Deliverable report

WP 1 – Cross-border Pilot Project Implementation Showcasing

D.1.2.1 – Report on hydrogen-related policy mismatch

Project acronym	H2GreenFUTURE
Project number	SIAT00076
Project dates	1 December 2023 – 30 November 2026
Activity	A1.2 Implementation of interregional hydrogen pilot
Deliverable	D.1.2.1 Report on hydrogen related policy mismatch
Contractual delivery date	30.11.2025
Actual delivery date	30.11.2025
Dissemination level	Public
Responsible partner	FB
Involved partners	NIC
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Acknowledgements	The information and views expressed in this report are those of the author(s) and do not necessarily reflect the official opinion of the Interreg Programme Slovenia-Austria (IP SI-AT). Neither the bodies of IP SI-AT nor any person acting on its behalf may be held responsible for the use which may be made of the information contained herein.
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WP 1 – Cross-border Pilot Project Implementation Showcasing (A1.2 Implementation of interregional hydrogen pilot; D.1.2.1 Report on hydrogen-related policy mismatch): The report will represent a draft of potential policy mismatches, but in addition, also technical, safety and regulation country variations, laying the foundations for the replication or expansion within T1.3, comparing some ubiquitous features, as well as dissimilarities, focusing on barriers.

DOCUMENT APPROVAL

Name	Organization	Role	Action	Date
Petra Props	NIC	Project Coordinator	Approval	15/12/2025

DOCUMENT HISTORY

Version	Date	Modifications	Authors
V1	28.08.2025	Initial version	Nora Kirchknopf
V2	26.11.2025	Second version	Tomaž Čebela
V3	30.11.2025	Third version	Christian Seidl

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Abstract / Povzetek / Zusammenfassung

English

The element Hydrogen plays a central role in Europe's decarbonisation strategy. While technological innovations in hydrogen production, storage, and distribution are advancing rapidly, regulatory frameworks often lag behind. This study examines the mismatch between technology and regulation in the hydrogen sector, using Austria and Slovenia as illustrative case studies. The analysis is based on concepts of technology governance and innovation diffusion and is complemented by empirical data. The findings indicate that Austria demonstrates a high level of technological maturity, supported by numerous electrolyser projects and substantial public funding, but is simultaneously confronted with regulatory complexity and administrative delays. Slovenia, by contrast, shows promising project developments but lacks dedicated regulatory structures, resulting in legal uncertainty. Addressing these discrepancies through regulatory sandboxes, dynamic regulatory approaches, and stronger EU-wide harmonisation is essential to enable replication in T1.3 and to support Europe's hydrogen scale-up ambitions.

Slovene

Element vodik ima osrednjo vlogo v evropski strategiji razogljičenja. Medtem ko tehnološke inovacije na področju proizvodnje, shranjevanja in distribucije vodika hitro napredujejo, regulativni okviri pogosto zaostajajo. Ta študija preučuje neskladje med tehnologijo in regulacijo v vodikovem sektorju na primeru Avstrije in Slovenije kot ilustrativnih študij primerov. Analiza temelji na konceptih upravljanja tehnologij in difuzije inovacij ter je dopolnjena z empiričnimi podatki. Ugotovitve kažejo, da Avstrija izkazuje visoko stopnjo tehnološke zrelosti, ki jo podpirajo številni projekti elektrolizatorjev in obsežno javno financiranje, hkrati pa se sooča z regulativno kompleksnostjo in administrativnimi zamudami. Slovenija pa nasprotno kaže obetaven razvoj projektov, vendar nima namenskih regulativnih struktur, kar povzroča pravno negotovost. Odpravljanje teh neskladij z uvedbo regulativnih peskovnikov, dinamičnih regulativnih pristopov in močnejše harmonizacije na ravni EU je bistveno za omogočanje replikacije v T1.3 ter za podporo ambicijam Evrope glede širjenja uporabe vodika.

German

Das Element Wasserstoff spielt eine zentrale Rolle in der europäischen Dekarbonisierungsstrategie. Während technologische Innovationen in der Wasserstoffproduktion, -speicherung und -verteilung rasch voranschreiten, bleiben die regulatorischen Rahmenbedingungen häufig zurück. Diese Studie untersucht das Missverhältnis zwischen Technologie und Regulierung im Wasserstoffsektor anhand der Fallbeispiele Österreich und Slowenien. Die Analyse basiert auf Ansätzen der Technology Governance und der Innovationsdiffusion und wird durch empirische Daten ergänzt. Die Ergebnisse zeigen, dass Österreich über eine hohe technologische Reife verfügt, die durch zahlreiche Elektrolyseurprojekte und umfangreiche Fördermaßnahmen unterstützt wird, jedoch gleichzeitig mit regulatorischer Komplexität und administrativen Verzögerungen konfrontiert ist. Slowenien hingegen weist vielversprechende Projektentwicklungen auf, verfügt jedoch nicht über spezialisierte regulatorische Strukturen, was zu rechtlicher Unsicherheit führt. Um diese Diskrepanzen zu überwinden, sind regulatorische Sandboxes, dynamische Regulierungsansätze und eine stärkere EU-weite Harmonisierung erforderlich, um die Replizierbarkeit in T1.3 zu ermöglichen und Europas Wasserstoff-Hochlauf zu unterstützen.

Introduction

Hydrogen has emerged as a cornerstone of the European Union's ambition to achieve climate neutrality by 2050. Recognised for its potential to decarbonise hard-to-abate sectors such as industry, transport, and energy storage, hydrogen occupies a central position in the European Commission's Hydrogen Strategy. This strategy outlines a pathway for scaling up renewable and low-carbon hydrogen technologies across the Union and envisions hydrogen as a backbone of future climate-neutral energy systems. However, while technological development in the hydrogen sector is progressing rapidly, legal and institutional frameworks frequently struggle to keep pace with these advancements.

Regulatory systems are often characterised by fragmented responsibilities, lengthy permitting procedures, and legal uncertainty, all of which can impede the deployment and diffusion of innovative hydrogen technologies. These challenges are particularly pronounced at the national level, where EU objectives must be translated into domestic legislation and administrative practice. As a result, a mismatch can emerge between technological readiness and regulatory preparedness, potentially slowing down investment and implementation.

Austria and Slovenia provide insightful case studies for examining these dynamics. Both countries are actively engaging in hydrogen-related projects and align with the broader EU hydrogen agenda, yet they differ significantly in their regulatory structures, administrative capacities, and levels of technological maturity. By analysing these two cases, this study seeks to identify how technology–regulation mismatches arise in practice and to explore governance approaches capable of bridging these gaps. In doing so, the paper contributes to the broader debate on adaptive regulation and effective technology governance in the context of Europe's hydrogen transition.

Theoretical Framework

Technology Governance

Technology Governance refers to the institutional and policy arrangements through which societies attempt to steer technological development. Its central dilemma lies in the fact that technological innovation often proceeds faster than the development of corresponding rules, creating regulatory lag. Scholars highlight that governance systems must balance innovation support with risk management (Borrás & Edler, 2020). In the hydrogen sector, this balance is delicate: while rapid scale-up is necessary to meet climate goals, safety concerns and infrastructural challenges demand cautious regulation.

Innovation Diffusion Theory

Rogers' (2003) Diffusion of Innovations provides a complementary lens. Innovations spread through societies based on perceived relative advantage, compatibility, complexity, trialability, and observability. Regulatory frameworks shape each of these factors. For instance, overly strict or outdated rules increase perceived complexity and reduce relative advantage, thereby slowing adoption. Conversely, adaptive regulatory systems can accelerate diffusion by reducing uncertainty and enhancing compatibility. Hydrogen technologies in Austria and Slovenia illustrate how regulation influences diffusion: Austria's strict frameworks increase complexity, while Slovenia's flexible but underdeveloped systems reduce predictability.

Hydrogen Technology and the Regulatory Challenge

The hydrogen value chain consists of production, storage, transport, and end-use. Each segment is technologically dynamic. Electrolysers, the backbone of green hydrogen, have become more efficient and scalable, while storage systems now employ high-pressure tanks, cryogenic solutions, or chemical carriers such as ammonia. Transport infrastructures range from retrofitted natural gas pipelines to new hydrogen-dedicated corridors. End-use sectors include heavy industry, mobility, and power storage, each with unique technical requirements.

Yet, regulation has not matched this dynamism. For example, in Austria, hydrogen pipelines remain regulated under natural gas frameworks, which inadequately address hydrogen's unique properties such as embrittlement and lower volumetric energy density. Safety regulations require exhaustive approval processes that do not yet incorporate new sensor-based technologies capable of detecting leaks in real time. In Slovenia, the absence of hydrogen-specific rules means that projects proceed under generic energy law, creating both flexibility and legal uncertainty.

Case Illustration: Austria

Austria's Hydrogen Strategy 2022 sets clear targets for scaling up domestic hydrogen production, with a particular focus on green hydrogen. Pilot projects, including electrolysers integrated into renewable energy plants, demonstrate strong technological readiness. Austrian industry, particularly in steel and chemicals, has expressed demand for large-scale hydrogen solutions.[1]

The regulatory environment, however, has proven to be conservative. The adaptation of existing laws to hydrogen contexts is slow, with pipeline authorisations and refuelling station approvals requiring extensive administrative procedures. Investors face legal ambiguity regarding certification of hydrogen origin, as EU-wide frameworks are still under development.[2] This mismatch slows private sector engagement and threatens Austria's ambition to become a hydrogen hub in Central Europe.

Austria demonstrates a high level of technological readiness in the hydrogen sector, supported by a growing portfolio of pilot and large-scale projects across the value chain. Flagship initiatives such as the H2FUTURE project at the voestalpine steel plant in Linz, which operates a 6 MW PEM electrolyser, showcase the technical feasibility of integrating green hydrogen into industrial processes and the electricity system. Further large-scale developments, including OMV's planned 140 MW electrolyser in Bruck an der Leitha, underline Austria's ambition to scale up domestic hydrogen production.[3] In addition, projects such as Underground Sun Storage illustrate Austria's advanced capabilities in hydrogen storage, particularly for seasonal balancing.[4]

These technological advances are embedded in a supportive policy framework. Austria's Hydrogen Strategy 2022 sets clear priorities, focusing on renewable hydrogen for hard-to-abate sectors and aligning with the national climate neutrality target for 2040.[1] Substantial public funding and targeted support schemes reinforce this strategic direction and have stimulated strong interest from industry, especially in steel, chemicals, and energy-intensive manufacturing. From a technological and economic perspective, Austria is therefore well positioned to become a hydrogen hub in Central Europe.

However, the regulatory environment has proven comparatively conservative and fragmented. Hydrogen projects often fall under multiple legal regimes, including industrial permitting, environmental impact assessment, spatial planning, and gas regulation. Approval procedures for electrolysers, pipelines, storage facilities, and refuelling infrastructure are frequently complex and time-consuming, particularly as projects scale beyond pilot size. While many early projects avoid mandatory environmental impact assessments, legal uncertainty increases significantly for larger installations, slowing down investment decisions.

Additional challenges arise from infrastructure regulation and market design. The gradual adaptation of national gas legislation to hydrogen, in line with evolving EU market rules, creates transitional uncertainty for network access, tariffs, and operational models.[2] At the same time, investors face ambiguity regarding the certification and recognition of renewable hydrogen, as EU-wide frameworks for RFNBOs are still being fully operationalised at the national level. This gap between technological maturity and regulatory clarity exemplifies a technology–regulation mismatch.

Overall, Austria illustrates how advanced technological capabilities and strong political ambition can coexist with regulatory inertia. While the country has the potential to play a leading role in Europe's hydrogen transition, unresolved legal ambiguities and administrative delays risk slowing private sector engagement and the large-scale deployment of hydrogen technologies. Addressing these governance challenges is therefore crucial for translating Austria's hydrogen ambitions into sustained market uptake and for enabling replication in future European hydrogen initiatives.

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[1] https://www.bmk.gv.at/themen/energie/energieversorgung/wasserstoff.html
[2] European Commission. (2020). A hydrogen strategy for a climate-neutral Europe. COM(2020) 301 final
[3] OMV Group. (2023). OMV to build Austria's largest green hydrogen plant in Bruck an der Leitha
[4] RAG Austria AG. (2022). Underground Sun Storage: Seasonal hydrogen storage in porous reservoirs

Case Illustration: Slovenia

Slovenia, although not yet equipped with a comprehensive hydrogen strategy comparable to Austria's, is actively involved in European initiatives such as the North Adriatic Hydrogen Valley, funded by the Clean Hydrogen Partnership. This project aims to integrate Slovenian infrastructure with Italian and Croatian ports and connect to central European markets. On the technological front, Slovenia is investing in various hydrogen technologies, like hydrogen refuelling stations, hydrogen buses, and electrolysers, signalling its readiness to participate in the emerging hydrogen economy.

The regulatory framework is evolving but remains constrained by limited institutional capacity. Slovenia currently relies heavily on EU directives and general industrial legislation, notably the upcoming transposition of Directive (EU) 2024/1788 on common rules for the internal markets for renewable gas, natural gas, and hydrogen[1], which must be transposed into national legislation by August 2026. This directive will harmonise Slovenia's approach with EU standards, providing clearer rules for hydrogen market integration.

Domestically, Slovenia has adopted key legislative measures:

- Act on the Promotion of the Use of Renewable Energy Sources[2] (July 2021) sets the foundation for renewable energy deployment.
- Act on Infrastructure for Alternative Fuels and Promoting the Transition to Alternative Fuels in Transport[3] (May 2023) supports the development of refuelling infrastructure and alternative fuel adoption.
- National Energy and Climate Plan (December 2024) sets a goal to reduce the use of fossil energy sources and dependence on their imports, with the implementation of pilot projects for the production of renewables and low-carbon gases (synthetic methane and hydrogen), with an indicative goal of achieving a 10 % share of renewable and low-carbon gases in the transmission and distribution system by 2030.[4]
- Amending the Act on the Introduction of Devices for the Production of Electricity from Renewable Energy Sources[5] (September 2025) with aim to strengthen provisions for integrating renewable electricity generation devices into the energy system.

In addition, the Ministry of the Environment, Climate and Energy is preparing an **Action plan for hydrogen technology development by 2030, with a vision extending to 2040**.[6] This plan will outline strategic priorities for production, infrastructure, and market integration. It will be published in June 2026 and will include comprehensive, harmonised and implementable set of measures that will enable Slovenia to achieve its targets for the integration of hydrogen into industry and transport by 2030, with a strategic outlook to 2040 and beyond.

Industry-driven initiatives are also gaining momentum. The SloH2U[7] initiative, launched in March 2025, brings together more than 50 major industrial and energy companies. Its focus is on preparing gas

[1] Direktiva (EU) 2024/1788 o skupnih pravilih notranjega trga plina iz obnovljivih virov, zemeljskega plina in vodika
[2] Zakon o spodbujanju rabe obnovljivih virov energije (ZSROVE)
[3] Zakon o infrastrukturi za alternativna goriva in spodbujanju prehoda na alternativna goriva v prometu (ZIAG)
[4] Nacionalni energetski in podnebni načrt (NEPN)
[5] Zakon o spremembah in dopolnitvah Zakona o uvajanju naprav za proizvodnjo električne energije iz obnovljivih virov energije (ZUNPEOVE-B)
[6] Slovenija pripravlja akcijski načrt za razvoj vodikove tehnologije do leta 2030 z vizijo do 2040
[7] SloH2U - Slovenska iniciativa vodnika za uporabnike

pipeline systems for hydrogen, developing hydrogen technologies, and connecting domestic production with end-use and cross-border transmission capacities. These efforts aim to integrate Slovenia into European hydrogen corridors and reduce dependence on fossil fuels.

While this regulatory and strategic progress signals commitment, challenges remain. The current framework offers flexibility for rapid project approvals but creates uncertainty for long-term investments. International partners often perceive Slovenia's legal environment as underdeveloped, which could hinder large-scale replication unless the forthcoming action plan and EU directive transposition provide greater clarity and stability.

Cross-Cutting Themes

Safety and Public Trust

Hydrogen's flammability and diffusivity require stringent safety measures. Technologies such as AI-assisted monitoring and advanced material science provide high levels of safety, yet regulatory frameworks continue to rely on conservative fossil-fuel-derived models. This creates delays in approval processes and reinforces public scepticism, as regulations fail to acknowledge the enhanced safety of modern systems.

Sustainability Certification

A second area of mismatch is certification. Technical systems already allow traceability of hydrogen's carbon intensity, but EU-wide certification mechanisms are still incomplete. Austria has the technological capability to generate detailed sustainability reports, while Slovenian enterprises demonstrate strong engagement in occupational safety and training. Nevertheless, without harmonised rules, the "green" value of hydrogen remains contested, complicating cross-border trade.

Conclusion

The hydrogen sector exemplifies the structural challenges that arise when technological innovation advances faster than the regulatory and institutional frameworks designed to govern it. As hydrogen technologies move from pilot stages toward large-scale deployment, mismatches between technical readiness and regulatory preparedness become increasingly visible. The comparative analysis of Austria and Slovenia illustrates two distinct yet interconnected manifestations of this problem. In Austria, a high level of technological maturity, supported by substantial public funding and a robust project pipeline, contrasts with conservative and fragmented regulatory frameworks that slow down approval processes and create legal uncertainty for investors. In Slovenia, by contrast, limited institutional capacity and less specialised regulatory structures allow for a certain degree of flexibility but do so at the expense of predictability, long-term planning security, and investor confidence.

These cases demonstrate that the primary barriers to hydrogen replication and scale-up are no longer technological. Electrolysers, storage solutions, and industrial applications are increasingly proven and commercially viable. Instead, governance-related factors, including administrative complexity, unclear legal classifications, and the delayed transposition of EU-level rules into national law, have emerged as decisive constraints. Without addressing these governance bottlenecks, even well-funded and technologically advanced hydrogen projects risk stagnation or underperformance.

For D.T.1.2, these findings carry important implications. Replication under T1.3 cannot rely solely on the transfer of technological solutions or best-practice project designs. Rather, it requires governance mechanisms capable of bridging technology–regulation mismatches across different national contexts. Instruments such as regulatory sandboxes can provide controlled environments in which innovative hydrogen applications are tested while allowing regulators to gain experience and confidence. Similarly, more dynamic and adaptive approaches to EU directive implementation could help reduce transitional uncertainty and better align regulatory timelines with technological development cycles. Strengthening the technical and legal expertise of regulatory authorities through targeted training is equally essential to ensure consistent and informed decision-making.

Ultimately, the successful scale-up of hydrogen in Europe depends on the evolution of regulatory systems from static rule-based frameworks toward adaptive governance models that can respond to technological change without compromising safety, environmental protection, or market integrity. Austria and Slovenia offer valuable lessons in this regard, showing that both regulatory rigidity and regulatory underdevelopment can hinder progress in different ways. Only by learning from these experiences and embedding flexibility, coordination, and foresight into hydrogen governance can Europe unlock the full potential of hydrogen technologies and advance decisively toward its climate neutrality objectives.

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