



Joint State of the Art



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Aalborg Municipality (Denmark)
Moravian-Silesian Region (Czech Republic)
South-East Energy Agency (Ireland)
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Content

Project identification	4
Partners / associated policy authorities	4
Project summary	5
Joint State of Art Executive summary	6
Key Findings	6
Recommendations	7
Conclusion	7
1. Introduction and Purpose	8
1.1. How the Report Can Be Used	8
2. Overview: European and National Context	10
2.1. European context	10
3. Regional Profiles – Comparative Overview	13
3.1. Extremadura (Spain)	16
3.2. Region Nordjylland (Denmark)	16
3.3. Kalmar County (Sweden)	16
3.4. Moravian-Silesian Region (Czech Republic)	17
3.5. Waterford County (Ireland)	17
3.6. Lubelskie Region (Poland)	18
3.7. Overview of Hydrogen Applications in the European Context	18
4. PESTLE Analysis – Comparative Themes	20
4.1. Overview of Comparative Themes	20
4.2. Regional Classification by Maturity	21
4.3. Key Insights and Recommendations	22
5. Value Chain Analysis and Stakeholder Maps	24
5.1. Comparative value chain overview	24
5.2. Key Actors and Collaboration Platforms	25
5.3. Summary and Insights	25
6. Identified Barriers and Opportunities (Synthesis)	26
6.1. Early-Stage Regions: Moravian-Silesian (CZ) and Lubelskie (PL)	26
6.2. Emerging Regions: Extremadura (ES) and Waterford (IE)	26
6.3. Advanced Regions: Nordjylland (DK) and Kalmar County (SE)	27

6.4.	Cross-Cutting Enablers	27
7.	Good Practices and Lessons Learned	28
8.	Recommendations for Policy and Continued Collaboration.....	31
8.1.	Joint Recommendations	31
9.	Synthesis and Key Conclusions	33
10.	Appendices	34
10.1.	Glossary.....	34
10.2.	Contact information.....	34
10.3.	Links to RSA reports.....	34

Project identification

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Partners / associated policy authorities

Project partners

- LP01 - Consortium Extremadura Energy Agency – AGENEX (Spain)
- PP02 – Aalborg Municipality (Denmark)
- PP03 – Energy Agency Southern Sweden (Sweden)
- PP04 – Moravian-Silesian Region (Czech Republic)
- PP05 – South-East Energy Agency (Ireland)
- PP06 – Lubelskie Voivodeship (Poland)

Associated policy authorities

- APA01 – Directorate General for Industry, Energy and Mines - Regional Government of Extremadura (Spain, LP01)
- APA02 – Region Kalmar County (Sweden, PP03)
- APA03 – Waterford City and County Council (Ireland, PP05)

Disclaimer:

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Project summary

In the EU Member States and their regions, there are different paces on the way to achieve climate neutrality; some of them are setting more ambitious targets and dates to reach it, while others are lagging to meet the intermediate targets established. For those regions that are in a favourable position, it is important to continue advancing in the more complex aspects of the energy transition, such as the transition of the gas sector to the use of renewable and low-carbon gases.

Although the share of renewable energy is increasing rapidly at EU level, the carbon dioxide emissions worldwide are still increasing. This means that all countries must also increase their efforts to decarbonize the energy sector, and the main challenge is to reduce fossil fuels in the end-use sectors, particularly in industry and transport.

Additionally, there are other challenges that must be overcome to decarbonize the energy sector, such as security of energy supply, environmental sustainability, and socio-economic aspects. To ensure a secure and stable energy supply, it is not enough to deploy new renewable power (wind, solar) if it cannot be stored to be used when demanded.

The set of proposals included in the Fit for 55 package provides a coherent and balanced framework for reaching the EU's climate objectives and it specifically includes shifting from gas to renewable and low-carbon gases, including hydrogen, and proposing a review of the EU gas market design. And in 2020, the European Commission proposed a hydrogen strategy for a climate-neutral Europe, aiming to accelerate the development of clean hydrogen as a cornerstone for a climate-neutral energy system.

UNIFHY will analyse policies and provide insights for policymakers in 6 EU regions: Aalborg Municipality (DK) and the Southern Sweden region (SE) in the North; Moravian-Silesian Region (CZ) and Lubelskie Region (PL) in the East; the South-East region of Ireland (IE) in the West; and Extremadura (ES) in the South.



Figure 1: Map of UNIFHY partners

Joint State of Art Executive summary

This report provides a consolidated overview of the current status, challenges, and opportunities for green hydrogen and biomethane across six European regions participating in the UNIFHY project: Extremadura (Spain), Nordjylland (Denmark), Kalmar County (Sweden), Moravian-Silesian Region (Czech Republic), Waterford County (Ireland), and Lubelskie Voivodeship (Poland). These regions represent a diverse spectrum of socio-economic contexts, energy system maturity, and policy environments, yet all share a commitment to decarbonisation through low-carbon gases.

The report builds on regional self-assessments and comparative analyses to support policy development, knowledge transfer, and the identification of good practices. It aims to inform regional and national authorities, energy agencies, industry, academia, and EU networks, providing a strategic foundation for continued collaboration and investment.

Key Findings

The comparative analysis classifies regions into three maturity levels: Advanced, Emerging, and Early-stage. Advanced regions (Nordjylland (DK) and Kalmar County (SE)) have mature biogas ecosystems, strong policy alignment, and active hydrogen pilots. Emerging regions (Extremadura (ES) and Waterford (IE)) show strategic intent and innovation potential but face regulatory and infrastructure gaps. Early-stage regions (Moravian-Silesian (CZ) and Lubelskie (PL)) are beginning their transition, with limited hydrogen and biomethane deployment and high reliance on fossil fuels. This classification helps tailor recommendations and knowledge transfer to regional needs.

Biogas is mature and widely deployed, particularly in the advanced regions, with established infrastructure and integration into agriculture and transport. Waterford (IE) also demonstrates strong biogas uptake. Hydrogen remains at an emerging stage, with pilot projects in all regions and strategic potential in industry and heavy transport.

Political and regulatory frameworks vary significantly. Advanced regions benefit from strong national alignment and regional autonomy, while emerging and early-stage regions face fragmented governance and slow transposition of EU directives.

Economic readiness is uneven. High capital costs and uncertain market conditions hinder investment, with advanced regions leveraging industrial capacity and funding mechanisms, while others rely heavily on EU support.

Social acceptance is strongest where local benefits are visible, such as job creation and circular economy models that enhance legitimacy. Safety concerns and low awareness remain barriers in early-stage regions.

Technological maturity differs across regions. Advanced regions lead in biogas and PtX integration, while emerging regions show innovation potential. Early-stage regions face infrastructure gaps and limited hydrogen deployment.

Environmental governance is critical. Circular models (e.g. digestate use, sector coupling) and life cycle assessments support sustainability. Regions with integrated planning demonstrate best practices.

Recommendations

The report identifies four priority areas for action: Policy Development, Investment and Infrastructure, Skills and Workforce Development, and Collaboration and Knowledge Exchange. Recommendations include accelerating transposition of EU directives, streamlining permitting, consolidating funding mechanisms, expanding infrastructure, promoting sector coupling, launching education programs, and strengthening regional clusters. Detailed implementation context is provided in Chapter 8.

Conclusion

The transition to low-carbon gases is underway across all UNIFHY regions but its success depends on enabling conditions: coherent policy frameworks, streamlined legal procedures, strategic investment, skilled workforce, and collaborative governance. By acting on the joint recommendations and leveraging comparative insights, regions can accelerate their energy transition, contribute to EU climate goals, and foster innovation ecosystems around hydrogen and biomethane.

This report serves as a roadmap for continued collaboration within the UNIFHY partnership and beyond, and a practical tool for regional planning, funding applications, stakeholder coordination, and policy advocacy.

1. Introduction and Purpose

The joint State of the Art report is a strategic tool for mapping the current situation, challenges, and opportunities regarding green hydrogen and other low-carbon gases in the participating regions. Its purpose is to support policy development, knowledge transfer between regions of different maturity levels, and the dissemination of good practices, with a target audience ranging from project partners to authorities (local, regional, national), energy agencies, industry, business, academia, EU networks, and the general public.

This report builds on the Regional Self-Assessment (RSA) reports from each partner region and aims to:

- Identify the barriers and challenges that are hindering the development of value chains for low-carbon gases (such as biomethane and hydrogen) as well as the opportunities these gases can bring to the energy transition in the partner regions.
- Identify good practices and support knowledge transfer between partners.
- Provide a current vision of the political, economic, sociocultural, technological, legal, environmental, and other factors that may influence the development of a low-carbon gas ecosystem in each region.
- Enable a detailed comparative analysis that supports policy improvements for regional and national instruments, through several key objectives:
 - Map the regulatory frameworks affecting the development and implementation of low-carbon gases within each region's energy system, including legislation, incentives, and potential constraints.
 - Analyse the existing energy infrastructure and identify public and private facilities where low-carbon gases can be integrated as part of the energy transition.
 - Explore challenges – such as funding limitations, regulatory barriers, technological bottlenecks, and the need for cross-sectoral coordination – in the implementation of low-carbon gas-based energy solutions.
 - Identify the potential for low-carbon gases within each region's energy system and propose feasible strategies aligned with the region's long-term energy and climate goals.

By synthesizing the findings from all partner regions, this joint State of the Art report provides a comprehensive and comparative overview that will facilitate knowledge sharing, inspire policy improvements, and highlight good practices that can be scaled or adapted across Europe.

1.1. How the Report Can Be Used

This joint State of the Art report serves as a strategic tool for:

- Regional planning and prioritization: Authorities can use the comparative insights to benchmark progress, identify gaps, and align with EU targets.
- Funding applications: The report provides evidence-based context for proposals to Horizon Europe, Innovation Fund, CEF, and national programs.
- Stakeholder coordination: It supports the formation of regional working groups and clusters by mapping key actors and collaboration platforms.

- Policy feedback and advocacy: Regions can use the findings to inform national frameworks and advocate for flexible, region-sensitive EU regulations.
- Monitoring and evaluation: The maturity classification and PESTLE analysis offer a baseline for tracking progress and adjusting strategies.

Disclaimer:

This report is compiled based on regional self-assessment reports submitted by the partners of the UNIFHY project. The accuracy, completeness, and reliability of this document are contingent upon the quality and scope of the underlying regional inputs. For verification of data, references, and contextual details, readers are advised to consult the respective regional reports.

Links to the regional self-assessment reports:

<https://www.interregeurope.eu/unifhy/library>

2. Overview: European and National Context

2.1. European context

In 2020, 42% of the energy consumed within the EU¹ was also produced within the union, while nearly 60% was imported. The Russian Federation had long been the largest single supplier of energy to the EU. Some member states were more dependent on Russian energy than others, making them particularly vulnerable to energy shortages and rising energy prices.

The share of renewable energy in the EU's energy mix has steadily increased in recent years. Renewable energy accounted for approximately 22% of the EU's total energy supply in 2020. Regarding specific energy sources, oil products, including crude oil, made up about 35% of the energy mix, while natural gas accounted for 24%. Nuclear power contributed 13%, and solid fossil fuels, such as coal, represented 12% in the same year.

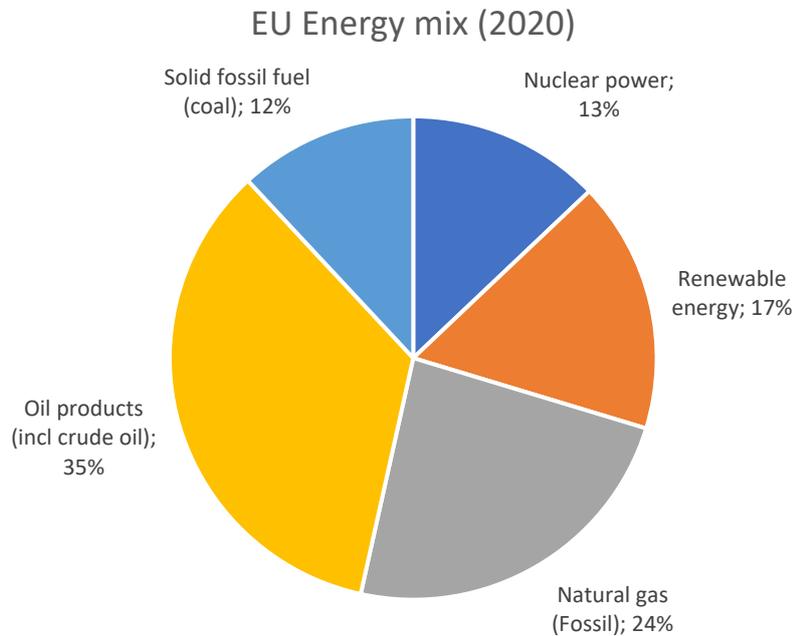


Figure 2: EU Energy mix (2020)

The European Union's transition to a climate-neutral economy necessitates a fundamental transformation of its energy system, with a particular emphasis on decarbonizing sectors that are hard-to-electrify. Low-carbon gases, including green hydrogen, biomethane, and synthetic gases, are key enablers of this transition, supporting the EU's efforts to reduce reliance on fossil fuels, enhance energy security, and achieve a more integrated and resilient energy system. They serve as critical

¹ [EEA](#)

complements to renewable electricity from wind and solar, providing solutions for energy storage, industrial applications, and transport where direct electrification is impractical. Low-carbon gases are essential to achieving a secure, competitive, and sustainable European energy system. Through coordinated policy measures, infrastructure investments, and market incentives, EU is paving the way for a future where green energy gases play a central role in ensuring both climate neutrality and energy resilience.

At the core of this transformation is the EU Green Deal², which sets an ambitious target of achieving net-zero greenhouse gas emissions by 2050³. To meet this objective, the EU has developed a series of strategic frameworks aimed at scaling up the production, infrastructure, and market integration of green energy gases.

A pivotal policy in this context is the EU Hydrogen Strategy (2020)⁴, which seeks to establish green hydrogen as a cornerstone of the European energy and industrial system⁵. The strategy outlines a phased approach, aiming to deploy 40 GW of electrolyser capacity by 2030 and foster the development of regional hydrogen clusters (hydrogen valleys) and cross-border infrastructure. This strategy is closely linked to broader European industrial policies, reinforcing hydrogen's role in decarbonizing hard-to-abate sectors such as steel production, chemicals, and heavy transport.

The geopolitical landscape has further underscored the urgency of energy diversification. The REPowerEU plan (2022),⁶ introduced in response to the energy crisis and the need to reduce dependence on Russian fossil fuels, significantly accelerates the deployment of renewable gases. Under this plan, the EU aims to produce and import 20 million tons of renewable hydrogen annually by 2030 and expand biomethane production to 35 billion m³/y, leveraging domestic resources and international partnerships. The current (year 2024) installed capacity⁷ of biomethane production is 5,2 billion m³ within EU.

Legislative frameworks such as the Fit for 55 package (2021)⁸ reinforce these efforts by introducing carbon pricing mechanisms and sectoral targets that enhance the competitiveness of green energy gases. The updated Renewable Energy Directive (RED III, 2023)⁹ further strengthens their role by setting a legally binding 42.5% renewable energy target by 2030, with additional support for biogas, green hydrogen, and Power-to-X technologies. Simultaneously, the TEN-E Regulation (2022)¹⁰ provides the regulatory foundation for cross-border infrastructure development, ensuring the seamless integration of renewable gases into the European energy market.

² [EU Green Deal](#)

³ [2050 long-term strategy](#)

⁴ [EU Hydrogen Strategy \(2020\)](#)

⁵ [A hydrogen policy framework](#)

⁶ [REPowerEU \(2022\)](#)

⁷ [Biomethane Europe](#)

⁸ [Fit for 55 \(2021\)](#)

⁹ [RED III \(2023\)](#)

¹⁰ [TEN-E](#)

Beyond policy and regulation, the EU is actively fostering industrial innovation through IPCEI (Important Projects of Common European Interest)¹¹. This initiative channels funding into large-scale projects that support electrolyser manufacturing, hydrogen infrastructure, and advanced biogas applications, positioning Europe at the forefront of global low-carbon gas technologies.

The implementation of the European strategies and initiatives described above varies depending on each EU country's specific conditions and needs. By adapting these strategies to their national contexts, each EU country can contribute to achieving the EU's overarching goals of climate neutrality and energy security. Recent developments in the European regulatory landscape have further clarified the requirements and challenges for the deployment of low-carbon gases. The updated Renewable Energy Directive (RED III) introduces stricter certification criteria for renewable hydrogen, including the principles of additionality, temporal and geographical correlation. These criteria mean that, to be classified as renewable, hydrogen must be produced from newly installed renewable electricity sources, with production and consumption matched in time and location.

While these rules aim to ensure the environmental integrity of renewable hydrogen, they also present significant challenges for regions with limited renewable energy potential or less flexible energy systems.

In addition, the need for a coordinated European industrial strategy has been highlighted by recent policy analyses, such as the Draghi report¹². This report points to the importance of simplifying and harmonising financial instruments, strengthening support for European technology production, and reducing dependence on imported components. The implementation of mechanisms such as Carbon Contracts for Difference and the European Hydrogen Bank is intended to accelerate market development and reduce investment risks.

It is therefore essential that the application of European rules allows for a certain degree of flexibility and takes into account the diverse technical and economic conditions across regions. The successful development of low-carbon gas value chains will depend not only on ambitious targets, but also on the ability to adapt regulatory frameworks, mobilise sufficient investments, and foster innovation and cross-sectoral collaboration.

In summary, the European context for low-carbon gases is characterised by ambitious targets, increasingly detailed regulatory requirements, and a growing emphasis on industrial policy and innovation support. Regional self-assessments should therefore pay particular attention to how these evolving frameworks impact local opportunities and challenges, and identify needs for flexibility, investment, and capacity building to ensure an effective and just energy transition.

¹¹ [IPCEI](#)

¹² [Draghi report](#)

3. Regional Profiles – Comparative Overview

The six UNIFHY regions represent a wide spectrum of socio-economic structures and energy system maturity, yet all share a commitment to decarbonization through low-carbon gases.

Table 1 provides a comparative overview of the socio-economic characteristics that shape each region's conditions for developing low-carbon gas value chains. The regions differ notably in territorial size—from Waterford County's 1,858 km² to Extremadura's 41,635 km²—and in population levels, which range from 127,360 inhabitants in Waterford to nearly 2 million in Lubelskie. These differences influence available labour markets, administrative capacity, and potential energy demand. Municipal structures also vary widely: Extremadura's 388 municipalities, most of them very small, contrast with Nordjylland's 11, reflecting differing governance complexity.

Income levels show further variation, with median household incomes spanning from €23,577 in the Moravian-Silesian Region to over €60,000 in Nordjylland and Kalmar County. The industrial landscapes range from agriculture-dominated regions such as Lubelskie and Extremadura to more diversified or industrialised economies such as Nordjylland and Moravian-Silesian. Together, these indicators provide important context for understanding the structural conditions that shape each region's opportunities and constraints in scaling biomethane and hydrogen.

Kalmar County (SE) and Nordjylland (DK) stand out for their established biogas ecosystems and integration of renewables, supported by strong regional collaboration and infrastructure as further illustrated in Table 2. Lubelskie Region (PL), while agriculturally rich and rapidly expanding its renewable energy capacity, remains heavily reliant on coal and lacks hydrogen infrastructure. Extremadura (ES) and Waterford County (IE) are both rural regions with growing renewable portfolios, solar in Extremadura (ES) and wind in Waterford County (IE), but face challenges in scaling infrastructure and industrial demand. Moravian-Silesian Region (CZ), with its legacy of coal and heavy industry, is undergoing structural transformation and exploring hydrogen for industrial decarbonization. While Nordjylland (DK) and Kalmar County (SE) are already piloting hydrogen and PtX technologies, Lubelskie (PL) and Extremadura (ES) are in earlier stages of market development. The regions differ in industrial intensity, infrastructure readiness, and policy integration, yet all are navigating the same transition pressures, balancing energy security, climate goals, and economic development.

Table 1: Overview socio-economic context in the UNIFHY-regions.

Indicator	Description					
Territory	Spain: Extremadura	Denmark: Region Nordjylland	Sweden: Kalmar County	Czech Republic: Moravian-Silesian Region	Ireland: Waterford County	Poland: Lubelskie Region
Surface area (km ²)	41 635 km ²	7 884 km ²	11 160 km ²	5 431 km ²	1 858 km ²	25 122 km ²
Population	1 052 863	592 768	246 352	1 182 613	127 360	1 987 787
Number of municipalities	388	11	12-----	300	33	213
Number of municipalities (<5,000 inhabitants)	353	1	0	268	30	98
Number of municipalities (>5,000 inhabitants)	35	10	12	32	3	115
Average number of inhabitants per municipality	2 713	53 888	20 529	3 942	42 454	9 332
Median net household income (€) in the region	€ 29 341	€ 60,150	€ 62,401	€ 23,577	€ 37 600	Data not available
Median net household income (€) in the country	€ 36.996	€ 77,510	€ 67,116	€ 25,150	€ 43 221	Data not available
Industrial landscape	Key sectors: agri-food, extractive industries, solar energy, metallurgy, chemicals.	Key sectors: agriculture, construction, manufacturing, energy, ICT, maritime (under transportation).	Key sectors: manufacturing, agriculture, food processing, forestry, pulp & paper, bioenergy, e-health.	Key sectors: motor vehicles, metallurgy, machinery, chemicals, food, energy.	Key sectors: pharmaceuticals, food & beverage, glass, engineering, ICT, port logistics.	Key sectors: agro-food, chemical, mining, construction, trade, market services

Table 2: Overview of energy context in the UNIFHY-regions.

Description						
Territory	Spain: Extremadura	Denmark: Region Nordjylland	Sweden: Kalmar County	Czech Republic: Moravian-Silesian Region	Ireland: Waterford County	Poland: Lubelskie Region
Total Production (GWh)	31 108	21 445 (electricity)	11 874	3 008,8 (electricity)	180	3 344 ¹³
Renewable Share (%)	51.2%	45%	<i>Not specified</i>	30,6%	<i>Not specified</i>	53,8% ¹⁴
Main Sources	Solar PV, Hydro, Wind, Thermal solar	Wind, Biomass, Biogas	Wind, Solar, Biofuels	Coal, Biomass, Industrial Gases	Wind, Solar PV, Biomass	Solar PV, Wind, Biogas
Biogas (GWh)	<i>Not specified</i>	1 422	63	152,4	<i>Not specified</i>	<i>Not specified</i>
Biomass (GWh)	237	2 679	<i>Not specified</i>	<i>Not specified</i>	38	<i>Not specified</i>
Hydrogen	Pilot-projects	Not yet in production	Pilot-projects	Grey hydrogen only	Blending pilots	Grey hydrogen only
Self-Sufficiency (%)	>600% (net exporter)	100%	38% (excl. nuclear)	50,73%	~6%	56,9% ¹⁵

¹³ the year of the statistical data (2024)

¹⁴ the year of the statistical data (2024)

¹⁵ the year of the statistical data (2024)

3.1. Extremadura (Spain)

Extremadura, located in southwestern Spain, has a population of approximately 1.05 million across 388 municipalities, most of which are small (over 90% have fewer than 5,000 inhabitants). The region spans 41,635 km² and has a relatively low median household income compared to the national average. Its economy is shaped by agri-food processing, energy (solar and hydro), mining, metallurgy, and chemicals, with 90% of enterprises being small or micro-sized.

Energy consumption per household averages 4.8 MWh annually, with many households reporting challenges in maintaining comfortable indoor temperatures. Industrial activity contributes 7.1% to regional GVA, and exports, primarily agri-food products, amount to €3.3 billion. Extremadura is a national leader in renewable electricity generation, particularly solar photovoltaic, which accounts for nearly 60% of installed capacity. In 2024, the region produced 31,108 GWh of electricity, with renewables contributing over 51%. Regional electricity demand was only 4,801 GWh, indicating significant surplus production. The energy mix includes nuclear (48.7%), solar PV (33.4%), hydro (11.3%), and solar thermal (5.2%), with minimal wind and other renewables.

This strong renewable base positions Extremadura as a potential hub for green hydrogen and biomethane production, though local consumption and infrastructure integration remain limited.

3.2. Region Nordjylland (Denmark)

Region Nordjylland, located in northern Denmark, comprises 11 municipalities and has a population of approximately 593,000. Covering 7,884 km², it includes major cities such as Aalborg, Hjørring, and Frederikshavn. The region has a strong industrial base, particularly in manufacturing, construction, and energy supply, with over 6,400 companies in sectors relevant to low-carbon gas development.

The region's economy is driven by industrial production, including cement, chemicals, food processing, and wind turbine components. It contributes significantly to Denmark's green employment, with over 10,000 people working in green jobs, especially in manufacturing and construction.

Energy consumption in Nordjylland totals around 15,692 GWh annually, with approximately 60–70% produced locally. Electricity production is dominated by wind (15,519 GWh), supplemented by biomass (2,700 GWh) and biogas (1,200 GWh). The region has one of Denmark's highest shares of renewable energy, though fossil fuel use remains significant in heavy industry and transport. Industry (6,022 GWh) and households (5,087 GWh) are the largest energy consumers. The region faces challenges in decarbonizing hard-to-electrify sectors such as cement, maritime transport, and agriculture, but also has strong potential for innovation and integration of low-carbon gases like biomethane, hydrogen, and synthetic fuels.

3.3. Kalmar County (Sweden)

Kalmar County, located in southeastern Sweden, has a population of approximately 246,000 across 12 municipalities and covers 11,160 km². The region is characterized by a strong agricultural base, a

diverse industrial landscape including food processing, forestry, and bioenergy, and a relatively low unemployment rate (6.6%).

Energy consumption in Kalmar County totals approximately 11,600 GWh annually, with industry accounting for the largest share (48%), followed by households (19%) and transport (17%). Around 38% of this energy is produced locally. However, nuclear power (9,165 GWh) is classified as part of the national energy system and is therefore excluded from regional self-sufficiency statistics. Local electricity generation includes wind power (1,542 GWh), solar energy (131 GWh), and additional contributions from biofuels and ambient heat. Kalmar is also a net exporter of biogas, producing 63 GWh in 2023.

Biogas is well-established, primarily used in transport and agriculture, and supported by strong regional collaboration and infrastructure. Hydrogen is emerging, with two refuelling stations under development and pilot projects underway. The region's access to renewable electricity and nuclear power enables both green and pink hydrogen production, positioning Kalmar as a strategic player in Sweden's energy transition.

3.4. Moravian-Silesian Region (Czech Republic)

The Moravian-Silesian Region, historically rooted in coal mining and heavy industry, is undergoing a significant socio-economic and energy transition. With a population of approximately 1.18 million and a high population density (217 inhabitants/km²), the region faces structural challenges including elevated unemployment (4.1%) and lower average wages compared to the national average.

Industry remains central to the regional economy, accounting for nearly half of electricity consumption. Key sectors include automotive, metallurgy, engineering, and chemicals, supported by a strong educational base led by the Technical University of Ostrava. Despite the decline of coal, the region retains a robust industrial infrastructure and is actively pursuing decarbonisation.

The regional energy mix is still dominated by hard coal (44.9%), but renewables now contribute over 30% of electricity production. Total regional energy demand is approximately 19,849 GWh, with only 22% produced locally. Households are the largest energy consumers (46%), followed by industry (22%). The heating sector remains heavily reliant on fossil fuels, though biomass, waste heat, and other gases are increasingly integrated.

The region's above-average renewable energy share, combined with industrial demand and academic capacity, positions it well for the development of low-carbon gases such as hydrogen and biomethane, particularly in hard-to-electrify sectors.

3.5. Waterford County (Ireland)

Waterford County, located in Ireland's South-East, has a population of approximately 127,000 and covers 1,858 km². The region features a mix of small municipalities and urban centres, with a growing workforce and a strong presence of SMEs. Key industrial sectors include pharmaceuticals, food and beverage processing, precision engineering, and ICT, supported by infrastructure such as Belview Port and the South-East Technological University (SETU).

Energy demand in Waterford is dominated by transport (38%) and households (27%), followed by industry (15%). Local energy production is entirely renewable, comprising wind, solar PV, and anaerobic digestion, but meets only 6% of the region's total energy needs. The remaining demand is covered by national supply, primarily fossil based. The regional energy mix is still heavily reliant on oil and natural gas, though several offshore wind projects are planned, offering future potential for green hydrogen integration.

3.6. Lubelskie Region (Poland)

Lubelskie Voivodeship, located in eastern Poland, is the third largest region by area (25,122 km²) and has a population of approximately 2 million. It is predominantly rural, with 53.9% of residents living in rural areas and agriculture employing nearly 19% of the workforce. The region has 213 municipalities, with a majority having fewer than 10,000 inhabitants.

The economy of the Lubelskie region, despite having the lowest GDP per capita in Poland, has shown strong growth. Between 2018 and 2023, the region's GDP increased by 53%, while GDP per capita rose by nearly 65%. In 2024, the largest share of business entities operated in the market services sector (approx. 62%), followed by construction (approx. 16%), non-market services (approx. 12%), industry (approx. 12%), and agriculture, forestry, hunting, and fishing (approx. 2%).

In 2023, electricity production reached 2.95 TWh, covering 53.4% of regional consumption (5.53 TWh). Renewable energy sources accounted for 53% of electricity production, with solar and wind leading. Installed electrical capacity was 1,800 MW, of which 1,358 MW came from renewables. Heat production remains heavily reliant on hard coal (80.5%) and natural gas (14.7%).

Energy consumption is highest in industry (40%), followed by households (22%) and services. Natural gas consumption was 44,993 TJ, with 62% used in industry and construction. The region has over 10,000 km of active gas network and 841 km of heating network, though rural access is limited.

Lubelskie has made progress in renewable energy, with a 329% increase in installed RES capacity between 2018 and 2025. However, it still accounts for only 2.25% of Poland's total RES capacity. The region's solar and wind potential is high, but further investment and infrastructure development are needed to support decarbonization and energy security.

3.7. Overview of Hydrogen Applications in the European Context

To complement the regional profiles and ensure a balanced understanding of hydrogen's role across Europe, this section provides a concise overview of the main hydrogen application areas at EU level. While the preceding regional analyses highlight the specific priorities and maturity levels of each partner region, they also illustrate that different hydrogen pathways are emphasised according to local industrial structures, resource availability, and policy frameworks. To support comparability and provide a consistent baseline, the following overview summarises the key hydrogen use sectors recognised across the European Union.

At the European level, hydrogen deployment spans several strategic end use areas:

- Industry (steel, chemicals, refining): Hydrogen is essential for decarbonising hard to abate sectors and is expected to anchor early large-scale demand across the EU.
- Heavy-duty road transport: Hydrogen offers operational advantages for long-distance transport due to fast refuelling and longer range compared to battery-electric vehicles.
- Maritime and aviation: Hydrogen, ammonia and synthetic fuels are emerging as key options for the decarbonisation of long-haul shipping and aviation.
- Energy storage and grid balancing: Hydrogen provides long-duration storage solutions that complement the increasing penetration of variable renewable energy, enabling sector coupling between electricity, heat and gas systems.
- Heating and combined heat and power (CHP): Although limited today, hydrogen blending and dedicated hydrogen heating pilots are being tested in selected European regions.

This EU-wide framing provides a consistent reference point for interpreting regional differences in hydrogen development across the six UNIFHY partner regions. It supports a more even and representative comparison of hydrogen applications and clarifies how regional priorities align with, or diverge from, broader European trends.

4. PESTLE Analysis – Comparative Themes

This chapter presents a comparative analysis of the political, economic, social, technological, legal, and environmental (PESTLE) factors influencing the development of green gases, primarily hydrogen and biogas, across the six European regions involved in the UNIFHY project. The analysis identifies common themes, regional strengths and weaknesses (section 4.1), and classifies each region according to its maturity in the green gas transition (section 4.2).

4.1. Overview of Comparative Themes

The PESTLE framework reveals both shared challenges and region-specific dynamics. While all regions demonstrate commitment to decarbonisation and renewable energy integration, their progress varies significantly due to differences in governance structures, market readiness, infrastructure, and public engagement. Table 3 below shows the overview of comparative themes in the PESTLE-format: Political, Economic, Social, Technical, Legal and Environmental factors.

Table 3: Consolidated PESTLE-analysis for the UNIFHY-regions

P	<p>Political Factors: Most regions align with EU climate and energy directives, but the degree of policy coherence and regional autonomy varies. Region Nordjylland (DK) and Kalmar County (SE) exhibit strong political leadership and integration of green gases into regional strategies. Waterford County (IE) and Extremadura (ES) show emerging policy frameworks, while the Moravian-Silesian Region (CZ) and Lubelskie Region (PL) face challenges due to fragmented governance and slow legislative alignment.</p>
E	<p>Economic Factors: Access to EU funding is a common enabler, yet high capital expenditure and uncertain market conditions hinder investment. Region Nordjylland (DK) and Kalmar County (SE) benefit from established industrial bases and funding mechanisms. Waterford County (IE) and Extremadura (ES) are building momentum through regional collaboration and entrepreneurship programs. The Moravian-Silesian Region (CZ) and Lubelskie Region (PL) remain reliant on external funding and face economic risks due to technological immaturity and market volatility.</p>
S	<p>Social Factors: Public support for green gases is generally positive, especially where local benefits, such as job creation and rural development, are evident. Kalmar County (SE) and Region Nordjylland (DK) lead in public engagement and acceptance. Waterford County (IE) and Extremadura (ES) are investing in awareness campaigns and education. The Moravian-Silesian Region (CZ) and Lubelskie Region (PL) face challenges related to unemployment, low awareness, and resistance to new infrastructure.</p>
T	<p>Technical Factors: Technological readiness varies widely. Region Nordjylland (DK) and Kalmar County (SE) have mature biogas systems and active pilot projects in hydrogen. Waterford County (IE) and Extremadura (ES) are developing infrastructure and innovation capacity. The Moravian-Silesian Region (CZ) and Lubelskie Region (PL) are in earlier stages, with limited operational hydrogen systems and significant integration challenges.</p>

L

Legal Factors: Legal frameworks are evolving across all regions. Region Nordjylland (DK) and Kalmar County (SE) have relatively streamlined permitting processes and clear certification schemes. Waterford County (IE) and Extremadura (ES) are progressing but face regulatory fragmentation. The Moravian-Silesian Region (CZ) and Lubelskie Region (PL) struggle with slow transposition of EU directives and unclear legal definitions, which deter investment.

E

Environmental Factors: All regions recognize the environmental benefits of green gases, including GHG reduction and circular economy integration. Kalmar County (SE) and Region Nordjylland (DK) demonstrate strong environmental governance and co-benefits, although Kalmar County (SE) highlights risks related to water scarcity where hydrogen production may conflict with agriculture in drought-prone areas. Waterford County (IE) and Extremadura (ES) highlight potential but require improved permitting and resource management. The Moravian-Silesian Region (CZ) and Lubelskie Region (PL) face risks related to land use, biodiversity, and waste management.

4.2. Regional Classification by Maturity

Based on the comparative PESTLE analysis, the regions are classified into three maturity levels, as shown in Table 4 below. The classification synthesises each region’s self-assessment using a comparative PESTLE lens, focusing on concrete deployment, infrastructure, market and governance signals. As regions are progressing at different speeds towards developing the green gases, biogas and hydrogen maturity is distinguished separately in the justification. The maturity levels of the two gases have then been grouped into an overall status for each region, based on a definition of the different maturity levels as:

- **Advanced:** Commercial deployment plus enabling infrastructure and offtake anchors; supportive governance; multiple pilots scaling.
- **Emerging:** Clear strategy/pilots and first infrastructure or offtake anchors, but gaps remain (permitting, offtake, scale, logistics).
- **Early-stage:** Intent and/or pilots in preparation; limited assets and missing enablers (standards, offtake, finance or policy support).

Table 4: Regions classified into three categories of maturity.

Regions and Justification	Classification
Region Nordjylland (DK) Strong national and regional alignment, mature biogas sector, PtX readiness, robust legal and technological frameworks.	Advanced
<u>Biogas</u> : advanced and integrated	Advanced
<u>Hydrogen</u> : emerging but scaling via PtX hubs	Emerging → Advanced
Kalmar County (SE) Integrated biogas strategy, strong local leadership, Klimatklivet funding, technological maturity, and environmental benefits.	Advanced
<u>Biogas</u> : advanced and exporting	Advanced
<u>Hydrogen</u> : emerging with first refuelling stations	Emerging
Waterford County (IE)	Emerging

Promising hydrogen strategy, EU funding access, strong local engagement, but lacks full legal and infrastructure maturity.	
<u>Biogas</u> : solid base with AD plants	Emerging
<u>Hydrogen</u> : hydrogen blending pilots commencing	Early-stage → Emerging
Extremadura (ES) Strategic intent and innovation potential, but fragmented legal and regulatory frameworks hinder investment readiness.	Emerging
<u>Biogas</u> : Select initiatives, but limited deployment	Emerging
<u>Hydrogen</u> : Emerging with strong resource base and active pilots, 3 GW ambition by 2030, permitting/market clarity still maturing	Emerging
Moravian-Silesian Region (CZ) Regional initiatives exist and ambitions are high, but national support is weak, and legal/technological gaps persist.	Early-stage, but advancing towards Emerging
<u>Biogas</u> : Present in energy balance with integration potential but modest base	Early-stage → Emerging
<u>Hydrogen</u> : first public H ₂ station, regional strategy but still early, demonstration-to-market conversion is not yet evident, and policy alignment remains a constraint	Upper end of Early-stage
Lubelskie Region (PL) High ambition and potential, but political volatility, legal confusion, and infrastructure challenges slow progress.	Early-stage
<u>Biogas</u> : deployment remains modest relative to potential	Early-stage
<u>Hydrogen</u> : shows early hydrogen mobility uptake (buses) yet lacks refuelling infrastructure and faces high delivered H ₂ prices	Early-stage

4.3. Key Insights and Recommendations

The comparative PESTLE analysis across the six regions reveals a diverse landscape of readiness and ambition in the transition to green gases. While all regions share a commitment to decarbonisation and renewable energy integration, their pathways are shaped by distinct political structures, economic conditions, technological maturity, and social dynamics. These differences offer valuable lessons and highlight areas where targeted interventions could accelerate progress.

Several overarching insights emerge from the analysis:

- Policy coherence and regional autonomy play a decisive role in enabling green gas deployment. Regions such as Region Nordjylland (DK) and Kalmar County (SE) benefit from strong national frameworks and empowered local governance, which facilitate strategic planning and implementation. In contrast, regions with fragmented or slow-moving policy environments, like Lubelskie Region (PL) and the Moravian-Silesian Region (CZ), struggle to attract investment and coordinate development.
- Investment readiness is closely tied to legal clarity and streamlined permitting processes. Where regulatory frameworks are well-aligned with EU directives and offer predictable pathways for project approval, investor confidence is higher. Region Nordjylland (DK) and Kalmar County (SE) exemplify this, while Extremadura (ES), Waterford County (IE), and Lubelskie Region (PL) face challenges due to complex or incomplete legal landscapes.
- Public engagement and education are essential for building trust and social acceptance. Regions with strong community involvement, transparent communication, and inclusive planning, such as Kalmar County (SE) and Nordjylland (DK), report higher levels of support

for biogas and hydrogen initiatives. Conversely, safety concerns and low awareness in early-stage regions can hinder project rollout.

- Technological integration must be supported by innovation ecosystems and infrastructure upgrades. Advanced regions are leveraging existing assets and research capacity to scale green gas technologies, while emerging and early-stage regions require targeted support to overcome grid constraints, storage limitations, and supply chain dependencies.
- Environmental governance is a critical enabler of sustainable development. Life cycle assessments, resource efficiency strategies, and biodiversity safeguards are increasingly important as green gas projects scale. Kalmar County (SE) and Region Nordjylland (DK) demonstrate how environmental benefits can be maximized through circular economy principles and integrated planning.

In summary, the transition to green gases is underway across all six regions, but its pace and effectiveness depend on a combination of enabling conditions. Strengthening policy frameworks, simplifying legal procedures, investing in infrastructure and innovation, and fostering public trust will be key to unlocking the full potential of hydrogen and biogas in Europe's energy future.



5. Value Chain Analysis and Stakeholder Maps

The development of low-carbon gases across the six UNIFHY partner regions reveals diverse approaches shaped by local resources, industrial profiles, and governance structures. This chapter compares the regional value chains and identifies key actors, clusters, and collaboration platforms that support the transition to green gases.

5.1. Comparative value chain overview

Table 5 below shows a comparative overview of the biogas and hydrogen value chains across the six UNIFHY partner regions highlights key similarities and differences in 1) feedstock sourcing, 2) production technologies, 3) infrastructure development, and 4) end-use applications.

Table 5: Comparative value chain overview.

	Biogas	Hydrogen
Feedstock and Input Supply	All regions utilize agricultural residues, organic waste, and sewage sludge. Kalmar County (SE), Lubelskie (PL), and Extremadura (ES) have strong agricultural bases, while Waterford (IE) and Moravian-Silesian Region (CZ) integrate industrial and municipal waste streams.	Renewable electricity (solar, wind) is common across regions. Extremadura (ES) and Kalmar County (SE) also leverage nuclear power (pink hydrogen). Nordjylland (DK) and Moravian-Silesian Region (CZ) explore hydrogen from PtX and CCUS integration.
Production and Conversion	Farm-based digesters and municipal plants dominate in Kalmar County (SE), Waterford (IE), and Lubelskie (PL). Extremadura (ES) and Waterford (IE) host commercial biomethane facilities.	Pilot-scale electrolysis is active in Extremadura (ES), Kalmar County (SE), and Lubelskie (PL). Moravian-Silesian Region (CZ) and Nordjylland (DK) are scaling up industrial hydrogen production linked to transport and industry.
Upgrading and Distribution	Upgraded to biomethane or liquefied biogas (LBG) for grid injection and transport. Kalmar County (SE) and Waterford (IE) have operational infrastructure; Lubelskie (PL) and Moravian-Silesian Region (CZ) are emerging.	Refuelling stations are under development in Kalmar County (SE), Lubelskie (PL), and Waterford (IE). Nordjylland (DK) and Moravian-Silesian Region (CZ) plan hydrogen corridors and blending infrastructure.
End Use and Applications	Used in public transport (Kalmar County (SE), Waterford (IE), agriculture (digestate), and industry (food, metal).	Applied in municipal fleet (Lubelskie (PL)), heavy transport (Moravian-Silesian Region (CZ), Nordjylland (DK)), and industrial processes (Extremadura (ES), Moravian-Silesian Region (CZ)). Backup power and district heating integration are explored in Kalmar County (SE) and Extremadura (ES).

5.2. Key Actors and Collaboration Platforms

Table 6 below shows the key actors and collaboration platforms in the studied regions.

Table 6: Key actors and collaboration platforms.

Public Authorities	<ul style="list-style-type: none"> Regional governments (e.g., Junta de Extremadura (ES), Region Kalmar (SE), Lubelskie Voivodeship (PL)) lead strategy and permitting. Municipalities (e.g., Kalmar (SE), Chełm (PL), Waterford (IE)) anchor demand through fleet procurement and infrastructure planning.
Industry and Technology Providers	<ul style="list-style-type: none"> Large companies: Grupa Azoty Puławy (PL), Aalborg Portland (DK), OKG Nuclear (SE), Ormonde Organics (IE), Třinecké železářny (CZ). SMEs and cooperatives: Active in biogas production and hydrogen pilots, especially in Kalmar County (SE) and Waterford County (IE).
Research and Academia	<ul style="list-style-type: none"> Universities and institutes: CIAE and University of Extremadura (ES), SETU (IE), LUT and UMCS University of Life Sciences in Lublin (PL), VSB–TU Ostrava (CZ), Aalborg University (DK). These actors support R&D, pilot validation, and workforce development.
Clusters and Platforms	<ul style="list-style-type: none"> Hydrogen Clusters: Extremadura Hydrogen Cluster (ES), MSVK (CZ), Lublin Hydrogen Valley (PL), SOIH2 (ES/PT). Biogas Networks: Biogas Sydost (SE), regional farming cooperatives (SE, PL). Innovation Missions: MissionGreenFuels (DK), Green Hydra (PL), UNIFHY interregional cooperation.
Funding Bodies	<ul style="list-style-type: none"> EU programs (Horizon Europe, CEF, Interreg), national funds (e.g., Klimatklivet in Sweden, NFOŚiGW in Poland), and regional innovation grants support all stages of the value chain.

5.3. Summary and Insights

Across the six regions, biogas is more mature, with established production and use in transport and agriculture. Hydrogen is emerging, with pilot projects and infrastructure development underway. Key success factors include:

- Public procurement anchoring demand (e.g., biogas buses in Kalmar, hydrogen buses in Lubelskie).
- Clusters and platforms enabling coordination and visibility (e.g., MSVK, SOIH2).
- Research institutions bridging innovation and deployment.
- Funding and permitting as critical enablers or bottlenecks.

To accelerate deployment, regions must strengthen stakeholder coordination, streamline permitting, and align infrastructure planning with national and EU strategies. The diversity of approaches offers rich opportunities for mutual learning and joint innovation across the UNIFHY partnership.

6. Identified Barriers and Opportunities (Synthesis)

This chapter provides a consolidated view of the barriers and opportunities for developing low-carbon gas ecosystems across the six UNIFHY regions. While the pace and maturity of transition vary, all regions face common barriers such as infrastructure gaps, policy misalignment, and investment uncertainty. At the same time, each region offers unique opportunities based on its industrial profile, renewable energy potential, and stakeholder engagement. Drawing on the maturity classification presented in Chapter 4 (Table 3), the synthesis organizes insights into three categories: Early-stage, Emerging, and Advanced regions, bearing in mind that biogas vs hydrogen maturity can diverge by region as shown in Table 4. This highlights common challenges and strategic opportunities identified in the PESTLE analyses made by each of the UNIFHY-regions.

6.1. Early-Stage Regions: Moravian-Silesian (CZ) and Lubelskie (PL)

The early-stage regions face the most significant structural and regulatory challenges. Both regions remain heavily reliant on fossil fuels and legacy infrastructure, which constrains the transition to low-carbon gases. Legal frameworks are underdeveloped, with slow transposition of EU directives and unclear definitions creating uncertainty for investors. Hydrogen and biomethane production capacity is minimal, and integration into energy and transport systems is limited. Social acceptance is weak, with low awareness and resistance to new infrastructure, particularly in rural areas.

Despite these barriers, opportunities exist. Large industrial emitters in Moravian-Silesian Region (CZ) provide strong use cases for hydrogen in steelmaking, chemicals, and heavy transport, while Lubelskie's (PL) agricultural base offers abundant feedstock for biogas and biomethane. Regional clusters and universities can serve as catalysts for innovation and skills development, and EU structural funds present a critical lever for early adoption through targeted pilot projects. Strategic planning that aligns regional ambitions with national and EU frameworks will be essential to unlock these opportunities.

6.2. Emerging Regions: Extremadura (ES) and Waterford (IE)

Emerging regions demonstrate strategic intent and growing innovation capacity but face structural and regulatory hurdles. Fragmented permitting procedures and incomplete transposition of EU directives create uncertainty for investors and delay project implementation. Infrastructure for hydrogen and biomethane distribution is limited, and public awareness remains low, reducing social acceptance and slowing market uptake. High capital expenditure and electricity price volatility further challenge the economic viability of hydrogen production.

Nevertheless, these regions possess significant potential. Extremadura's (ES) abundant solar resources and Waterford's (IE) offshore wind projects position them as future hubs for renewable hydrogen. Pilot initiatives, such as anaerobic digestion plants and hydrogen blending trials, demonstrate early progress and provide models for replication. Industrial sectors, including agri-food in Extremadura and pharmaceuticals in Waterford, offer anchor demand for green gases, while regional clusters and academic institutions strengthen innovation ecosystems. Access to EU and

national funding instruments can accelerate infrastructure rollout and support workforce development.

6.3. Advanced Regions: Nordjylland (DK) and Kalmar County (SE)

The advanced regions exhibit strong political alignment, mature biogas systems, and active pilot projects for hydrogen and Power-to-X technologies. However, their progress is not without obstacles. High investment costs for hydrogen infrastructure and electrolysis facilities remain a significant barrier, compounded by grid bottlenecks and complex permitting processes for large-scale projects. In Kalmar County (SE), water availability introduces an additional constraint, as hydrogen production through electrolysis is water-intensive and may compete with agricultural needs during recurring droughts. Skills shortages in specialized areas such as hydrogen safety and carbon capture further limit the pace of deployment.

Despite these challenges, advanced regions offer substantial opportunities. Their established biogas ecosystems and industrial clusters create ideal conditions for sector coupling, integrating green gases into district heating, transport, and industrial processes. Ports and logistics hubs in Nordjylland (DK), combined with Kalmar's cooperative biogas models, provide replicable frameworks for infrastructure development. Public procurement strategies, such as biogas bus fleets, anchor demand and de-risk investment, while strong research capacity and innovation platforms enable technology transfer and scaling.

6.4. Cross-Cutting Enablers

Across all maturity levels, several enabling conditions are critical to success. Streamlined permitting and legal clarity are prerequisites for investor confidence and timely project delivery. Coordinated funding packages that combine EU, national, and regional instruments can support the full value chain, from production to end-use. Public-private partnerships are vital for anchoring demand and de-risking investment, while education and training programs will address skills gaps and build capacity for a sustainable transition.

7. Good Practices and Lessons Learned

The transition to low-carbon gases is not only driven by policy and infrastructure but also by practical, region-specific initiatives that demonstrate how barriers can be overcome and opportunities realised. This chapter presents selected good practices from the six UNIFHY partner regions, grouped into four thematic areas:

- Infrastructure and Deployment (Table 7),
- Circular Economy and Agriculture (Table 8),
- Public Procurement and Local Anchors (Table 9), and
- Governance and Innovation Platforms (Table 10).

These examples offer transferable lessons for other regions aiming to accelerate the uptake of hydrogen and biomethane.

Table 7: Examples of good practices and lessons learned: Infrastructure and deployment.

Infrastructure and deployment	
<p>Turn2x Power-to-Gas Plant (ES) A pioneering facility producing renewable natural gas by combining green hydrogen with biogenic CO₂. Operates under long-term off-take contracts.</p>	<p>Lesson: Secure off-take agreements and co-location with renewables are key to de-risking investment and proving market readiness.</p>
<p>Hydrogen Refuelling Stations (SE, PL) Stations under development in Kalmar and Oskarshamn (Sweden), and planned in Lublin and Chełm (Poland), co-financed by national and EU programs.</p>	<p>Lesson: Strategic public-private partnerships and targeted funding can kickstart hydrogen infrastructure in emerging regions.</p>
<p>Port of Aalborg PtX Hub (DK) Developing large-scale electrolysis and e-methanol production, integrated with industrial heat sinks and logistics.</p>	<p>Lesson: Ports can serve as strategic hubs for green fuel production and sector coupling.</p>
<p>Hydrogen Refuelling Infrastructure in Ostrava (CZ) Public and university-based hydrogen stations support early adoption and visibility.</p>	<p>Lesson: Early infrastructure deployment builds regional leadership and supports pilot fleets.</p>

Table 8: Examples of good practices and lessons learned: Circular economy and Agriculture.

Circular Economy and Agriculture	
<p>Farm-Based Biogas Cooperatives (SE) Farmers supply manure and receive biofertilizer, reducing investment risk and strengthening rural economies.</p>	<p>Lesson: Cooperative models unlock biogas potential in agricultural regions and support circular farming.</p>
<p>Ormonde Organics Anaerobic Digestion Plant (IE) Processes organic waste into biomethane, demonstrating circular economy principles and local energy autonomy.</p>	<p>Lesson: Local bioresources can be effectively harnessed for renewable gas production when aligned with planning and policy.</p>
<p>Mine Methane Utilisation (CZ) Exploring hydrogen production from degasification gases in closed coal mines.</p>	<p>Lesson: Repurposing legacy assets supports just transition goals and reduces environmental impact.</p>
<p>Biogas Digestate Integration (SE) Use of digestate as biofertilizer reduces reliance on mineral fertilizers and closes nutrient loops.</p>	<p>Lesson: Linking energy production with agricultural benefits enhances sustainability and economic viability.</p>

Table 9: Examples of good practices and lessons learned: Procurement and Local Anchors

Public Procurement and Local Anchors	
<p>Kalmar Länstrafik Biogas Bus Fleet (SE) A long-standing biogas bus fleet anchors demand and supports local biogas producers.</p>	<p>Lesson: Public procurement can serve as a stable demand anchor, enabling infrastructure investment.</p>
<p>Hydrogen Bus Deployment (PL) Chełm (26 buses), Lublin (1 bus + 20 planned), and Świdnik (3 buses) demonstrate municipal leadership in hydrogen adoption.</p>	<p>Lesson: Municipal investment and targeted funding can catalyse early adoption of hydrogen technologies.</p>
<p>Danone Nutricia (IE) Industrial integration of renewable gases provides a replicable model for food and pharma sectors.</p>	<p>Lesson: Industrial offtakers can drive demand and de-risk infrastructure investment through long-term procurement.</p>
<p>Demand-First Procurement Models (DK) Municipalities and ports commit to long-term fuel offtake contracts for biomethane and e-methanol.</p>	<p>Lesson: Public sector demand guarantees unlock private investment and accelerate infrastructure rollout.</p>

Table 10: Examples of good practices and lessons learned: Governance and Innovations Platforms

Governance and Innovation Platforms	
<p>Hydrogen Roundtables and Clusters (ES, CZ, PL) Extremadura (ES), Moravian-Silesian, and Lubelskie (PL) have established hydrogen clusters and strategic platforms to coordinate stakeholders and attract funding.</p>	<p>Lesson: Regional platforms foster collaboration, align priorities, and improve visibility in national and EU funding landscapes.</p>
<p>Green Hydra Project (PL) Integrates SMEs into the hydrogen value chain through engineering and design support.</p>	<p>Lesson: Targeted innovation programs build capacity and connect local businesses to emerging energy markets.</p>
<p>SETU Hydrogen Research (IE) South East Technological University anchors regional hydrogen R&D and workforce development.</p>	<p>Lesson: Academic institutions can bridge research and deployment through training and partnerships.</p>
<p>CIIAE and University of Extremadura (ES) Lead multiple EU-funded projects on hydrogen and Power-to-X, supporting regional innovation.</p>	<p>Lesson: Strong research institutions anchor innovation ecosystems and support technology transfer.</p>
<p>Biogasboost Awareness Campaigns (SE) Public campaigns have increased acceptance and addressed concerns about odour and safety.</p>	<p>Lesson: Transparent communication builds trust and facilitates smoother permitting and community support.</p>



8. Recommendations for Policy and Continued Collaboration

The UNIFHY project brings together six European regions at different stages of readiness in the transition to low-carbon gases. While each region faces unique challenges, the comparative analysis reveals shared priorities and opportunities for joint action. This chapter consolidates recommendations for policy development, investment, skills, and collaboration, providing context for implementation and highlighting cross-cutting issues that affect all regions. It provides a roadmap for continued collaboration, within the UNIFHY partnership and beyond, serving as a practical tool for regional planning, funding applications, and stakeholder coordination.

8.1. Joint Recommendations

Policy Development and Regulatory Alignment

To accelerate the transition to low-carbon gases, coherent and predictable regulatory frameworks are essential. Regions should prioritize the timely transposition of EU directives such as RED III and the Hydrogen Directive into national and regional law to provide legal clarity and investor confidence. Streamlined permitting processes, including regional fast-track mechanisms and one-stop shops, will reduce delays and enable early deployment of infrastructure. Procurement frameworks must align with EU sustainability criteria to ensure biogas and hydrogen remain competitive in public tenders. While EU-level frameworks such as RED III and the Hydrogen Directive set important enabling conditions, many regions continue to face uncertainty regarding the practical implementation of certification and permitting requirements. In this context, the European Commission's Delegated Act on RFNBO and low-carbon hydrogen is a relevant example: in its current form, the Delegated Act is difficult to apply in practice and creates uncertainties that hinder early deployment and investment. Low-carbon gases should be integrated into regional energy and climate strategies, with clear targets and timelines for infrastructure, production, and end-use. Furthermore, resource planning should integrate water considerations, particularly in drought-prone regions, to prevent conflicts between hydrogen production and agriculture.

Investment and Infrastructure

Strategic investment is critical to scaling low-carbon gas technologies. Regions should consolidate funding streams by combining EU, national, and regional instruments into coherent packages that support the entire value chain, from production to end-use. Infrastructure expansion must prioritize freight corridors, ports, and rural areas to ensure equitable access and market uptake for both biogas and hydrogen. Sector coupling, such as linking hydrogen with district heating and biogas with agriculture, offers opportunities to maximize efficiency and sustainability. Demonstration hubs in transport, industry, and agriculture will validate technologies and build stakeholder confidence.

Skills and Workforce Development

A skilled workforce is a cornerstone of the energy transition. Regions should launch vocational and higher education programs focused on hydrogen safety, biogas operations, CCUS, and digital energy systems. Regional competence centres can coordinate training, innovation, and knowledge transfer between academia, industry, and public authorities. Engaging SMEs and cooperatives through

targeted innovation programs and capacity-building initiatives will ensure that rural and early-stage regions are not left behind.

Collaboration and Knowledge Exchange

Collaboration across regions and sectors is essential to accelerate deployment and share best practices. Regional platforms and clusters, such as Extremadura Hydrogen Cluster, MSVK, and Biogas Sydost, should be strengthened to coordinate stakeholders and attract funding. Interregional learning through joint workshops, study visits, and shared pilot projects across UNIFHY regions will foster innovation and reduce duplication of effort. Public-private partnerships can anchor demand and de-risk investment, especially in transport and industrial sectors, while academic institutions should act as bridges between research and deployment, supporting technology transfer and workforce development.

9. Synthesis and Key Conclusions

The transition to low-carbon gases is underway across all six UNIFHY regions, but its success depends on several enabling conditions: coherent policy frameworks, streamlined legal procedures, strategic investment, a skilled workforce, and collaborative governance structures. By acting on these recommendations and leveraging the comparative insights in this report, regions can accelerate their energy transition, contribute to EU climate objectives, and foster resilient innovation ecosystems around hydrogen and biomethane.

The Joint State of the Art report demonstrates that although the six regions differ significantly in their maturity levels, resource bases, industrial profiles, and institutional environments, several cross-cutting insights emerge. The following five points summarise the central findings:

- 1. Regions progress at different maturity levels but face shared systemic challenges.**
 The six partner regions range from advanced (Kalmar County, Nordjylland) to early-stage (Moravian-Silesian, Lubelskie), yet all struggle with similar issues: lengthy permitting, unclear national frameworks, infrastructure gaps, and limited coordination across governance levels.
- 2. Regulatory uncertainty remains a major barrier to investment and deployment.**
 Fragmented rules, incomplete transposition of EU legislation, and unclear definitions—particularly in relation to RFNBO and low-carbon hydrogen certification—create operational and financial uncertainty. Many regions find the Delegated Act difficult to apply in practice, which slows market development.
- 3. Hydrogen applications vary significantly by region, requiring tailored strategies.**
 Industrial hydrogen demand dominates in Moravian-Silesian, transport needs drive development in Lubelskie, and PtX opportunities lead in Nordjylland. An improved EU-level overview of applications is useful, but strategies must remain grounded in each region's specific economic structure, maturity, and resource base.
- 4. Biogas is already a mature solution while hydrogen remains in an emerging stage.**
 Biogas systems are well established across the regions and already contribute to transport, agriculture, and industry. Hydrogen, by contrast, remains at pilot scale and requires clearer regulation, stronger infrastructure, and better demand anchoring before large-scale deployment becomes feasible.
- 5. Strong governance, collaboration, and cluster structures accelerate progress.**
 Regions with strong political leadership, active hydrogen/biogas clusters, and collaboration between public authorities, industry, and academia—such as Kalmar, Nordjylland, and Extremadura—advance faster and more coherently. These structures are essential for reducing uncertainty, attracting investment, and building capacity.

10. Appendices

10.1. Glossary

Table 11: Glossary

Biogas / Biomethane	In this report, “biogas” refers to raw biogas produced through anaerobic digestion, and “biomethane” refers to upgraded biogas suitable for grid injection or transport. For simplicity, the terms are used interchangeably unless otherwise specified.
CCUS	Carbon Capture, Utilization, and Storage.
Green Hydrogen	Hydrogen produced via electrolysis using renewable electricity.
Hydrogen Valley:	A regional cluster integrating hydrogen production, distribution, and end-use applications.
Pink Hydrogen	Hydrogen produced via electrolysis using nuclear power.
PtX (Power-to-X)	Technologies that convert electricity into other energy carriers, such as hydrogen or e-fuels.
RFNBO	Renewable Fuels of Non-Biological Origin
Sector Coupling	Integration of energy carriers (electricity, gases, heat) across sectors to improve efficiency and flexibility.

10.2. Contact information

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10.3. Links to RSA reports

Links to the RSA on <https://www.interregeurope.eu/unifhy/library>