Ref. Ares(2025)6245234 - 31/07/2025

D4.4 Policy relevant market uptake measures for biohydrogen

Deliverable n.4.4

GREENMEUP

Funded by the European Union

Document control sheet

Project	**GreenMeUp - Green biomethane market uptake**
Call identifier	HORIZON-CL5-2021-D3-02: Sustainability and educational aspects for renewable energy and renewable fuel technologies
Grant Agreement n°	101075676
Coordinator	CRES - Centre for renewable energy sources and saving foundation
Work package n°	4
Work package title	Market uptake measures
Work package Leader	CRES
Document title	D4.4 Policy relevant market uptake measures for biohydrogen
Author	Kyriakos Maniatis / KM-IIC Christos Tourkolias, Dimitris Mezartasoglou, Christos Zafiris, Myrsini Christou / CRES
Reference period	01/02/2024 - 31/07/2025
Due date	31/07/2025 (M36)

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Contents

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

List of figures

List of tables

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 1: Introduction

The EU has achieved significant progress the last decades in biogas and biomethane technologies and there is significant market deployment of several applications with a variety of feedstocks and uses of biogas and biomethane. In short, the EU is considered as a global leader in biogas and biomethane production technologies and applications. Furthermore, under the FIT for 55 legislation strong policy initiatives have been undertaken and the GreenMeUp project aims to contribute to these to whatever possible extend.

A relative recent development concerns the production and use of biohydrogen and given the wider EU and global policies on green or renewable hydrogen, the anticipated policy and market needs for biohydrogen have been carefully analysed and will be reported in this Deliverable.

The work undertaken is based on the results generated under Task 4.3 “Design policy relevant market uptake measures” and extrapolate them to a situation where biohydrogen has progressed significantly and is ready for market up-take. It will anticipate the policy market uptake measures necessary for the biohydrogen market development. This is expected to be achieved before 2030.

The work carried out in this task aims to define the focus and typology of future policy interventions which can be developed and implemented to improve the market uptake of biohydrogen value chains in EU and the target countries. Fuzzy cognitive mapping techniques were investigated and combined with competitive priorities and performance-based indicators to interpret policy relevant attributes that are important but challenging for both the establishment and operation of biohydrogen value chains. The work was facilitated by numerous collected questionnaires from the participants conducted with MS Excel based simulation tool FCMapper.

Furthermore, an analysis on the present status of biohydrogen is undertaken to place the work in perspective.

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 2: Current status of biohydrogen

2.1 Biohydrogen definitions

Hydrogen is the most common element in nature, however, due to its high reactivity, it can't be found in its molecular form unless in underground deposits and geological formations. It is used expensively in refineries, chemistry and fuel industry. Hydrogen is mainly produced from natural gas reforming as shown in Figure 1. Overall, 96 % of hydrogen is today produced from fossil resources while electrolysis of renewable electricity is the main production route for green hydrogen.

Although hydrogen is a colorless gas in its natural state, in today's policy/industrial terminology it can be distinguished by one of eight different colors based on the feedstock used to produce the hydrogen, see Figure 2.

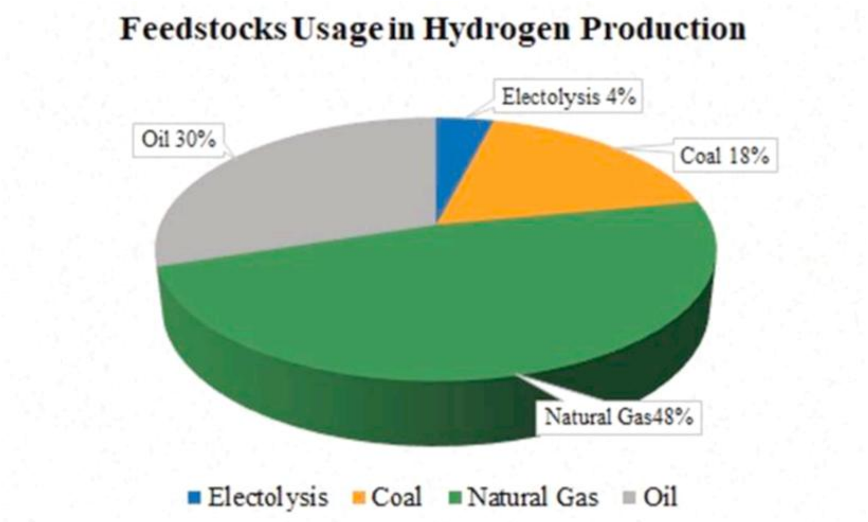

Figure 1: Feedstocks used in Hydrogen production. [1]

[1] M.G. Eloffy et al, Biomass to sustainable biohydrogen : Insights into the production routes and technical challenges, Chemical Engineering Journal Advances, 12 (2022)100410.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Type of hydrogen	Feedstock	Energy source	Process	Products	Comment
Brown/Black	Coal or lignite	Coal	SMR in combination with gasification	H_2 + CO + $CO_{2\,(released)}$	Established process used in industries that convert organic or fossil-based carbon materials into CO, H_2, and CO_2.
White	Naturally occurring			H_2	Naturally occurring geological hydrogen, found in underground deposits and created through fracking.
Grey	Natural Gas	Natural Gas	SMR	H_2 + $CO_{2\,(released)}$	Sources are derived from fossil fuels. Grey hydrogen is currently the most common form of H_2 production, in which the hydrogen is created from natural gas (methane), using SMR, with no GHG capture process.
Blue	Natural Gas	Natural Gas	SMR	H_2 + $CO_{2\,(\%\ captured\ and\ stored)}$	Produced mainly from natural gas, using SMR technology. CO_2 obtained as co-product, is captured using CCS technology.
Turquoise	Natural Gas	Natural Gas	Pyrolysis	H_2 + $C_{(solid)}$	Uses methane pyrolysis to produce H_2 and carbon materials.
Red	Water	Nuclear Power	Catalytic splitting	H_2 + O_2	Generated through catalytic splitting powered by nuclear energy.
Purple/Pink	Water	Nuclear Power	Electrolysis	H_2 + O_2	Generated through electrolysis powered by nuclear energy.
Green – RFNBO (non-biological origin)	Water	Renewable electricity	Water splitting processes (thermolysis, photolysis, electrolysis)	H_2 + O_2	The best known green H_2 is obtained via electrolysis of water using clean electricity from surplus renewable energy sources, such as solar or wind power.
Green – Bio-hydrogen (biological origin)	Biogenic sources (biomass, Biogas, Biomethane	Biomass derived energy[22]	Biological, thermochemical and bioelectrochemical (See Chapter 2)	H_2 + biogenic CO_2 + co-product (digestate, C, biochar, others)	Can be C negative when combined with CCS or when obtained from feedstocks such as wastes and manure. Low electricity needs.

Figure 2: Color definition of hydrogen production routes.[2]

2.2 Biohydrogen production methods

The production routes for green hydrogen are depicted in Figure 3. Biohydrogen can be produced via biological and thermochemical processes which may be combined with electrolytic hydrogen if necessary. The thermochemical processes are more complex than biological ones and are better suited for large scale industrial plants.

[2] EBA, Decarbonising Europe's hydrogen production with biohydrogen, June 2023.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

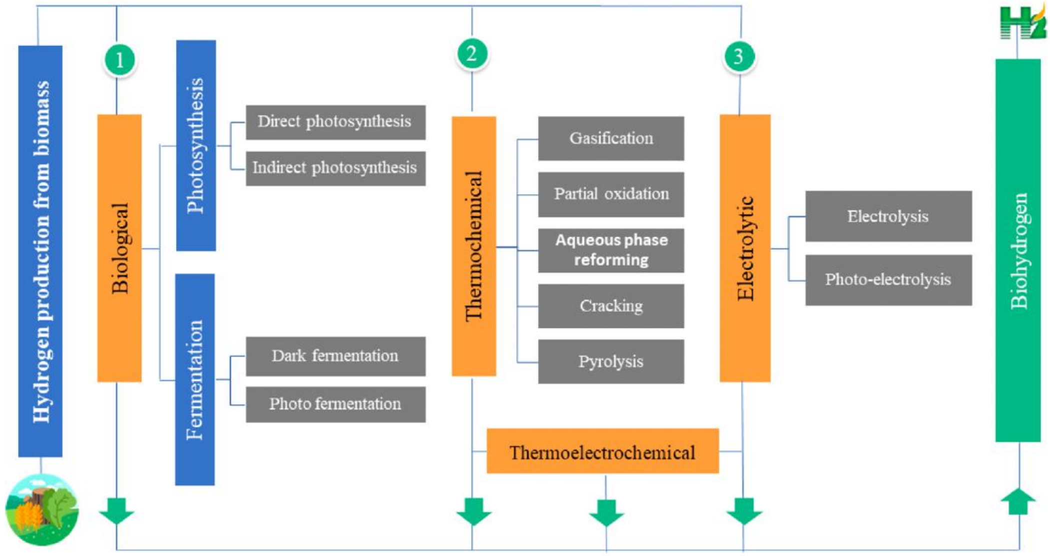

Figure 3: The main production routes for renewable hydrogen. [3]

The most advanced technologies for biohydrogen production are those of gasification and fermentation. Simplified diagrams for both process are depicted in Figures 4 and 5 respectively for the gasification and fermentation processes. Gasification is a complicated set of chemical reactions occurring in sequence or in parallel and they are either exothermic or endothermic and depending on the reactants they can be either heterogenous (e.g. when gaseous components react with the biomass cahr) or homogeneous (e.g. reactions between gases). It takes place at temperatures above 700°C and, under certain gasification operating conditions, at pressures above atmospheric.

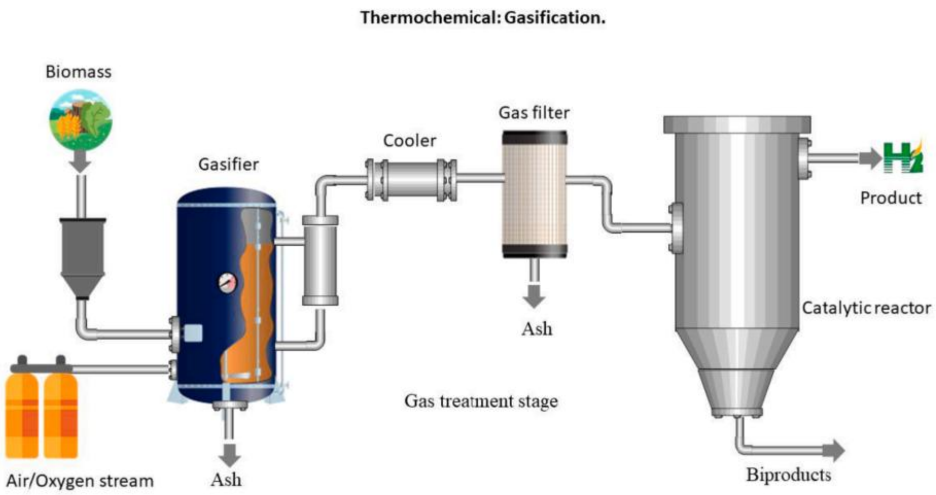

Figure 4: Simplified schematic of the biomass gasification. Process for biohydrogen. [4]

[3] M.G. Eloffy et al, Biomass to sustainable biohydrogen : Insights into the production routes and technical challenges, Chemical Engineering Journal Advances, 12 (2022)100410.
[4] M.G. Eloffy et al, Biomass to sustainable biohydrogen : Insights into the production routes and technical challenges, Chemical Engineering Journal Advances, 12 (2022)100410.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Fermentation processes to produce biohydrogen are divided into dark fermentation and photo-fermentation (photo fermentation requires light for the photosynthetic bacteria to employ solar energy to produce hydrogen from organic substrates). Fermentation takes place in the temperature region of 24-70 °C and atmospheric pressure.

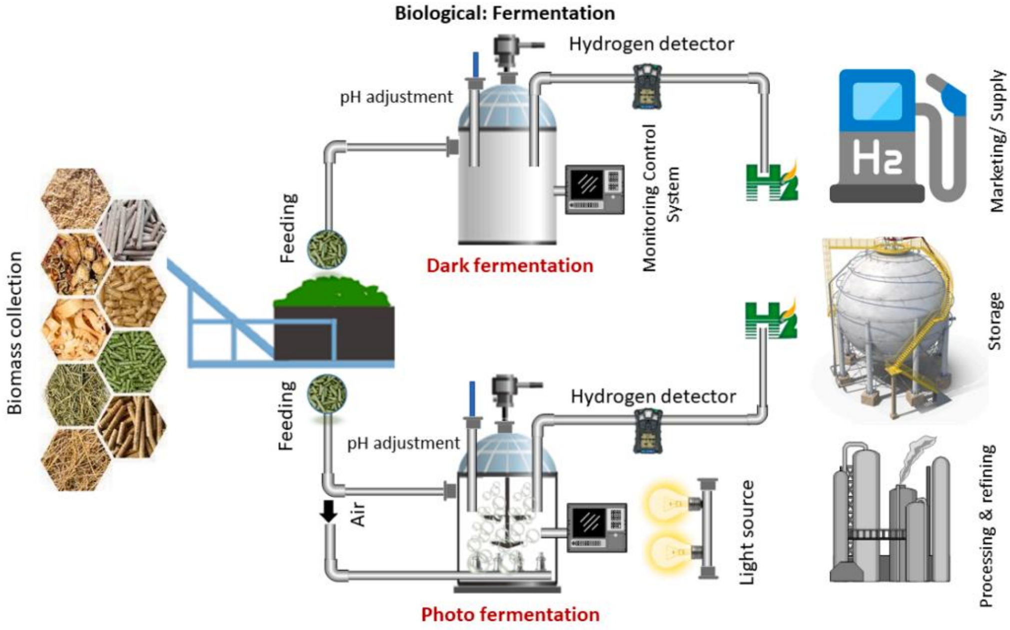

Figure 5: Simplified schematic of the biomass fermentation processes. [5]

The gasification technology is well developed and used in industrial applications; therefore, its Technology Readiness Level (TRL) is relatively high in the range of 8-9. Nevertheless, for hydrogen production from biomass gasification further optimization and testing is necessary and the TRL is lower (6-8). The other thermochemical technologies (such as pyrolysis) are a a lower TRL of 5-6. The fermentation and other biological technologies are emerging ones and thus their TRL level is lower than that of gasification, 3-5.

There are several other processes to convert biomass to biohydrogen, but a detailed description is out of the scope of this report (for further information see Ref 1 and 2).

2.3 Biohydrogen market applications and costs

Like most forms of hydrogen, biohydrogen has numerous applications in the circular economy as depicted in Figure 6; however, its main advantage is that biohydrogen, in contrast to the other forms of hydrogen, can be carbon negative if it is produced from resources such as waste streams, agricultural residues and manures, and, if combined with CCS. The carbon footprint of Grey hydrogen is 10-20 $kgCO_2/kg\ H_2$, that of Blue hydrogen 1.5-

[5] M.G. Eloffy et al, Biomass to sustainable biohydrogen : Insights into the production routes and technical challenges, Chemical Engineering Journal Advances, 12 (2022)100410.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

5 $kgCO_2/kg\ H_2$ while that of biohydrogen ranges from -26.5 $kgCO_2/kg\ H_2$ (when combined with CCS) to 10.8 $kgCO_2/kg\ H_2$ when produced from biomethane (Ref 2).

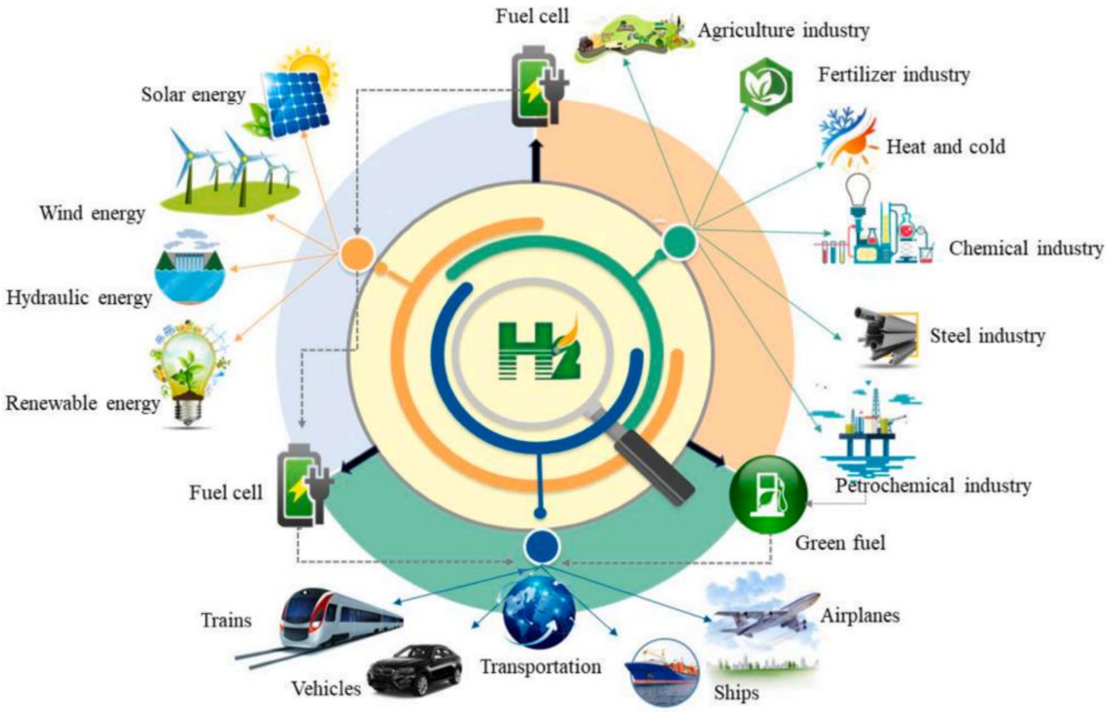

Figure 6: Biohydrogen applications in circular economy. [6]

The global demand of hydrogen is expected to grow exponentially in the coming years with the highest demand in the chemical industry[7], as indicated in Figure 7.

The green hydrogen demand is however expected to increase rapidly in the hard to abate sectors and energy storage.

Furthermore, it is expected that more that 70% of green hydrogen will be produced by electrolysis of renewable electricity thanks to reduced costs in renewable electricity production and electrolysis.

[6] M.G. Eloffy et al, Biomass to sustainable biohydrogen : Insights into the production routes and technical challenges, Chemical Engineering Journal Advances, 12 (2022)100410.
[7] IEA Bioenergy, Biomass gasification for hydrogen production, Task 33, February 2025.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

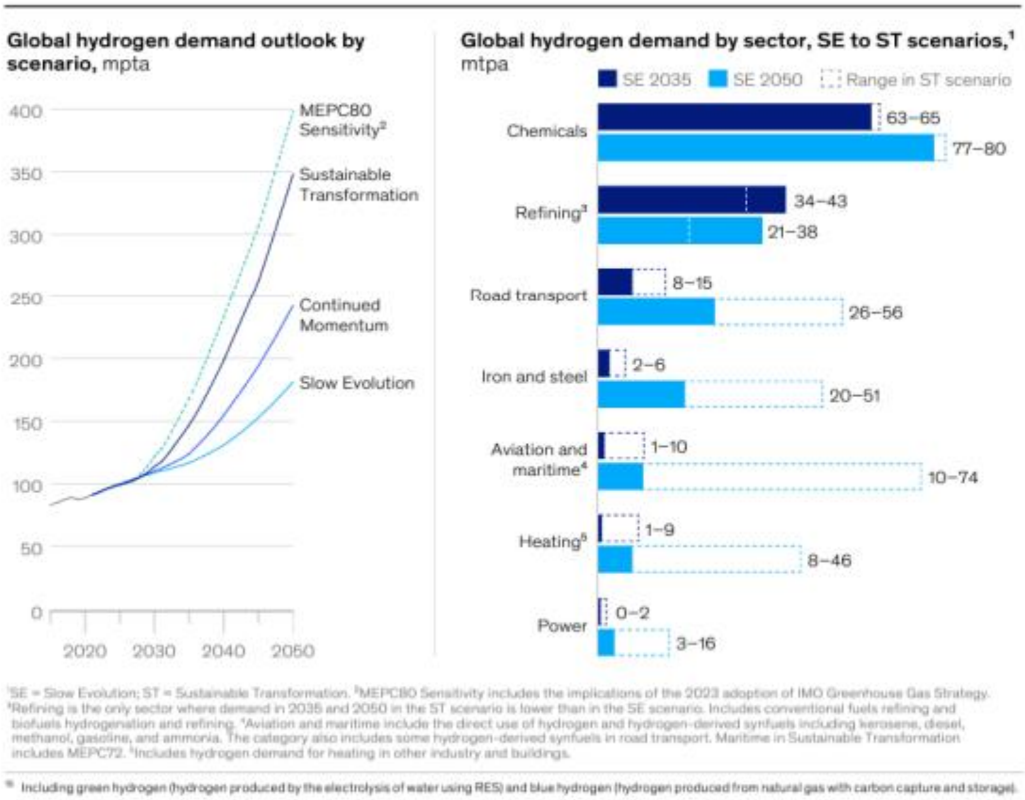

Figure 7: Global demand for hydrogen.

Biohydrogen offers some important advantages when compared to hydrogen produced from water electrolysis the most important of which is that its production is continuous and not intermittent as is that of hydrogen produced from renewable electricity from wind and solar It can be done at large industrial scale, with some important byproducts such as biochar, heat, electricity and a clean food quality CO_2 stream that offers negative emissions if stored in CCU applications.

Various studies[8,9,10] indicate that a reasonable cost for biohydrogen is in the range of 82 – 120 € per MWh or 2.7 – 4 € per kg hydrogen at a biomass price of 20 € per MWh. Although this can be considered a reasonable average cost for biohydrogen, more detailed studies and data from large scale demonstration or commercial plants are needed to verify the mentioned numbers.

---

[8] Ahlström JM. 2020. Renewable Hydrogen Production from Biomass, 2020. https://www.etipbioenergy.eu/images/Renewable_Hydrogen_Production_from_Biomass.pdf.

[9] Brown A., Waldheim L., Landälv I., Saddler J., Ebadian M., McMillan JD., Bonomi A., Klein B. 2020. Advanced Biofuels – Potential for Cost Reduction. IEA Bioenergy Task 41: 2020:01.

[10] International Energy Agency (IEA). 2024a. The Global Hydrogen Review 2024.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 3: Methodology for the identification of policy measures to promote biohydrogen

A specialized methodological approach has developed, which consists of five different steps (Figure 8), in order to achieve the objectives of the current deliverable.

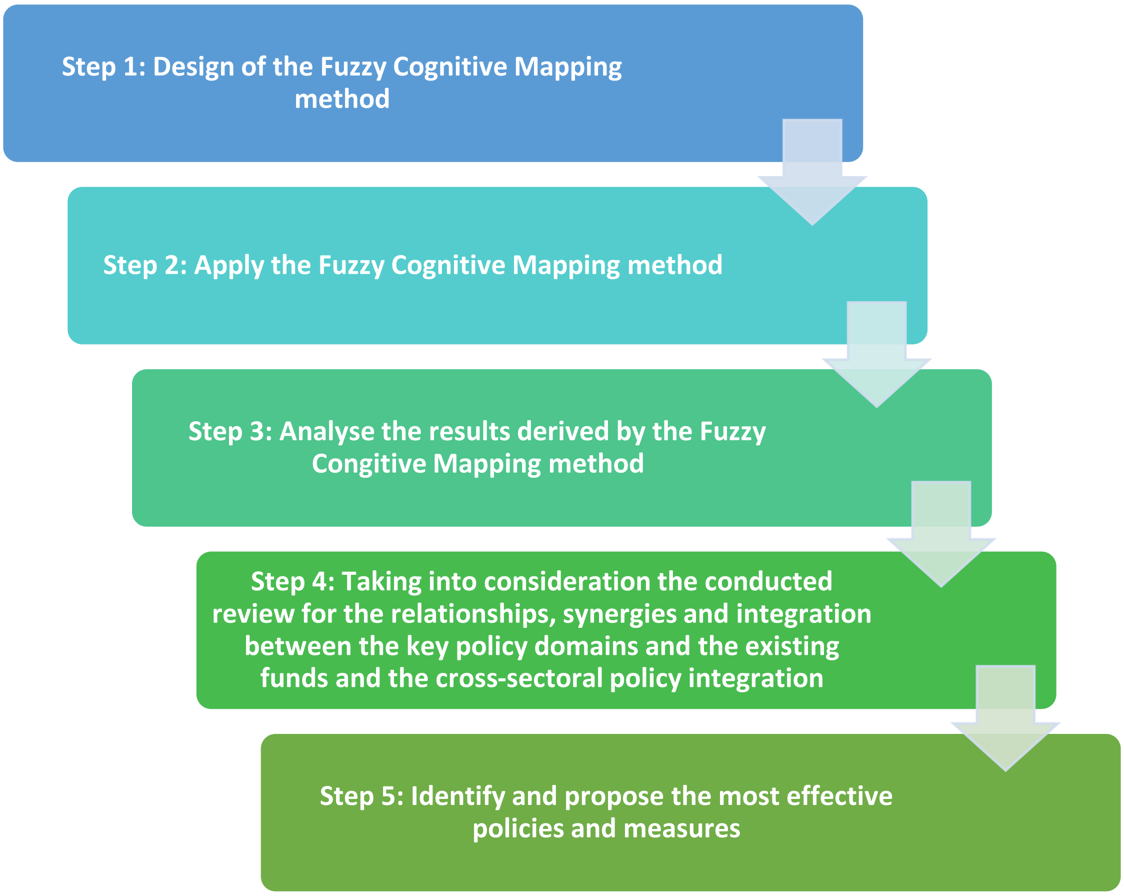

Figure 8: Applied methodological approach for identifying and proposing the most effective policies and measures in the target countries.

Firstly, the design of the Fuzzy Cognitive Mapping method was carried out (Step 1), which has been utilized for identifying the main policies and measures for the further deployment of biohydrogen.

The Fuzzy Cognitive Mapping method was applied in six out of the seven target countries (Step 2) based on the prepared guidelines for the implementation of the Fuzzy Cognitive Mapping (Annex I: Guidelines for the implementation of the Fuzzy Cognitive Mapping (FCM)) and the template for describing the performed activities for each interview separately (Annex II: Template for describing the performed activities for each interview separately).

It should be mentioned that the question, which was explored within the framework of the Fuzzy Cognitive Mapping method, focused on the most crucial parameters for the effective

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

penetration and utilization of biohydrogen in the examined countries. Obviously, the main risks and challenges are taken into consideration during the identification of the main parameters, while the proposed policies and measures will ensure that they will be addressed effectively and the main defined targets for the further penetration of biohydrogen will be achieved.

The obtained feedback from the interviews was analyzed (Step 3) so as to unveil the main parameters, which should be taken into consideration for the design and implementation of targeted and effective policies and measures.

Finally, the identification of the most effective policies and measures (Step 5) occurred taking into account the identified relationships, synergies and integration between key policy domains and existing funds and the perceived cross-sectoral policy integration of biomethane (Step 4).

The Fuzzy Cognitive Maps is considered as a powerful tool, which is based on neural networks, to solve complicated chains of casual relationships. The FCMs manage initially to depict the fuzzified relationships among nodes quantifying the degree of relationship between two specific concepts. Moreover, the FCMs construct a connection matrix and calculate the activation levels of the identified nodes as state vectors.

The construction of the FCMs is resulted by the collection of the various feedback from face-to-face interviews. The procedure for constructing the individual FCMs consists of various steps. More specifically, the various concepts, which are associated with the examined problem should be identified. Then, each interviewee assesses the causal relationship among the identified concepts with a qualitative scale, which has been determined. The utilized scores are then aggregated so as to estimate an overall qualitative weight, which is transformed into a numerical weight by utilizing the defuzzification method of the centre of gravity. It should be noted that all the specified weights are quantified from the previously transformed weights. Each produced weight provides information about the relationship between the two concepts and specifies the grade of causality between them.

The construction of the individual FCMs signals the respective construction of the collective FCMs. The procedure for resulting in the collective FCMs include the identification of the associated parameters with the examined problem, the classification of the individual parameters into groups, the determination of the causal relations and their strengths, the calculation of the strength of each link within the framework of the collective FCM, the presentation of the collective FCM and the conduction of various simulation runs for assessing the impact of each parameter separately.

The collective FCM is characterized from additional metrics, such as number of transmitters, the number of receivers and the number of the ordinary concepts. These concepts are characterized by their out-degree and in-degree. Out-degree provides an indication about how much a given concept affects the other concepts. In-degree depicts the cumulative strength of the identified concepts.

Furthermore, the complexity of the collective FCMs is analyzed taking into account the number of Receiver to Transmitter ratios (e.g. indicating more complex FCMs in the case of higher values of ratio), the Density (e.g. presenting how connected or sparse the FCMs are)

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

and the Centrality (e.g. displaying the overall interaction strength of each mentioned concept).

The analysis of the (available at: http://www.fcmappers.net/joomla/).

It should be noted that the outcomes of the implemented methodological approach were discussed with the involved stakeholders providing the opportunity to comment and complement the formulated policy recommendations within the context of the organized policy, market and policy hubs so as to take into consideration evolution of the performed work conducted by GreenMeUp project.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 4: Policy measures to promote biohydrogen in Czech Republic

Totally, ten stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 1 for the case of Czech Republic.

Table 1: Overview of the applied Fuzzy Cognitive Mapping in Czech Republic.

Individual maps	**10**
Number of variables	41
Number of connections	104
Number of transmitter variables	13
Number of receiver variables	4
Number of ordinary variables	24
Receiver to transmitter ratio	0.31
Density	0.062

According to the results of the FCM method in Czech Republic, the lack of investment and operational support, the problematic economics of operation, the high price of technology and the absence of legislative target for biohydrogen in combination with the insufficient legislation at EU and national level for the promotion of hydrogen create investment uncertainty for the further development of biohydrogen market.

The balance between supply and demand, the development of automotive industry and the improvement of the social acceptance are considered crucial prerequisites for the further exploitation of biohydrogen.

All the identified concepts are summarized in Table 9 of Annex III for the case of Czech Republic.

The proposed policies and measures are summarized in Figure 9 outlining the main aspects, which should be taken into consideration in Czech Republic.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Policy measure No1
- Designing pilot projects for the production and consumption of biohydrogen in order to acquire the required balance between supply and demand

Policy measure No2
- Introducing targeted financial support measures in order to implement projects for the production of biohydrogen

Policy measure No3
- Adopting the legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen

Policy measure No4
- Specifying ambitious targets for the promotion of biohydrogen

Policy measure No5
- Improving the social acceptance with the conduction of targeted awareness raising activities

Policy measure No6
- Spurring the industries to consume the produced biohydrogen

Figure 9: Proposed policies and measures in Czech Republic for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 5: Policy measures to promote biohydrogen in Danube region

Totally, three stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 2 for the case of Danube region.

Table 2: Overview of the applied Fuzzy Cognitive Mapping in Danube region.

Individual maps	**3**
Number of variables	10
Number of connections	45
Number of transmitter variables	0
Number of receiver variables	0
Number of ordinary variables	10
Receiver to transmitter ratio	0.00
Density	0.450

According to the results of the FCM method in Danube region, the most important factors consist of the establishment/integration of biohydrogen supply chains with RES, the promotion of public/private partnerships for biohydrogen infrastructure/projects and the development of financial tools and incentives for the further promotion of biohydrogen.

Moreover, the definition of ambitious targets for the promotion of biohydrogen and the design of targeted policies are considered highly significant parameters also.

Last but not least, the enhancement of the public awareness for the production of biohydrogen and the assessment of the available feedstock potential should be taken also into consideration.

All the identified concepts are summarized in Table 10 of Annex III for the case of Danube region.

The proposed policies and measures are summarized in Figure 10 outlining the main aspects, which should be taken into consideration in Danube region.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Policy measure No1
- Establishment of the supply chain for the collection of the required feedstocks to produce the biohydrogen

Policy measure No2
- Introducing targeted financial support measures in order to implement projects for the production of biohydrogen

Policy measure No3
- Fostering the implementation of public/private partnerships for the production of biohydrogen

Policy measure No4
- Specifying ambitious targets for the production of biohydrogen, which will be attained through the design of targeted policies and measures

Policy measure No5
- Improving the existing awareness levels for hydrogen

Policy measure No6
- Assessing the available feedstock potential for the production of biohydrogen

Figure 10: Proposed policies and measures in Danube region for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 6: Policy measures to promote biohydrogen in Estonia

Totally, nine stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 5 for the case of Estonia.

Table 3: Overview of the applied Fuzzy Cognitive Mapping in Estonia.

Individual maps	**9**
Number of variables	148
Number of connections	207
Number of transmitter variables	64
Number of receiver variables	17
Number of ordinary variables	66
Receiver to transmitter ratio	0.27
Density	0.009

According to the results of the FCM method in Estonia, the lack of investments for the production of hydrogen, the limited experience on hydrogen projects, the high production cost of hydrogen and the absence of legislative for the production and consumption of hydrogen are considered as the most essential barriers hindering the development of biohydrogen market.

Moreover, the high RES potential, the low awareness and readiness and the lack of a roadmap for the production of hydrogen are considered also as highly significant parameters during the design of policies and measures.

All the identified concepts are summarized in Table 11 of Annex III for the case of Estonia.

The proposed policies and measures are summarized in Figure 11 depicting the main aspects, which should be taken into consideration in Estonia.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

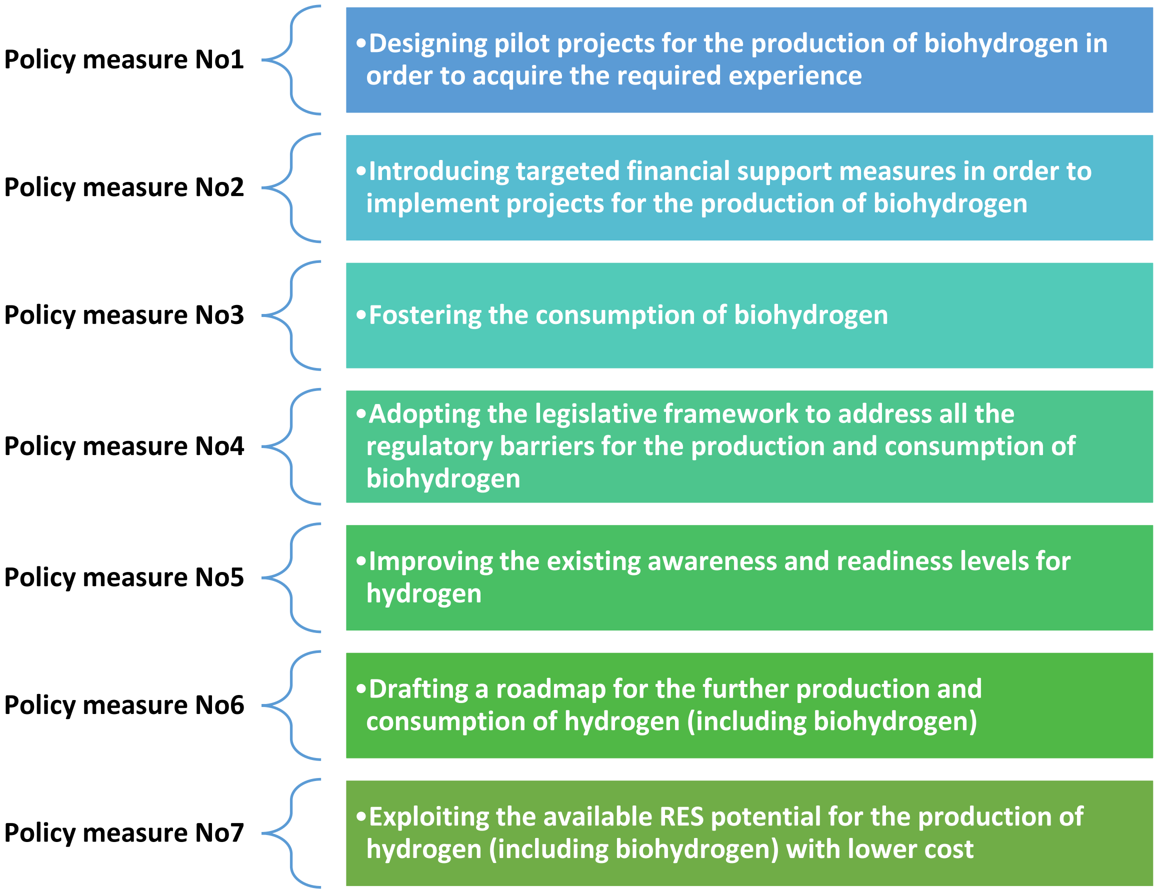

Figure 11: Proposed policies and measures in Estonia for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 7: Policy measures to promote biohydrogen in Greece

Totally, five stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 4 for the case of Greece.

Table 4: Overview of the applied Fuzzy Cognitive Mapping in Greece.

Individual maps	**5**
Number of variables	40
Number of connections	83
Number of transmitter variables	12
Number of receiver variables	1
Number of ordinary variables	27
Receiver to transmitter ratio	0.08
Density	0.052

According to the results of the FCM method in Greece, the preparation of a national strategy, the adoption of a legislative framework, the development of the biohydrogen market, the adoption of the regulatory and legislative framework, the provision of financial support, the availability and collection of raw materials along with the availability of the technologies can be characterized as the most important parameters for the promotion of biohydrogen.

It should be noted that the need to promote decentralized biohydrogen production systems and to improve the social acceptance must be taken into consideration during the design of policies and measures.

All the identified concepts are summarized in Table 12 of Annex III for the case of Greece.

The proposed policies and measures are summarized in Figure 12 depicting the main aspects, which should be taken into consideration in Greece.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

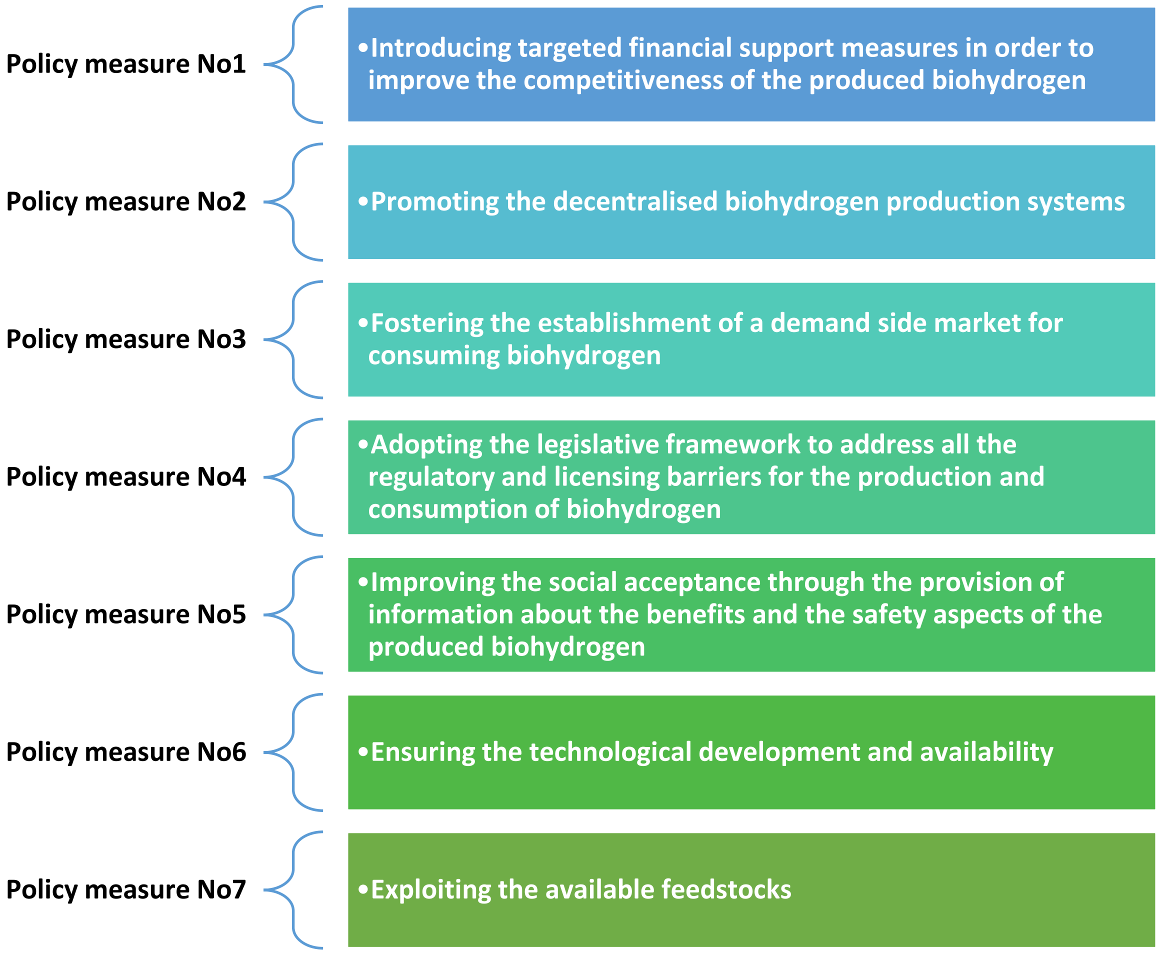

Figure 12: Proposed policies and measures in Greece for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 8: Policy measures to promote biohydrogen in Poland

Totally, five stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 5 for the case of Poland.

Table 5: Overview of the applied Fuzzy Cognitive Mapping in Poland.

Individual maps	**5**
Number of variables	15
Number of connections	50
Number of transmitter variables	2
Number of receiver variables	0
Number of ordinary variables	13
Receiver to transmitter ratio	0.00
Density	0.222

According to the results of the FCM method in Poland, the high hydrogen vehicle cost, the high hydrogen fuel cost and the various safety issues with the utilization of hydrogen should be addressed. Moreover, the provision of market incentives to promote hydrogen, the enhancement of the hydrogen demand, the technological availability and the provision of information about are of paramount importance.

All the identified concepts are summarized in Table 13 of Annex III for the case of Poland.

The proposed policies and measures are summarized in Figure 13 summarizing the main aspects, which should be taken into consideration in Poland.

Policy measure No1
- **Introducing targeted financial support measures to reduce the high costs (e.g., hydrogen vehicles, hydrogen fuel, technological cost)**

Policy measure No2
- **Fostering the hydrogen demand with targeted market incentives**

Policy measure No3
- **Providing information to the consumers about the benefits and the safety aspects of the produced biohydrogen**

Policy measure No4
- **Ensuring the technological development and availability**

Policy measure No5
- **Exploiting the natural gas distribution network to facilitate the consumption of the biohydrogen**

Figure 13: Proposed policies and measures in Poland for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 9: Policy measures to promote biohydrogen in Spain

Totally, eleven stakeholders participated in the application of the FCM analysis. The main results of the FCM method are presented in Table 6 for the case of Spain.

Table 6: Overview of the applied Fuzzy Cognitive Mapping in Spain.

Individual maps	**11**
Number of variables	11
Number of connections	20
Number of transmitter variables	2
Number of receiver variables	2
Number of ordinary variables	7
Receiver to transmitter ratio	1.00
Density	0.165

According to the results of the FCM method in Spain, the public-private collaboration is essential to promote biohydrogen. It is crucial that both private and public sectors recognize technology's importance and the importance of the establishment of targets for their integration into the energy system. Collaboration between public administration and private enterprises implies legal certainty.

Moreover, measures to address the regulatory uncertainty and to support economically the planned investments should be initiated. It is essential to establish a regulatory framework and direction for the sector's development. Administrative barriers discourage investors and large-scale project developers. It is crucial to implement a system of financial aid to foster the growth of an "emerging" sector that must undertake entirely new initial investments and cannot compete with established conventional sectors.

Finally, the contribution of biohydrogen to the energy security and the confrontation of the technological risks should be taken into consideration. Biohydrogen is an emerging energy carrier with significant potential for use in transportation, industry, and the chemical sector as an alternative fuel, offering clear benefits for decarbonization and energy security. Biohydrogen is a promising emerging energy vector with wide-ranging applications in transportation, industry, and the chemical sector. As an alternative fuel, it plays a key role in advancing decarbonization and enhancing energy security.

All the identified concepts are summarized in Table 14 of Annex III for the case of Spain.

The proposed policies and measures are summarized in Figure 14 outlining the main aspects, which should be taken into consideration in Spain.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Policy measure No1
- Introducing targeted financial support measures in order to confront mainly the high investment cost for producing the biohydrogen

Policy measure No2
- Fostering the public-private collaboration through a structured and coherent framework leading to sufficient market competition

Policy measure No3
- Adopting the legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen

Policy measure No4
- Ensuring the technological development and availability with the confrontation of the technological risks related to biohydrogen

Policy measure No5
- Revising the vision for the evolution of the energy sector based on the energy security and the diversified energy mix

Figure 14: Proposed policies and measures in Spain for the promotion of biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Chapter 10: Conclusions

The demand for biohydrogen is expected to grow exponentially in the near future offering advantages compared to water electrolysis with renewable electricity.

The main production technologies are biomass gasification and dark fermentation with the former being in TRL 6-8 while the later has a TRL 3-5.

The average costs of biohydrogen is estimated in the range of 2.7 – 4 € per kg hydrogen.

Totally, 43 stakeholders participated into the application of the FCM in the six target countries identifying 265 concepts, which are related to the further penetration of biohydrogen.

A synopsis of the main outcomes of the FCM in the seven target countries is presented in Table 7.

The analysis of the numerous maps led to identification of the most effective policies and measures in the examined target countries.

Table 7: Overview of the applied Fuzzy Cognitive Mapping in the target countries.

Individual maps	**68**
Number of variables	265
Number of connections	509
Number of transmitter variables	93
Number of receiver variables	24
Number of ordinary variables	147

The identified policies and measures are displayed in Table 8. It should be noted that the 36 proposed policies and measures are characterized by both considerable similarities and differences demonstrating that both the main national conditions and priorities have been taken into consideration during the applied co-designed approach within the framework of the GreenMeUp project.

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 8: Overview of the proposed policies and measures for the promotion of biohydrogen in the target countries.

Czech Republic	Danube Region	Estonia	Greece	Poland	Spain
PM1: Designing pilot projects for the production and consumption of biohydrogen in order to acquire the required balance between supply and demand **PM2**: Introducing targeted financial support measures in order to implement projects for the production of biohydrogen **PM3**: Adopting the legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen **PM4**: Specifying ambitious targets for the promotion of biohydrogen	**PM1**: Establishment of the supply chain for the collection of the required feedstocks to produce the biohydrogen **PM2**: Introducing targeted financial support measures in order to implement projects for the production of biohydrogen **PM3**: Fostering the implementation of public/private partnerships for the production of biohydrogen **PM4**: Specifying ambitious targets for the production of biohydrogen, which will be attained through the design of targeted policies and measures	**PM1**: Designing pilot projects for the production of biohydrogen in order to acquire the required experience **PM2**: Introducing targeted financial support measures in order to implement projects for the production of biohydrogen **PM3**: Fostering the consumption of biohydrogen **PM4**: Adopting the legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen **PM5**: Improving the existing awareness and readiness levels for hydrogen	**PM1**: Introducing targeted financial support measures in order to improve the competitiveness of the produced biohydrogen **PM2**: Promoting the decentralised biohydrogen production systems **PM3**: Fostering the establishment of a demand side market for consuming biohydrogen **PM4**: Adopting the legislative framework to address all the regulatory and licensing barriers for the production and consumption of biohydrogen **PM5**: Improving the social acceptance through the provision of information about the benefits and the safety	**PM1**: Introducing targeted financial support measures to reduce the high costs (e.g., hydrogen vehicles, hydrogen fuel, technological cost) **PM2**: Fostering the hydrogen demand with targeted market incentives **PM3**: Providing information to the consumers about the benefits and the safety aspects of the produced biohydrogen **PM4**: Ensuring the technological development and availability **PM5**: Exploiting the natural gas distribution network to facilitate the consumption of the biohydrogen	**PM1**: Introducing targeted financial support measures in order to confront mainly the high investment cost for producing the biohydrogen **PM2**: Fostering the public-private collaboration through a structured and coherent framework leading to sufficient market competition **PM3**: Adopting the legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen **PM4**: Ensuring the technological development and availability with the confrontation of the

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Czech Republic	Danube Region	Estonia	Greece	Poland	Spain
PM5: Improving the social acceptance with the conduction of targeted awareness raising activities **PM6**: Spurring the industries to consume the produced biohydrogen	**PM5**: Improving the existing awareness levels for hydrogen **PM6**: Assessing the available feedstock potential for the production of biohydrogen	**PM6**: Drafting a roadmap for the further production and consumption of hydrogen (including biohydrogen) **PM7**: Exploiting the available RES potential for the production of hydrogen (including biohydrogen) with lower cost	aspects of the produced biohydrogen **PM6**: Ensuring the technological development and availability **PM7**: Exploiting the available feedstocks		technological risks related to biohydrogen **PM5**: Revising the vision for the evolution of the energy sector based on the energy security and the diversified energy mix

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

The provision of economic incentives to produce biohydrogen is considered as a prerequisite for all the target countries. The assessment of the available feedstock potential for the production of biohydrogen and the adoption of the required legislative framework to address all the regulatory barriers for the production and consumption of biohydrogen should be implemented for the vast majority of the examined target countries as supplementary measures.

The design of pilot projects for the production and consumption of biohydrogen and the provision of incentives to accelerate the consumption of biohydrogen should be initiated in order to acquire the required balance between supply and demand.

Last but not least, the conduction of targeted awareness raising activities is essential so as to both improve the social acceptance and to reinforce the existing level of knowledge of all the involved stakeholders.

It should be noted that policy market uptake measures should be launched at EU level in order to ensure the technological availability and to reinforce the commercialization of the produced biohydrogen.

An initial combination of policy market uptake measures at EU level is presented in Figure 15 ensuring the smooth penetration of biohydrogen.

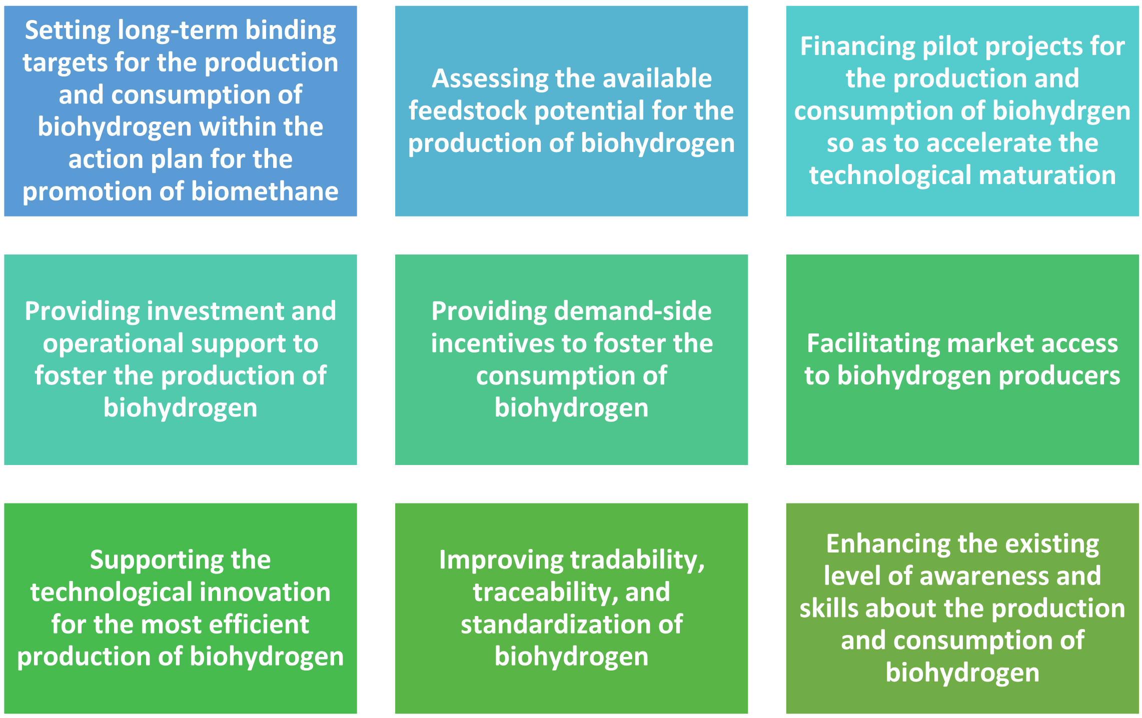

Figure 15: Proposed policy market uptake measures at EU level to promote biohydrogen.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Annex I: Guidelines for the implementation of the Fuzzy Cognitive Mapping (FCM)

I. Conduct the required preparatory activities

Please organize the interviews, which have to be carried out for the implementation of the FCM.

At least ten interviews should be conducted with the most important stakeholders.

Ideally, three stakeholders from each of the different category of stakeholders (namely decision makers, market and society) have to participate into the planned interviews.

The foreseen work should be implemented for the seven target countries (e.g., Czech, Danube region, Estonia, Greece, Latvia, Spain and Poland).

II. Formulate the question

Firstly, present very briefly the main objective of the interviews, which is to identify the most important design aspects for achieving the design and implementation of the required market uptake measures for the further penetration of the biohydrogen.

Then, please make the following question:

- ***What are the most important enabling factors for the market uptake for the further penetration of biohydrogen in your country?***

It is recommended to mention indicative key words (such as the provision of investment and operational subsidies, the establishment of the required supply chain, the selection of the most effective technology etc.)

III. Draw the main factors

Please display all the factors into a sheet as identified by the interviewee.

Please ask from the interviewee to elaborate about the reasons for selecting them.

It is recommended to mention potential factors without affecting his judge.

IV. Connect the identified factors

Please connect with an arrow the identified factors, which are affected. It should be noted that the line ⟶ indicates that the one factor affects the other one, while the line ⟷ indicates that a mutual interaction exists between the identified factors.

V. Quantify the influence of each connection

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Please quantify the influence of each connection with the following Likert scale:

- -5 negatively very strong connection
- -4 negatively strong connection
- -3 negatively medium connection
- -2 negatively weak connection
- -1 negatively very weak connection
- 1 positively very weak connection
- 2 positively weak connection
- 3 positively medium connection
- 4 positively strong connection
- 5 positively very strong connection

VI. Complete interview protocol

Please complete the template, which is presented in Annex, for each interview separately in order to summaries the performed activities.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Annex II: Template for describing the performed activities for each interview separately

i. Information about the interview

Please provide information about the conducted interview such as:

- Place
- Date
- Name of the interviewee
- Position of the interviewee
- Other

ii. Identified factors

Please elaborate briefly about the main rationale, which led the interviewee to the selection of the factors.

iii. Relationships among the identified factors

Please document briefly the reasons for the specified direction of the arrows among the identified factors.

iv. Influence of the identified relationships

Please document briefly the reasons for the specified strength of influence of the arrows among the identified factors.

v. Fuzzy Cognitive Map

Please insert the developed Fuzzy Cognitive Map as resulted by the previous steps.

vi. Areas of improvement

Please mention briefly potential difficulties, which have been confronted during the conduction of the interview.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Annex III: Identified concepts by the conduction of the Fuzzy Cognitive Mapping (FCM) in the examined target countries

Table 9: Results of the applied Fuzzy Cognitive Mapping in Czech Republic.

Concepts	Centrality	Outdegree	Indegree
Development of biohydrogen	1.36	0.34	1.02
Lack of investment and operational support	0.78	0.46	0.32
Problematic economics of operation	0.76	0.30	0.46
High price of technology	0.76	0.14	0.62
No legislative target for bio-hydrogen (targets are only for non-biological hydrogen)	0.72	0.36	0.36
Supply and demand	0.64	0.20	0.44
Biohydrogen cannot meet the targets (they are on the RNFBO)	0.64	0.36	0.28
Preparing low-carbon targets	0.62	0.50	0.12
Insufficient legislation at EU and national level for H_2	0.58	0.40	0.18
Development of the automotive industry, greater use of hydrogen	0.56	0.30	0.26
Hydrogen is an interesting and desirable energy fuel of the future	0.50	0.28	0.22
Financial support, subsidies	0.48	0.24	0.24
Social acceptance, PR, social discussions	0.42	0.22	0.20
Available technologies for the production of biohydrogen from methane and biogas	0.36	0.04	0.32
EU hydrogen legislative framework has major gaps for biohydrogen	0.32	0.20	0.12
High demand for renewables	0.32	0.06	0.26
Research and technology development	0.32	0.32	0.00
Complicated chemical and physical properties and difficult transport	0.30	0.30	0.00
Economics of operation and demand for biohydrogen	0.30	0.00	0.30
Biohydrogen policy framework	0.30	0.12	0.18
Demand in relation to emission reductions	0.26	0.26	0.00
High energy consumption for production and low price competitiveness	0.24	0.16	0.08
Possible future adoption of biohydrogen as RNFBO or low carbon fuel	0.24	0.24	0.00
Low clearance of biotic production with respect to unaccountable hydrogen targets	0.22	0.00	0.22
Great potential for transport (either batteries or hydrogen in the future)	0.22	0.06	0.16
Media space in educational institutions	0.16	0.10	0.06
Inadequate hydrogen transport infrastructure	0.16	0.04	0.12
Physicochemical properties, energy carrier	0.16	0.16	0.00
Low social awareness of biohydrogen, lack of information	0.14	0.08	0.06

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
Lack of feedstock (biomethane)	0.12	0.06	0.06
Development of new hydrogen technologies (e.g. the new JCB hydrogen combustion engine)	0.10	0.10	0.00
Large number of biogas stations and potential biomethane stations	0.10	0.10	0.00
High cost of transporting biohydrogen	0.08	0.00	0.08
In terms of legislation, biohydrogen is considered as one of the gases for energy recovery	0.08	0.04	0.04
Hydrogen from renewable sources is relatively expensive	0.06	0.00	0.06
Not a one-size-fits-all solution for biogas plants	0.06	0.06	0.00
Objectives of replacing grey hydrogen with renewable hydrogen	0.06	0.06	0.00
Rural development	0.06	0.06	0.00
Efforts to green companies with renewable energies including hydrogen	0.04	0.04	0.00
Partial counting of biohydrogen towards RED targets	0.04	0.04	0.00
Technological barriers, hydrogen transport	0.04	0.04	0.00

Table 10: Results of the applied Fuzzy Cognitive Mapping in Danube region.

Concepts	Centrality	Outdegree	Indegree
Establishment/integration of biohydrogen supply chains with RES	5.53	1.93	3.60
Public/private partnerships for biohydrogen infrastructure/projects	5.40	2.60	2.80
Financial tools & incentives for biohydrogen promotion/adoption	5.00	2.47	2.53
Development & assessment of biohydrogen policies and strategies	4.73	2.20	2.53
Definition of national biohydrogen production targets aligned with EU Green Deal	4.67	2.27	2.40
Public awareness of biohydrogen contribution to achieving climate targets	4.00	2.00	2.00
Regional feedstock mapping/utilisation for biohydrogen production	3.33	2.13	1.20
Analyses of biohydrogen's market potential	2.13	1.47	0.67
Establishment of appropriate technology - competitive use of feedstock	1.87	1.07	0.80
Technology maturity	1.07	0.73	0.33

Table 11: Results of the applied Fuzzy Cognitive Mapping in Estonia.

Concepts	Centrality	Outdegree	Indegree
No investments in the development of H_2 projects	1.67	0.07	1.60
H_2 expensive price	1.36	0.69	0.67
No experience and practice	1.13	0.22	0.91

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
Renewable energy potential exists	1.11	0.67	0.44
Low H_2 consumption	1.04	0.87	0.18
The price of electricity in Estonia is rather high	1.04	0.40	0.64
No legislation for H_2	0.87	0.69	0.18
H_2 awareness and readiness are low	0.69	0.33	0.36
General H_2 development is in its early stages	0.64	0.07	0.58
H_2 Road map	0.64	0.22	0.42
Offshore wind farms have not been developed for 10 years	0.60	0.22	0.38
The long-term income expectation of offshore wind farms is too high for H_2 production	0.58	0.00	0.58
The majority of the biohydrogen value chain should remain in Estonia	0.56	0.09	0.47
Strong education & research structure	0.53	0.38	0.16
Estonian H_2 potential is not used	0.53	0.00	0.53
The total cost of the ownership of H_2 production is too high	0.49	0.20	0.29
There is no trained and qualified workforce for H_2 production	0.49	0.22	0.27
Development of the H_2 field was stalled for a long time, was on hold	0.49	0.00	0.49
Regulatory ambiguity, who is responsible for the operation and risks of the entire [H_2 value] chain, lack of central certainty	0.44	0.27	0.18
Legislative target to be CO_2 neutral by 2040	0.44	0.07	0.38
First national Hydrogen Valley	0.42	0.04	0.38
Low awareness of H_2	0.40	0.09	0.31
Support the development of H_2 technology (application study, 4 pilot production-consumption project investment support)	0.38	0.38	0.00
H_2 production is promoted by wind abundance, promotes the establishment of land and offshore wind farms evenly across the country	0.38	0.18	0.20
H_2 storage requires infrastructure that would also enable export, which would make H_2 economically reasonable	0.38	0.09	0.29
Large-scale H_2 production and consumption should be in 1 place, especially in the first stage of development, when there is no international H_2 HUB	0.36	0.18	0.18
The reception capacity of wind electricity on the mainland is limited by the reception capacity of existing networks [there is too much wind power for existing networks]	0.36	0.18	0.18
The volatility of [EU and Estonian renewable energy] policies is an obstacle	0.31	0.31	0.00
Offshore and onshore wind[i.e. electricity production] are not balanced	0.31	0.07	0.24

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
H_2 infrastructure increases local production and consumption, including security of supply, also large-scale consumption	0.31	0.07	0.24
Policies change back and forth [very quickly], one time the green revolution is a priority, then it is no longer	0.31	0.20	0.11
Combined wind and PV parks have potential	0.31	0.04	0.27
Electricity, natural gas, H_2 and bioCH4 need a joint development plan by 2027 at the latest	0.31	0.11	0.20
H_2 technology is developing on its own	0.29	0.29	0.00
Hydrogen falls under the jurisdiction of 4 ministries	0.29	0.18	0.11
It is not possible to install renewable energy production equipment (wind turbines, PV panels) near H_2 consumption points	0.29	0.20	0.09
H_2 HUB investment is hindered if the HUB itself has no production or consumption	0.29	0.09	0.20
Ensuring the safety of H_2 is a challenge	0.29	0.04	0.24
H_2 infrastructure is missing in transport	0.29	0.11	0.18
At the national level, it is dangerous to make empty promises, overestimating or underestimating the actual usable resource volume of H_2 or biohydrogen	0.27	0.18	0.09
Eastern Estonia has been historically chemical industry and oil shale mining area, which can be converted to the renewable energy production	0.27	0.09	0.18
H_2 production, storage and consumption have been combined	0.27	0.04	0.22
Strong network of H_2 technology companies, ecosystem, cooperation is flourishing, exchange of experiences	0.24	0.16	0.09
Green H_2 is rather good renewable energy source and internador	0.24	0.18	0.07
The heating industry is also integrated into a unified energy system	0.24	0.09	0.16
biohydrogen helps to meet the climate goals	0.24	0.11	0.13
EEsti Energia has a plan to produce 100,000 t in 2040	0.22	0.13	0.09
Natural H2 reserves are large, can bring down the price and be a game changer, promote the development of the field	0.22	0.22	0.00
New business model for H_2, which would ensure that the electricity price of offshore wind is sufficient for H_2 production	0.22	0.22	0.00
H_2 objectives are included into the draft Act of the Climate Resilient Economy	0.22	0.00	0.22
Development of green fuels and projects already underway	0.20	0.07	0.13
No H_2 production	0.20	0.07	0.13
H_2 production subsidies are necessary	0.20	0.20	0.00
Regulations support H_2	0.20	0.20	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
The H_2 cluster 5a project assesses H_2 danger zones within the framework of its project	0.20	0.20	0.00
The price of H_2 production must be favorable all the time	0.20	0.09	0.11
A lot of negative renewable energy sentiment has been heated up in society	0.20	0.11	0.09
H_2 consumption limited locally	0.20	0.11	0.09
Definition of green H_2 has now been agreed upon by the EU	0.18	0.18	0.00
Definition of renewable energy is constantly changing, vagueness of renewable energy legislation	0.18	0.18	0.00
H_2 will be in Elering [TSO] from 2030 onwards]	0.18	0.18	0.00
Strong local concentration of green hydrogen technology companies	0.18	0.18	0.00
Distributed H_2 production is an international business, transport H_2 as gas, not electricity	0.18	0.07	0.11
H_2 storage an important raw material for the chemical industry	0.18	0.07	0.11
People are against wind farms – out of ignorance	0.18	0.09	0.09
Small-scale consumption of H_2 at H_2 filling stations, local production, local consumption, profitability depends on the price of electricity	0.18	0.09	0.09
The country's renewable energy strategies have not reflected the full potential of offshore wind	0.18	0.09	0.09
Standard H_2 storage [with an electrolyzer?} is 24 h, which will happen if there is wind in the entire region for several days in a row	0.18	0.11	0.07
It is difficult to implement H_2 projects	0.18	0.00	0.18
Expensive purchase price of H_2 vehicles	0.18	0.00	0.18
Estonia lacks a long-term view of the HA field, which can move on from 4 pilot business models if they are not scalable or replicable	0.16	0.16	0.00
The development of technology (H_2 vehicles) is in its early stages	0.16	0.16	0.00
Financing a separate H_2 business entity is questionable in a situation where there is no real H_2 market yet	0.16	0.07	0.09
No priority to use H_2 for heating	0.16	0.07	0.09
H_2 is difficult to store, (we don't have salt caves ourselves)	0.16	0.09	0.07
Lack of (green) H_2 infrastructure	0.16	0.09	0.07
Onshore wind farm owners claim offshore wind farms are not needed	0.16	0.09	0.07
Transport value chains for H_2 consumption exist	0.16	0.11	0.04
Need to ensure energy security	0.16	0.00	0.16
No large-scale industry using H_2 in Estonia, i.e. there are no large consumers	0.16	0.00	0.16
Goals arising from REDII & REDIII	0.13	0.13	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
The driving range of H_2 cars varies depending on conditions	0.13	0.13	0.00
The role of H_2 is greater in sectors that are difficult to decarbonise	0.13	0.13	0.00
RES price	0.13	0.07	0.07
Retrofit Hub and related synergies and major opportunities, especially in maritime	0.13	0.07	0.07
Risks of being the first to move in Estonia, compared to the rest of the world we are relatively laggards – Estonian companies must find their competitive advantage	0.13	0.07	0.07
A sufficient amount of renewable energy and a sufficiently cheap price is a prerequisite for the production of green H_2	0.13	0.09	0.04
Regional specifics – security threat to gas infrastructure both on land and at (under)sea due to an aggressive eastern neighbor	0.13	0.09	0.04
H_2 transit, due to the small size of its market, Estonia will remain only a transit country with a pipe passing through H_2	0.13	0.00	0.13
Unused H_2 potential	0.13	0.00	0.13
Availability of favorable renewable electricity, without it, H_2 production is not competitive	0.11	0.09	0.02
State, government and their owned TSO should have a larger picture	0.11	0.04	0.07
Climate goals are to launch large renewable energy projects (H_2, biohydrogen, biomethanol, etc)	0.11	0.11	0.00
EIC 4 pilot investment support for H_2 business models	0.11	0.11	0.00
Estonian location close to aggressor countries is risk [for investors]	0.11	0.11	0.00
H_2 infrastructure grants	0.11	0.11	0.00
H_2 national development targets are adopted in long term energy plan	0.11	0.11	0.00
H_2 production is questionable	0.11	0.11	0.00
Important is fair access to the innovation	0.11	0.11	0.00
It is cheaper to capture CO_2 directly than to use green hydrogen in transportation	0.11	0.11	0.00
Lack of clear expectations of the network operator's owner	0.11	0.11	0.00
The method of transporting hydrogen from the producer to the consumer has not been decided – by pipeline, compressed or otherwise	0.11	0.11	0.00
There is no principle of regional equity for EU innovation funds	0.11	0.11	0.00
Unclear goals and ambitions weakening investment certainty	0.11	0.11	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
As producers of H_2 technology, we have to re-do the entire risk analysis after every technological change, which is expensive, tedious and time-consuming for us	0.11	0.00	0.11
one H_2 filling station makes H_2 price expensive 15 eur/kg	0.11	0.00	0.11
People do not come to TSOs to ask for H_2 for industrial consumption	0.11	0.00	0.11
A tiny internal market and a peripheral region in European terms	0.09	0.09	0.00
Assess the H_2 potential of the entire Baltic region together to make it more attractive for investments	0.09	0.09	0.00
Cooperation between H_2 promotional [civil] organizations works	0.09	0.09	0.00
Grey H_2 production requires green light for EC as transitional technology/fuel and enough time for technology development	0.09	0.09	0.00
H_2 could cover peak capacities in 2040, but profitability is unknown, neither the price of H_2 nor electricity, nor the competitiveness of H_2 in this situation	0.09	0.09	0.00
H_2 production electrolyzers should be placed right next to offshore wind turbines [inside masts]	0.09	0.09	0.00
International crises virus, Ukraine War of Independence, supply crisis	0.09	0.09	0.00
Lack of OPEX support for the deployment of green hydrogen	0.09	0.09	0.00
Local H_2 storage does not work	0.09	0.09	0.00
Low labor productivity in the EU, incl. Estonia [compared to the US]	0.09	0.09	0.00
Need to raise awareness about H_2	0.09	0.09	0.00
Offshore wind farm, transmission as electricity or gas, is undecided today, depends on who is where and to what extent consumer, before the H_2 hub is ready, H_2 transport via pipeline is also not relevant	0.09	0.09	0.00
Often outdated views or approaches	0.09	0.09	0.00
The bureaucracy and complexity of subsidies make applying for support difficult	0.09	0.09	0.00
The current 4 EIC green hydrogen investment subsidies are "fixed" and not scalable or replicable	0.09	0.09	0.00
The entire H_2 supply chain is divided between several legal entities [TSO may not own production or consumption, who bears the risks in this case]	0.09	0.09	0.00
The EU tax system does not favor renewable energy, incl. H_2 [development]	0.09	0.09	0.00
H_2 technology is developing rapidly but is still in its early stages	0.09	0.04	0.04
Large-scale H_2 production should be done in Paldiski, Pärnu and Narva or on the islands	0.09	0.00	0.09
Experience in the development of H_2 technologies	0.07	0.07	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Concepts	Centrality	Outdegree	Indegree
H_2 consuming industry should be established where H_2 is produced, so that we don't have to transport H_2 from Paldiski to Narva, generate electricity there and then transport electricity back from Narva to Paldiski	0.07	0.07	0.00
H_2 is a business of both large and small scale, the smallest are 1-2, 50-100 kW capacity	0.07	0.07	0.00
H_2 standards are being translated and adopted in national system (EVS)	0.07	0.07	0.00
In the USA there is strict control over investment subsidies for H_2 production	0.07	0.07	0.00
Large-scale H_2 transmission in pipelines is at too early a stage	0.07	0.07	0.00
No previous hydrogen-using industry	0.07	0.07	0.00
Not sure how big is the actual potential of the natural H_2	0.07	0.07	0.00
Part of Estonia may be more of an H_2 transit country, if H_2 transport connections are built and financed as a pan-European project and with EU subsidies	0.07	0.07	0.00
The scientific basis of H_2 is incomplete, slogans are uttered without sufficient [substantive] knowledge	0.07	0.07	0.00
The Ukrainian War of Independence has a negative impact on the development of the [energy] infrastructure of the Baltic Sea	0.07	0.07	0.00
Weakness in attracting support and a generally weak level of funding	0.07	0.07	0.00
Patent attorney has helped formalize patents	0.07	0.00	0.07
When building an H_2 filling station, it is important to know who will be filling up (700 vs. 350 bar) for cars and trucks respectively	0.07	0.00	0.07
Elering (TSO) has started developing H_2 infrastructure, but for this, a separate business entity must be created according to the EU directive	0.04	0.04	0.00
H_2 indicators are not fully developed	0.04	0.04	0.00
H_2 injection into the natural gas pipeline is not possible above 2%, because the pipes are in places depreciated and are not resistant to hydrogen leakage	0.04	0.04	0.00
Little interest in international cooperation in this area	0.04	0.04	0.00
Is there enough wind power to make it worth investing in H_2 production?	0.04	0.00	0.04
Local production of H_2 as a substitute for natural gas during peak loads, when there is no wind, the price of electricity is also more expensive	0.02	0.02	0.00
The opportunities for electricity export from H_2 are unused	0.02	0.02	0.00
Green H_2 storage in 2030 is rather expensive and unattainable	0.00	0.00	0.00

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 12: Results of the applied Fuzzy Cognitive Mapping in Greece.

Concepts	Centrality	Outdegree	Indegree
Biohydrogen market development	8.76	0.00	8.76
Regulatory and legislative framework	2.00	1.12	0.88
Availability of raw materials	1.84	1.12	0.72
Available technologies	1.52	1.04	0.48
Biohydrogen demand – quantities and use	1.44	1.44	0.00
Financial support	1.20	0.48	0.72
Lack of competitiveness compared to combustion	0.92	0.52	0.40
Decentralized biohydrogen production systems	0.92	0.52	0.40
Social acceptance	0.84	0.84	0.00
Lack of incentives for its production (CAPEX and OPEX)	0.80	0.40	0.40
Security issues	0.76	0.56	0.20
Licensing of biohydrogen projects	0.76	0.64	0.12
Biohydrogen production technologies – a cost issue	0.68	0.68	0.00
Lack of a central biowaste management system	0.60	0.40	0.20
Process of making the industry “green”	0.60	0.40	0.20
Appropriate research for biohydrogen development	0.60	0.40	0.20
Research on synthetic SAFs	0.60	0.40	0.20
Lack of a National Hydrogen Roadmap	0.60	0.36	0.24
Biohydrogen by-product management	0.56	0.36	0.20
Quality in relation to fuel cells	0.56	0.36	0.20
Biohydrogen specifications	0.56	0.56	0.00
Transport problem – remote networks	0.56	0.32	0.24
Differentiated management by region	0.52	0.32	0.20
Different qualities and seasonality of biowaste	0.48	0.32	0.16
Development of the hydrogen fuel cell market in heavy vehicles	0.44	0.16	0.28
Competition with biomethane and electrolytic hydrogen	0.44	0.24	0.20
Compatibility with existing networks	0.40	0.20	0.20
Non-simultaneous production/demand	0.36	0.36	0.00
Biohydrogen purity issue depending on end use	0.32	0.20	0.12
Need for hybrid operation of production units	0.32	0.16	0.16
Cost sharing of biohydrogen connections	0.32	0.32	0.00
Limited impact on stakeholders	0.28	0.08	0.20
Transport system	0.24	0.12	0.12
Technological maturity of electrolysis	0.24	0.24	0.00
Lack of carbon-free substitutes	0.20	0.20	0.00
Issues of prioritizing needs according to alternatives	0.20	0.20	0.00
Speed of stop using natural gas	0.20	0.08	0.12
Availability of excess RES for electrolysis	0.16	0.16	0.00
Competition with other sectors (e.g. buildings, transport, industry) in the use of RES	0.16	0.16	0.00
Location issue	0.08	0.08	0.00

This project has received funding from the European Union’s Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.

Table 13: Results of the applied Fuzzy Cognitive Mapping in Poland.

Concepts	Centrality	Outdegree	Indegree
H_2 vehicles cost	2.48	0.68	1.80
Market incentives promoting biohydrogen	2.40	2.08	0.32
H_2 fuel costs	2.20	0.72	1.48
Hydrogen demand	2.16	1.08	1.08
Safety of H_2 usage	2.04	1.32	0.72
Benefits for environment	1.64	0.80	0.84
Technology availability	1.44	0.60	0.84
Distribution system	1.08	0.60	0.48
Investment costs	0.80	0.40	0.40
Information for consumers	0.68	0.12	0.56
Legal regulations	0.56	0.28	0.28
Technology and service availability	0.56	0.28	0.28
Availability for consumers	0.44	0.08	0.36
Energy transformation	0.20	0.20	0.00
Lack of incentives for changing grey H_2 on biohydrogen	0.20	0.20	0.00

Table 14: Results of the applied Fuzzy Cognitive Mapping in Spain.

Concepts	Centrality	Outdegree	Indegree
Public-Private Collaboration	0.42	0.25	0.16
Regulatory uncertainty	0.38	0.07	0.31
Financing	0.29	0.15	0.15
Energy Security	0.22	0.05	0.16
Technological Risks	0.16	0.11	0.05
High Initial Investment	0.16	0.16	0.00
Market Competition	0.13	0.05	0.07
Technological Advances	0.11	0.11	0.00
Energy Mix	0.05	0.00	0.05
Waste Management	0.05	0.04	0.02
Technical Deployment	0.02	0.00	0.02

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101075676.