing **feedback** and proposing **solutions** to identified **barriers**. A key aim is the understanding of stakeholder needs for higher biomethane market uptake, including **societal acceptance** (17) for expansion projects. The hubs also facilitate involvement in defining necessary policy interventions, fostering informal agreements, and developing trust through open exchanges and co-creation, and the engagement extends to **local communities**, particularly **regional actors** near biomethane production sites and grid networks. The strategy involves aligning activities with key project tasks that support **sector analysis** and **strategic measure definition**. Stakeholder mapping is an iterative process conducted by country partners, using the "snowball technique" to identify additional actors, and to maintain the engagement, the project prioritizes identifying and addressing hub members' main interests and needs, while maintaining flexibility in thematic focus.

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Figure 6. Myrsini Christou and Christos Tourkolias from CRES during their presentation. Source: CRES

Figure 5. Audience attending the last hub workshop in Greece. Source: CRES

The official launch of national biomethane Hubs in most target countries occurred in the first half of 2023: the initial engagements revealed **strong stakeholder interest**, with discussions needing to be shaped around their primary interests. Input from shared views proved valuable for governmental biomethane policy drafting. The **multi-stakeholder approach** fostered creativity and innovation by attracting diverse skills, but risks, included **potential decrease in participation**, **knowledge transfer challenges** due to inconsistent attendance, and reluctance of key policy stakeholders to **fully discuss market responsibilities** in joint meetings. Proposed corrective actions included reinforcing open discussion spaces, ensuring policy hubs consider suggestions from market and society hubs, maintaining active communication, consulting members on decision-making, and promoting individual contacts and cooperation.

Figure 7. Attendees at the last "Hub Stakeholder Meeting" for Czech Republic organized by CZ BIOM. Source: CZ BIOM

Figure 8. Adam Moravec from CZ BIOM during his presentation at the last "Hub Stakeholder Meeting" for Czech Republic. Source: CZ BIOM

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9. Co-creation Actions: PESTEL Workshops

PESTEL workshops served as a key co-creation action, structuring collective knowledge and stakeholder perspectives on biomethane sector development. The PESTEL tool identifies Political, Economic, Social, Technological, Environmental, and Legal factors, providing a structured analytical framework (18). These workshops aimed to co-define **strategic actions** addressing **challenges**, **leverage enabling factors**, and **propose exemplary practices** from advanced biomethane markets applicable to national contexts. Workshops typically utilized the World-Café format, dividing participants into small groups for open discussions on PESTEL elements. A total of 195 stakeholders across the target countries participated between November and December 2023, validating key challenges and proposing solutions.

9.1. Key Findings from PESTEL Workshops by Country / Region

Needs and main challenges for target countries identified during the PESTEL workshops are the followings:

- The **Czech Republic** highlighted the significance of operational and investment support and the need for better communication between state administration and market actors;
- The **Danube Region** (Hungary, Romania, Serbia) reached consensus on necessary governmental measures, including reviewing national targets, providing supportive incentives, sharing grid injection costs, issuing export-qualified GOs, and certifying digestate;
- **Estonia** focused on biomethane injection, feedstock potential, and international gas trade to ensure business model security;
- **Latvia** emphasized the need for regulatory support and policy incentives, identifying barriers to be mitigated;
- **Greece** centered on the techno-economic analysis of biomethane production and policy recommendations;
- **Poland** discussed newly introduced regulations, missing elements for investors, and ongoing projects, focusing on legal, economic, and environmental factors;
- **Spain** focused on the need for a stable regulatory framework, long-term foresight to attract investment, and streamlined permitting processes.

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10. Summary and Conclusions of Stakeholder Engagement

The stakeholder engagement activities and PESTEL workshops undertaken as part of GreenMeUp have significantly contributed to moving the project into a propositional phase, and these efforts have not only validated existing challenges within the biomethane sector in each target country but have also led to the identification and validation of clear priorities to address them, informed by all interested parties.

Recurring themes emphasize the critical need for robust financial support mechanisms, including operational and investment aid, co-financing options, and subsidies for gas-grid injection points. Addressing **regulatory** and **procedural barriers** through simplified licensing and clearer frameworks is another key area for industry and decision-makers to collaborate on, and the utilization of **digestate** as an integral part of the business model is consistently recognized for its potential to improve biomethane plant profitability and enhance soil quality.

Furthermore, discussions have identified various aspects crucial for business model development, such as fostering **partnerships**, exploring innovative opportunities with **industry** partners, developing **liquefied bio-CH_4 options**, and promoting the **sharing of grid injection costs** between network operators and biomethane producers. Looking ahead, the GreenMeUp hubs play an important role in operationalizing these proposed solutions, facilitating connections among biomethane stakeholders, establishing communication bridges for cooperation, and ensuring key information is effectively conveyed to policymakers, thereby strengthening the sector and accelerating its integration into national energy and transport systems.

11. Biohydrogen Market Uptake Measures

As the project coordinator and a key contributor to its market uptake measures, CRES has undertaken extensive analysis to identify and propose effective policies and financial frameworks. This effort includes in-depth studies on both biohydrogen and biomethane, resulting in a comprehensive understanding of their market potential, barriers, and strategic policy interventions (19).

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CRES's work on biohydrogen involved developing a **specialized five-step methodological approach** to identify and propose effective policy measures. This approach began with the design and application of the **Fuzzy Cognitive Mapping (FCM) method** in six target countries: Czech Republic, Danube region, Estonia, Greece, Poland, and Spain. The core question explored was the most crucial parameters for effective biohydrogen penetration and utilization, inherently considering risks and challenges.

The FCM method, described by CRES as a powerful tool based on neural networks, allowed for depicting fuzzified relationships among concepts, quantifying the degree of connection, and analyzing complex causal chains. The process involved collecting feedback from face-to-face interviews, identifying concepts, assessing causal relationships qualitatively, and transforming these into numerical weights. This led to the construction of individual and collective FCMs, enabling the assessment of each parameter's impact. The analysis of the collected data was performed using the FCMapper simulation tool. The outcomes of this methodological approach were discussed with involved stakeholders through organized policy, market, and society hubs, allowing for refinement of the policy recommendations.

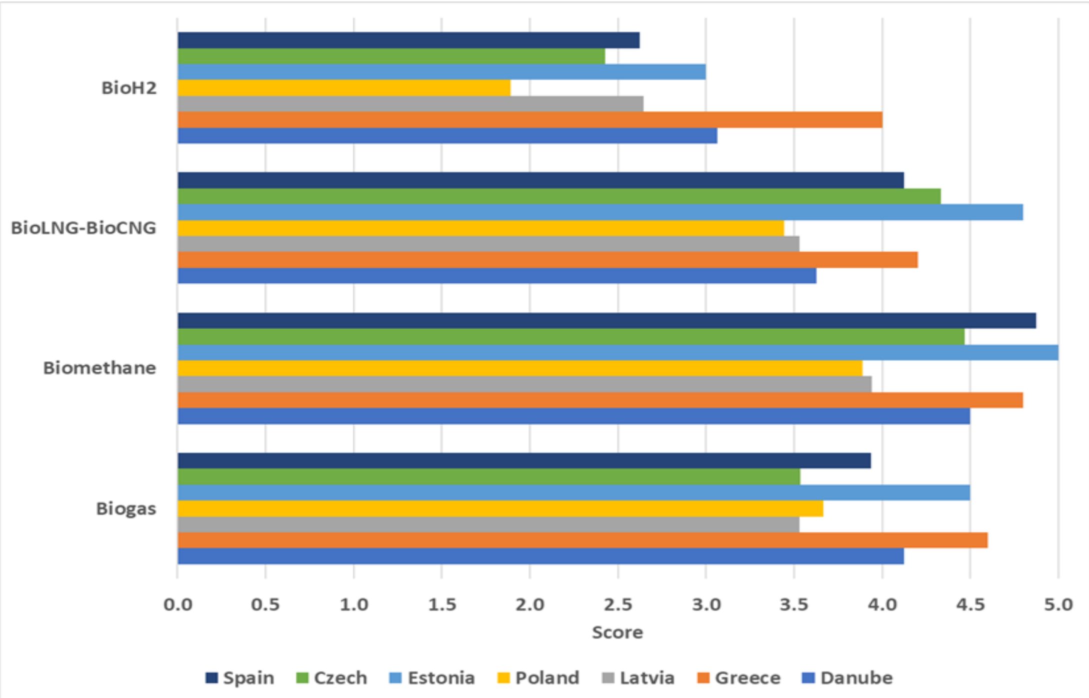

Figure 9. Potential role of the different alternative fuels to the fulfillment of the 2030's energy and climate targets in the examined countries. Source: CRES

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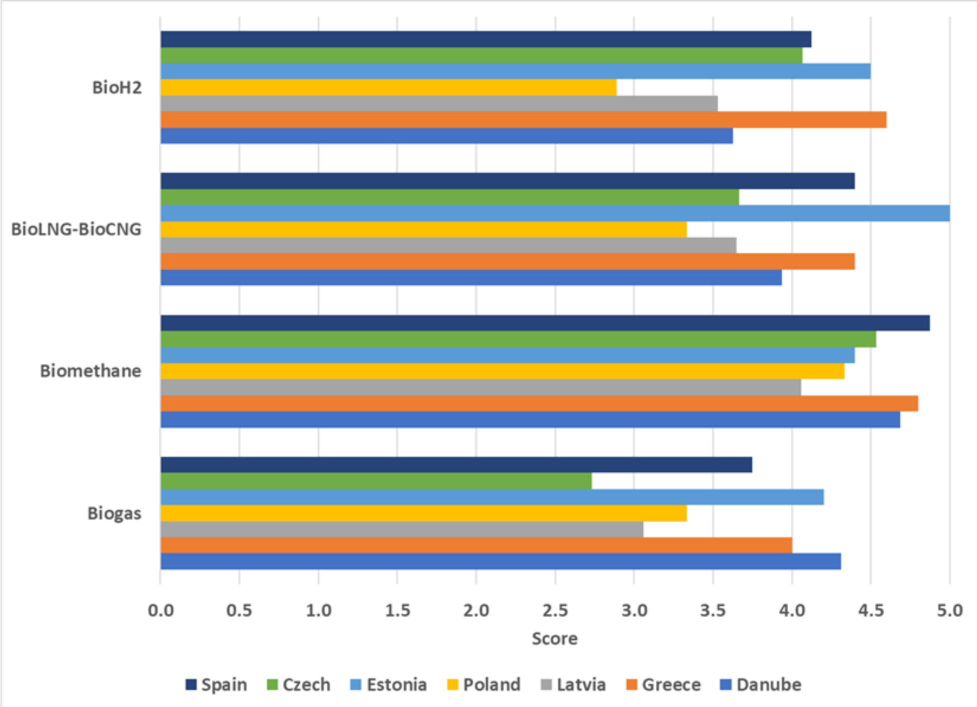

Figure 10. Potential role of the different alternative fuels to the fulfillment of the 2050's energy and climate targets in the examined countries. Source: CRES

11.1. Key findings regarding biohydrogen across the analyzed countries

Common Barriers: several shared obstacles were identified. In the **Czech Republic**, **lack of investment and operational support**, problematic economics, high technology prices, and insufficient legislation at EU and national levels created **investment uncertainty**. **Estonia** also highlighted a lack of investments, limited experience in H2 projects, and high production costs, coupled with an absence of relevant legislation. **Poland** noted high H2 vehicle and fuel costs, along with safety concerns.

Crucial Factors for Development: for the **Czech Republic**, achieving a balance between supply and demand, developing the automotive industry, and improving social acceptance were deemed crucial. The **Danube region** emphasized the establishment of biohydrogen supply chains integrated with renewable energy sources (RES), promotion of public-private partnerships, and development of financial tools. **Estonia** pointed to its high-RES potential, while **Greece** highlighted the need for a national strategy, a robust legislative framework, and financial support.

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Proposed Policy Measures: CRES's analysis led to specific policy suggestions for each country, often reflecting common themes:

- **Financial Support**: Advocated in the Czech Republic, Danube region, Estonia, Greece, Poland, and Spain to address high costs and attract investment.
- **Legislative and Regulatory Frameworks**: Measures to adopt or refine legislation were proposed for the Czech Republic, Estonia, Greece, and Spain, aiming to remove regulatory barriers and specify ambitious targets.
- **Pilot Projects and Supply Chain Development**: Designing pilot projects to gain experience (Estonia) or balance supply and demand (Czech Republic) were key. Establishing supply chains was important for the Danube region and Greece.
- **Social Acceptance and Awareness**: Improving public awareness was a common theme, highlighted in the Czech Republic, Danube region, and Greece. Providing information about benefits and safety was stressed for Poland.
- **Technological Development**: Ensuring technological development and availability was a focus in Greece and Poland, including confronting technological risks in Spain.

Overall, 43 stakeholders participated in the FCM application across six countries, leading to the identification of 265 concepts and 36 proposed policies, demonstrating a co-designed approach that considered national conditions and priorities.

12. Biomethane Market Uptake Measures

CRES also produced a comprehensive list of policy requirements for improved biomethane market uptake in seven target countries (Czech Republic, Danube region, Estonia, Greece, Latvia, Poland, and Spain) and at the EU level. This analysis, based on a five-step methodological approach, started with an in-depth bibliographical review and the development of a detailed questionnaire (20).

A survey was conducted involving 85 stakeholders classified into decision makers, market players, and society (21) (22) (23). The responses were thoroughly analyzed by country and stakeholder category to formulate policy recommendations.

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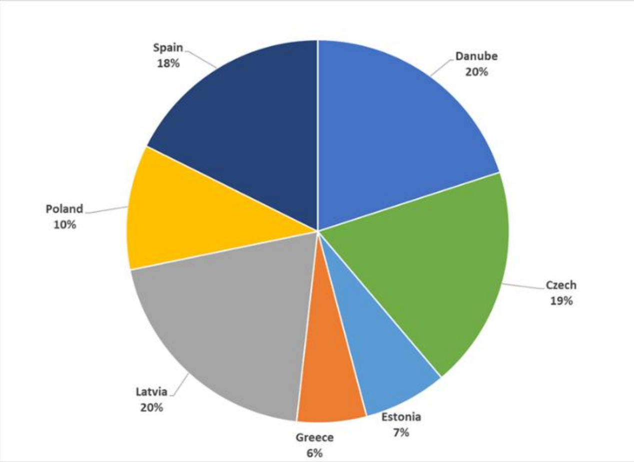

Figure 11. Allocation of the collected questionnaires to the different categories of stakeholders. Source: CRES

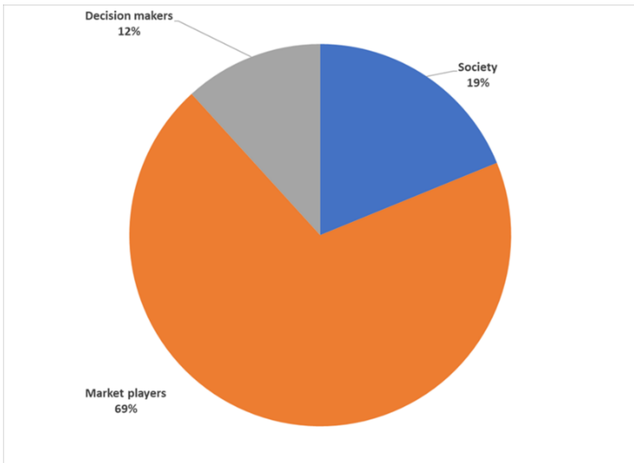

Figure 12. Allocation of the collected questionnaires to the different countries. Source: CRES

Key insights regarding biomethane, as identified by CRES, include:

- **Role of Alternative Fuels**: biomethane is considered the most prominent alternative for fulfilling both 2030 and 2050 energy and climate targets across all examined countries, with Estonia showing a stronger inclination towards BioLNG and BioCNG by 2050. Biohydrogen also shows auspicious prospects for Czech Republic, Estonia, Spain, and Greece by 2050.
- **Feedstock and Technology**: agricultural residues are consistently identified as the most prevalent feedstock. Membrane separation is the leading upgrading technology, with other technologies like pressure swing adsorption, water scrubbing, and cryogenic separation also having significant roles.
- **Distribution and Benefits**: distribution through the gas grid is expected to be primary. The benefits of biomethane are widely recognized, including improved energy supply security, reduced greenhouse gas emissions, and enhanced waste management.
- **Barriers**: significant barriers exist across technical (infrastructural challenges, poor waste collection), economic (high investment costs, lack of long-term subsidies), market (high price compared to fossil fuels, regulatory uncertainties for grid injection), institutional (lack of coordinated policy-making, bureaucracy, political instability), socio-cultural (low public awareness, resistance to change), and environmental aspects (non-internalization of environmental benefits). Poland and Estonia often reported higher severity for these barriers.

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- **Policy Drivers**: stricter CO_2 emission and RES targets at both European and national levels, alongside targeted feedstock management, digestate, and biogas utilization policies, are seen as effective drivers for biomethane penetration.

The analysis culminated in **main policy recommendations** aimed at promoting biomethane. These included facilitating the exploitation of agricultural and industrial wastes, promoting advanced upgrading technologies, enabling grid injection, and ensuring sustainable feedstock supply. On the policy and demand side, recommendations covered fostering biomethane's role in climate targets, communicating its benefits, addressing technical, economic, market, and institutional barriers through financial instruments, coordinated policy-making, and reduced bureaucracy. Enhancing public awareness, internalizing environmental benefits into fuel prices, and expanding biomethane uses were also emphasized. These conclusions were largely consistent across different countries and stakeholder groups.

12.1. Final Market Uptake Measures at National Level

In a further step, CRES provided a final list of market uptake measures at the national level for the seven target countries, designed to inform their National Energy and Climate Plans (NECPs). This involved revisiting the FCM method [2] and integrating SWOT analysis findings, as well as considering relationships, synergies, and integration between key policy domains and existing funds. The project actively involved stakeholders to co-design these measures (24).

A crucial component of this work involved identifying and leveraging various EU funding mechanisms:

- **Just Transition Fund (JTF)**: supports regions affected by climate transition, converting fossil-fuel infrastructure to biomethane production.
- **European Regional Development Fund (ERDF)**: co-finances anaerobic digestion plants, biomethane pipelines, and energy infrastructure modernization.
- **Cohesion Fund (CF)**: targets environmental investments and trans-European transport networks, supporting biomethane pipeline construction and integration into grids.

[2] Christos Tourkolias GreenMeUp presentation from last Policy Workshop in Brussels

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- **InvestEU Programme**: mobilizes public and private investment, providing risk-sharing and guarantee mechanisms for biomethane projects.
- **Public Sector Loan Facility (PSLF)**: supports public sector entities with grants and loans for biomethane infrastructure, addressing funding gaps.
- **Just Transition Platform (JTP)**: a knowledge-sharing hub facilitating best practices exchange and supporting regions in leveraging EU funds for biomethane.
- **Connecting Europe Facility (CEF)**: co-finances cross-border infrastructure projects for biomethane integration into EU gas grids and pipeline modernization.
- **Social Climate Fund (SCF)**: indirectly supports biomethane uptake by providing grants for clean heating systems and promoting low-emission mobility.

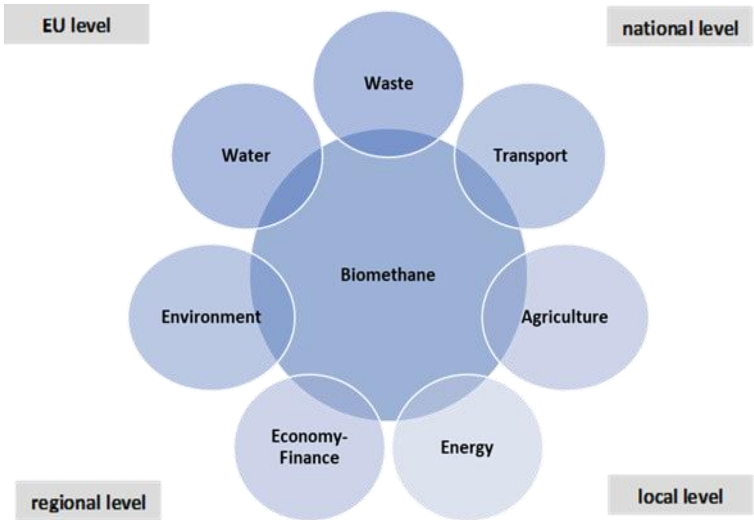

Figure 13. Relationship between biomethane and the different sectors. Source: CRES

CRES's proposed actions specifically recommended leveraging these funds to facilitate the construction of new biomethane plants, foster market uptake, deploy additional biomethane capacity, and build necessary pipeline infrastructure.

The work also strongly advocated for **cross-sectoral policy integration**. It highlighted that biomethane's benefits extend across waste, transport, agriculture, energy, and environmental sectors, necessitating coordinated policies across local, regional, national, and EU levels. Recommendations included developing a holistic framework to quantify cross-sectoral impacts, adopting a coherent biomethane strategy with binding targets, establishing multi-level governance mechanisms, prioritizing circular economy

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goals, and enhancing existing legislative frameworks like Fit-For-55 to support biomethane production and consumption. Furthermore, CRES suggested incentivizing biomethane in agriculture and transport, highlighting its role in methane mitigation, strengthening Common Agricultural Policy (CAP) incentives, introducing comprehensive CO_2 pricing, standardizing Guarantees of Origin (GoO) and Proof of Sustainability (PoS), and fostering cross-border cooperation and public-private partnerships.

This body of work, encompassing 68 stakeholders and 323 identified concepts, yielded 49 proposed policies for biomethane market uptake. These proposals reflect both commonalities and specific national conditions, ensuring a tailored yet harmonized approach to green energy transition across the target countries.

13. Societal awareness: main findings from GreenMeUp survey results

Ultimately, the broad societal acceptance of biomethane in Europe relies on a concerted effort to bridge the gap between its potential and the public's understanding. The mixed-methods research has consistently shown that **low self-reported knowledge of biomethane and related biofuels is a significant barrier**, with a large portion of the populace expressing minimal familiarity. Although citizens generally recognize biomethane's **environmental merits, particularly in waste management and reducing emissions**, their confidence in its economic benefits is far from universal.

Concerns about potential risks—spanning environmental, health, and safety issues—were consistently present, and **support for new facilities predictably diminished as their perceived proximity increased**. It was also observed a notable trust deficit, with citizens showing **higher confidence in scientists and academics** compared to government bodies and industry players.

Public knowledge must be elevated through tailored educational initiatives that clarify the technology and underscore its full spectrum of benefits and building confidence requires **transparent, proactive, and ongoing community dialogue** that integrates local communities and leverages trusted voices and addressing specific concerns about potential nuisances and safety with clear, evidence-based communication is crucial. Additionally, it is crucial to promote social equity by ensuring project benefits are distributed fairly and establishing clear guidelines for facility siting and operation will be

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key to building community support. Finally, developing **robust Public-Private-Community (PPC) partnerships** is essential for creating a shared vision and fostering the collaborative environment needed to accelerate biomethane's market expansion and secure lasting societal buy-in.

Figure 14. Recommendations on improving societal perception of biomethane based on citizen survey results. Source: CRES

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14. International cooperation with Mission Innovation countries: India, China, USA, Brazil and Canada

The GreenMeUp International Advisory Board (IAB) (25) (26) (27) , composed of experts from Brazil, Canada, China, India, and the USA, has provided a comprehensive overview of the global biomethane landscape and their insights reveal that while each country has a unique approach, they share a common goal of boosting biomethane production and its role in replacing natural gas. The IAB's findings, which cover market status, policy, technology, and challenges, are crucially important for developing effective strategies for both the EU and international markets and foster international collaboration.

In **Brazil**, a country with vast potential, biomethane development is driven by a number of progressive policies. The **new gas law** ensures biomethane is treated equally to natural gas, while the **Renovabio** program successfully uses decarbonisation credits to incentivize its production. Furthermore, a mandatory 10% biomethane blend in São Paulo's natural gas grid, alongside dedicated programs for green mobility and rural energy, shows a clear push towards adoption. However, these efforts are hindered by a limited gas grid, high technology costs for smaller businesses, and the complexity of state-specific regulations.

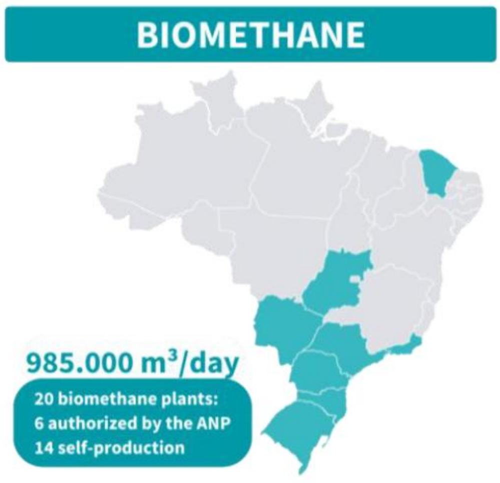

Figure 15. Biomethane geographical distribution in Brazil. Source: CRES

Canada, a leader in Renewable Natural Gas (RNG), has seen significant uptake, though its progress varies by province. While national targets aim for 10% RNG content in natural gas by 2030, these are not yet legally binding. Policy support is mixed; the federal Clean Fuel Standard doesn't include gaseous fuels, but some provinces have their own carbon offset systems that do. Technology is focused on optimizing anaerobic digestion and exploring new feedstocks. Major barriers include the need for investment tax credits, difficulties connecting to existing grids, and a general lack of public awareness. Still,

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provinces like Quebec and British Columbia are pushing ahead with mandatory RNG blending targets.

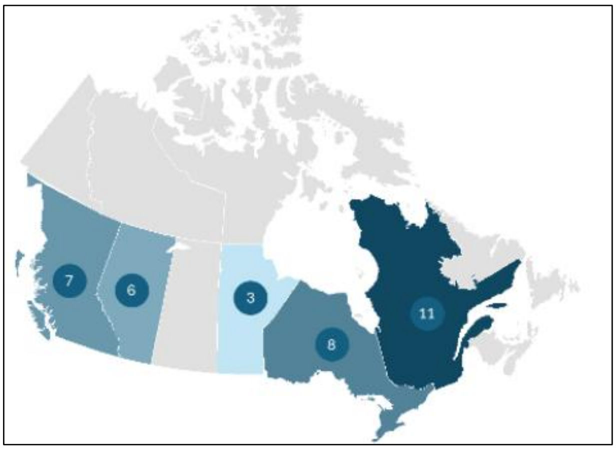

Figure 16. Biogas projects in Canada (2023), Source: Biogas Association Canada

India boasts a long history with biogas and has set ambitious goals for Compressed Biogas (CBG) under the **Satat** program, aiming for 5,000 plants by 2025-26. This initiative guarantees that Oil Marketing Companies will purchase all CBG at a remunerative price, with a blending mandate set to become compulsory, reaching 5% by FY2028-29. This is supported by financial assistance and schemes that simplify the collection of agricultural waste. Key challenges, however, include streamlining the diverse feedstock supply chain, developing pipeline infrastructure to meet off-take guarantees, securing low-cost financing, and improving inter-ministerial coordination.

The **USA's** Renewable Natural Gas (RNG) production is largely from landfills and agricultural waste. Policy drivers like the Low Carbon/Clean Fuel Standards and the **Inflation Reduction Act** are expanding with increasing ambition, offering tax credits for biomethane and related technologies. While the country has significant potential to increase its production, with many new installations under construction, its primary challenge is to scale up production to meet the ambitious targets set by various states.

China has a huge potential for biomethane, though its industry is still in its early stages. A suite of national plans, including the "Fourteenth Five-year Plan," aims to promote its development. However, progress is hindered by low profitability for producers, high feedstock costs, a lack of direct subsidies, and difficulties selling both biogas electricity and biomethane to existing grids. Proposed solutions include legislative mandates for blending, technological breakthroughs, and an independent certification system. Recent policy changes, such as the revised Renewable Energy Law, now require gas networks to accept biomethane, a significant step forward.

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Ultimately, a key finding across all these nations is that **technology is not a fundamental barrier to deployment**, but rather the high cost of upgrading biogas to biomethane remains a significant economic challenge, particularly in countries like India and China. Feedstock availability is generally not a concern, while managing liquid digestate remains a problem in some regions, and IAB's work has fostered invaluable information exchange and cooperation, bridging the gap between EU and global biomethane efforts and paving the way for future collaboration. The varying terminology—"biomethane" in the EU and China, "Renewable Natural Gas" in Canada and the USA, and "Compressed Biogas" in India—highlights the diverse global approaches to this single, crucial renewable energy source.

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15. Policy Workshops

Another important step of the GreenMeUp project, was the organization of policy events: these workshops, have gathered stakeholders from the biogas sector, hosting market and policy experts, technology providers and representatives from the European Commission (28) (29) (30).

The three events took place in the following order:

- **GreenMeUp first policy workshop** [3], EUBCE 2023 (5 – 8 June) in Bologna;
- **GreenMeUp second policy workshop** [4] in Leipzig, Germany (25th March 2025);
- **GreenMeUp third and last policy workshop** [5] in Brussels, Belgium (3rd July 2025) (26).

During these events, policy was set as the main topic to be addressed but also considering societal acceptance and technology aspects.

The current European biomethane market situation was addressed in each policy event, showing updates respectively, since they were organized in three different periods of the project lifetime.

The diverse **variety of feedstocks** and challenges related to **feedstock supply** were discussed in detail, in order to fully explore the potential of each one of them, and to have an overview of their availability at European and country levels. Additionally, attention was also given to the **role of digestate** as a co-product of the biogas production and its capability of being such a productive resource in terms of organic material as fertilizer. Furthermore, innovative biomass production systems, such as sequential cropping were addressed.

Societal awareness is also a crucial step of the project, as part of its three main pillars: policy, market, society. There is an increasing interest in regard to biomethane as a sustainable alternative to fossil gas, but in some countries, **societal acceptance is still low** and a lot of people still refuse this sustainable option, mainly due to lack of information or low public awareness on the topic.

[3] First policy workshop report

[4] Second policy workshop report

[5] Third and last policy workshop report

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An in-depth analysis was also given on the **integration of other existing technologies** in the production process of biomethane, especially in our last policy workshop that took place in Brussels, where several technology providers participated and presented their work and technologies.

Figure 17. Andrea Maria Rizzo from RECORD during his presentation at the GreenMeUp policy workshop in Brussels. Source: ETA-Florence

Figure 18. Prof. Yannis Maniatis from the European Parliament giving a speech at the 3rd and last policy workshop in Brussels. Source: ETA-Florence

Figure 19. From left: Maria Georgiadou (EC R&I), Prof. Yannis Maniatis (MEP), Myrsini Christou (CRES, GreenMeUp project coordinator), Kyriakos Maniatis (Advanced Biofuels, former EC). Source: ETA-Florence

16. Conclusions

The "GreenMeUp" project aimed to thoroughly analyze and promote the uptake of biomethane in the European market, recognizing its crucial role in achieving a sustainable and circular energy future. Through meticulous research, stakeholder engagement, and an in-depth analysis of regulatory frameworks, technological

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advances, and economic drivers, this final project publication consolidates our findings and offers a strategic roadmap to accelerate the integration of biomethane into the European energy mix.

Our investigations have underscored the great potential of biomethane as a versatile, renewable energy source capable of decarbonizing various sectors, including transport, heating, and industry. We have identified key success factors, such as supportive policy incentives, robust infrastructure development, and innovative financing mechanisms, that are crucial for unlocking this potential. Furthermore, the project has highlighted the diverse regional landscapes within Europe, emphasizing the need for tailored approaches that consider local resource availability, existing infrastructure, and specific market dynamics.

Despite significant progress, challenges remain, including regulatory complexity, public perception, and the need for continued investment in research and development. However, the "GreenMeUp" project firmly believes that these obstacles can be overcome with a concerted effort and collaborative action by policymakers, industry practitioners, researchers, and civil society.

Looking ahead, the successful market uptake of biomethane will not only contribute significantly to Europe's climate neutrality targets but also enhance energy security and foster rural development. The insights and recommendations presented in this publication serve as a valuable resource for all stakeholders committed to building a resilient, sustainable, and biomethane-powered Europe.

Figure 20. The GreenMeUp consortium and members from Mission Innovation Countries Tallin, Estonia. Source: ETA-Florence

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24. **C. Tourkolias, C. Zafiris, M. Christou.** *D4.3 - Market uptake measures at EU level.*

25. **K. Maniatis, M. Christou.** *D6.2 - Report on the IAB meetings.*

26. **K. Maniatis, M. Christou.** *D6.6 - Final report on the International Advisory Board meetings.*

27. **K. Maniatis, M. Christou.** *D6.5 - Updated Report on the International Advisory Board meeting.*

28. **Mezzetti, G.** *D5.5 - Updated report on the policy workshops.*

29. **Ridolfi, T.** *5.2 - Report on the policy workshops.*

30. **Mezzetti, G.** *D5.7 - Final report on the policy workshops.*

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