Potentials for transborder green gas and hydrogen certificate markets

Report M1 for task 7.b in the SuperP2G project

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General Disclaimer

The scenario results in this report represent simulations with the Balmorel model illustrating possible effects of certificates for green hydrogen and does not represent suggestions for national policies regarding targets for hydrogen production levels or mix. The responsibility for results relies solely with the authors of this particular report.

Introduction

This document describes the market situation for renewable gases and hydrogen relative to natural gas with the aim to identify and discuss future potentials for trade-in renewable gas and hydrogen certificates. The regional scope is Europe with a particular focus on the project countries in the 5 SuperP2G countries.

The present situation with existing certificate trade within biomethane is described and a comparison made concerning renewable electricity certificate trade developments. Specific emphasis is assigned to cross-border trade and the main drivers that impact it.

Existing production and demand for gas and hydrogen and especially variation in production cost and demand-supply imbalances among countries drive the trade in certificates. Therefore this document first highlights the important differences among countries in demand and supply for 4 categories of gas: biogas, biomethane, hydrogen and natural gas.

1. Renewable gas and hydrogen supply and demand

Biomethane is the most widely produced and traded renewable gas as it can directly use the natural gas network. The supply and demand for biomethane are shown in Figure 1. Germany produced 10 TWh of biomethane in 2018, while only consumed 85% of this energy. This is also the case of Denmark, where its biomethane production in 2018 accounted for 1.4 TWh and its consumption was only 22.6%. Austria and Italy have similar consumption and production quantities. Sweden produces only 43% of its total demand, which explains its high import share from Denmark.

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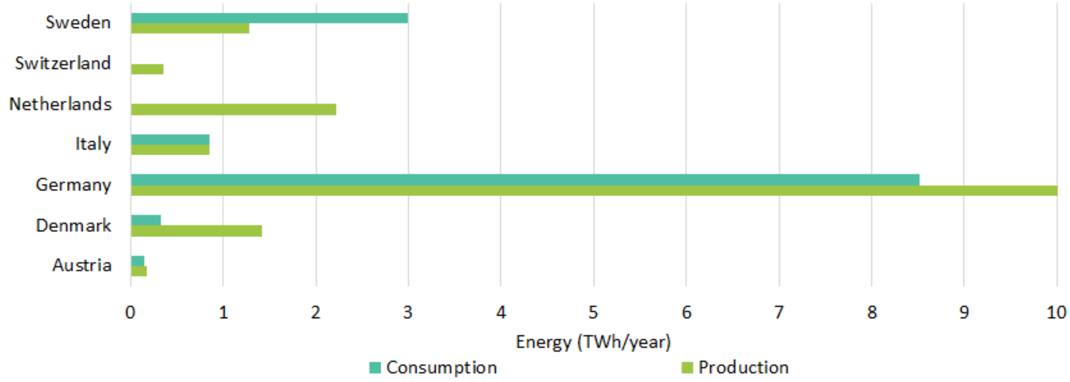

Figure 1. Current supply and demand of biomethane. Quantities from 2018. Own elaboration from [1].

The biomethane consumption by sector in some EU countries is depicted in Figure 2. The consumption in Germany is mainly for electricity production, the use for electricity production is incentivized by Feed-in-Tariff support, which is only granted if the plant produces electricity from biomethane. In Denmark, the share is 50% for the industry sector and 50% for heating and cooling. All the biomethane demand in Italy comes from the transport sector since there is already infrastructure and methane vehicle fleet. Moreover, in 2014, the Italian government introduced the first obligation for the use of biofuels in the transport sector. Finally, in Sweden, the highest share corresponds to transport due to a favourable support system, and to a lesser extent to industry and heating and cooling.

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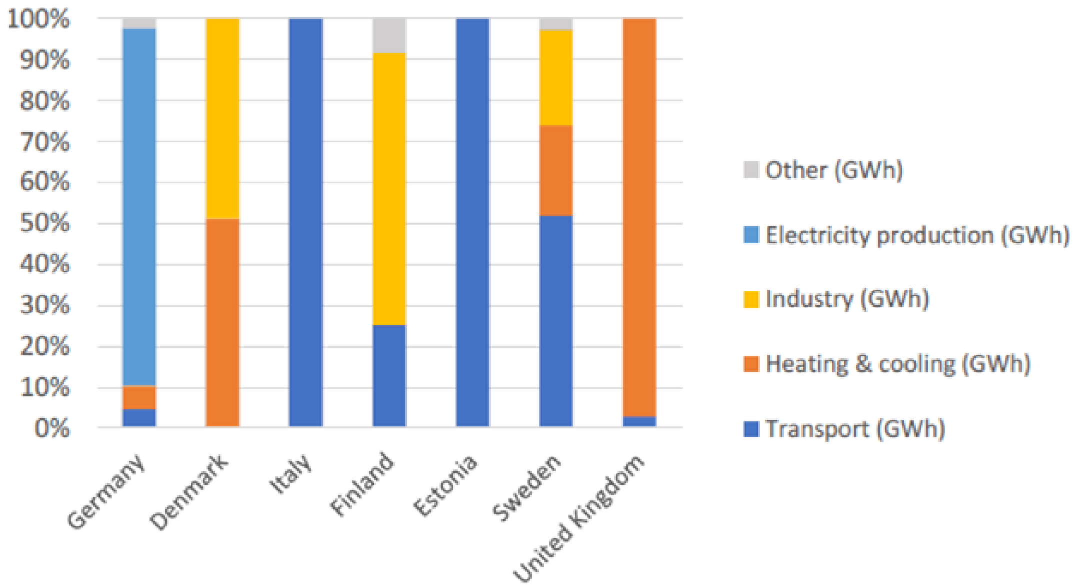

Figure 2. Consumption of biomethane per sector and country. [1]

Hydrogen demand is much more local/regional since there is only a limited hydrogen network for use and the demand is almost only related to industrial feedstock so far.

The current hydrogen demand in GWh can be seen in Figure 3 [2]. Germany is by far the country with the highest demand with 61,618 GWh, followed by the Netherlands with 39,361 GWh. Italy, Austria and Denmark have a smaller demand. Furthermore, the demand in all countries is mainly in the industrial sector and to a lesser extent to unspecified demand. Only Austria has demand in the transport sector with 26 GWh per year.

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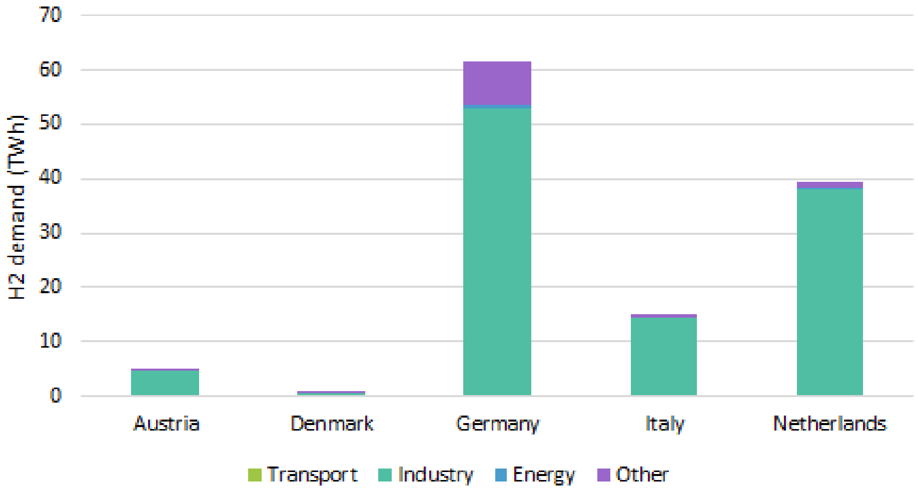

Figure 3. Current hydrogen demand [2].

Comparison of renewable gas and natural gas markets

Figure 4 shows the current hydrogen and biomethane demand. In most countries, the hydrogen market is bigger compared to the biomethane one, however, in Denmark, this is not the case. The hydrogen demand changes from one country to another, and it corresponds to the size of the country, therefore, Germany has the highest demand for both biomethane and hydrogen, while Denmark is the country with the lowest demand for both fuels. Compared to the annual energy consumption in each country, hydrogen contributes to a relatively small percentage, 5.8% in the Netherlands, 2.4% in Germany, 1.5% in Austria, 1.1% in Italy and 0.3% in Denmark.

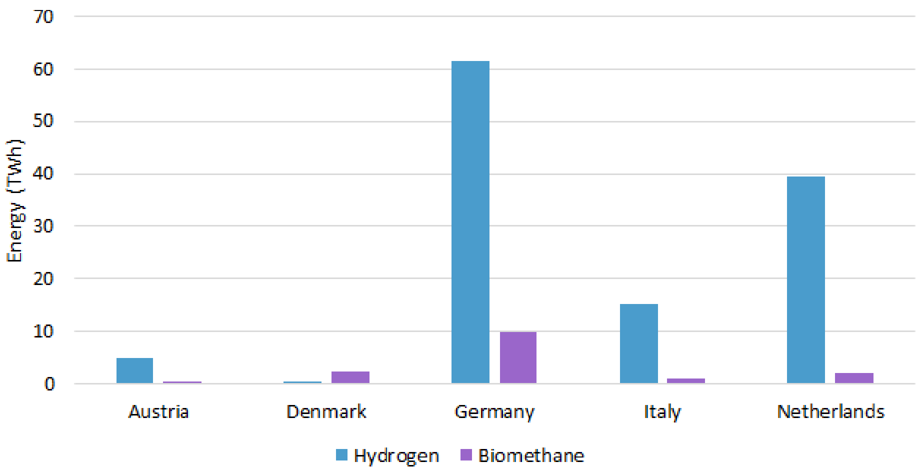

Figure 4. Hydrogen and biomethane demand. Own elaboration from [1], [2].

The natural gas demand can be seen as the highest potential of hydrogen. This will represent that all the gas demand is provided by hydrogen. Comparing the two fuels (Figure 5), the size of the hydrogen market corresponds to 9.5% of natural gas in the Netherlands. This share is lower in other countries: 5.9% in Germany, 4.8% in Austria, 1.9% in Italy and 1.3% in Denmark.

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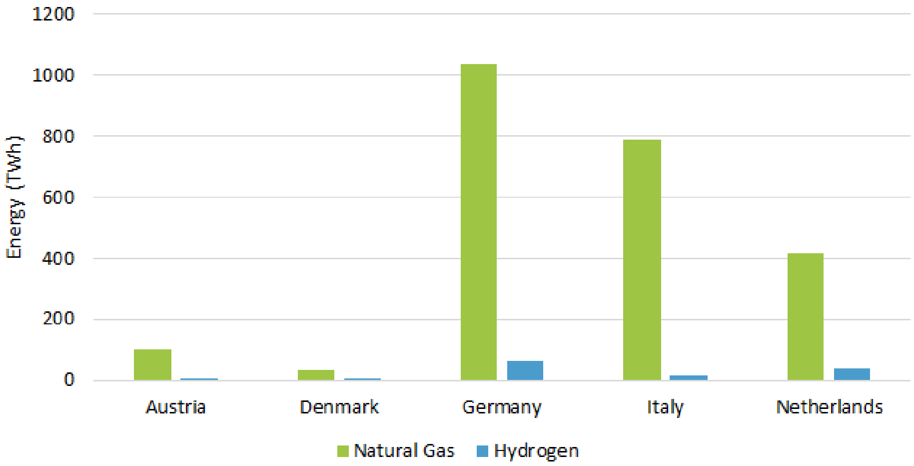

Figure 5. Hydrogen and natural gas demand. Own elaboration from [2], [3].

The biogas and biomethane demand per country is represented in Figure 6. Denmark is one of the leaders in biomethane production, 64% of the biogas is upgraded to biomethane, which can be further confirmed with Figure 10. The Netherlands is the second country with most of the upgraded biomethane with 54%, followed by Germany with 11%. In Italy and Austria, the upgraded biomethane accounts for less than 10% of the biogas.

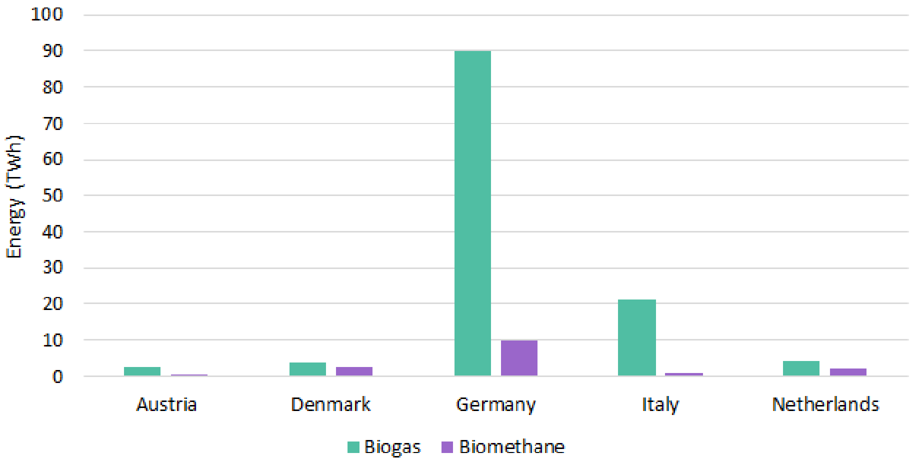

Figure 6. Biogas and biomethane demand. Own elaboration from [3]

Figure 7 shows all the renewable and fossil fuel demands: hydrogen, natural gas, biogas and biomethane. It is clear that biogas is the renewable gas with the highest share compared to the others, except in the Netherlands, where hydrogen has the highest share. Comparing biogas and natural gas, Denmark is the country with the highest share, biogas production represents 10.7% of the natural gas used. In Germany, this number is 8.7%, it is followed by Italy with 2.7%, Austria with 2.4% and finally the Netherlands with only 1%. In addition, most of the biogas is used in CPH plants for electricity and heat generation and only a small amount is upgraded to biomethane.

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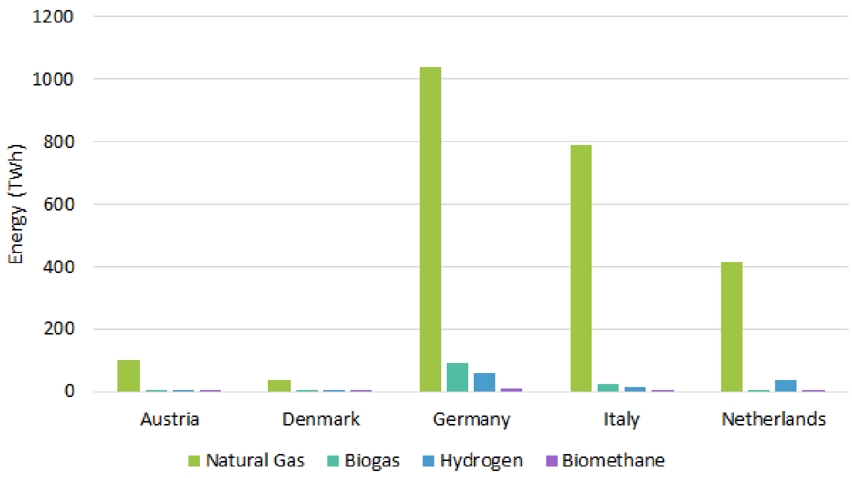

Figure 7. Comparison among all markets. Own elaboration from [1]–[3].

The use of biogas in Germany and Italy can be seen in Figure 8 and Figure 9, respectively. In Germany, 91% of biogas is used in CHP plants and only 8% is upgraded to biomethane. In the case of Italy, around 40% is being used only for electricity production, and almost 60% is used for heat and electricity generation in CHP plants. Finally, in Denmark (Figure 10), most of the biogas is upgraded and injected into the gas grid, some are used for electricity generation and only a few for heat and process. In the future, it is expected that more biogas will be upgraded to biomethane and injected into the gas grid.

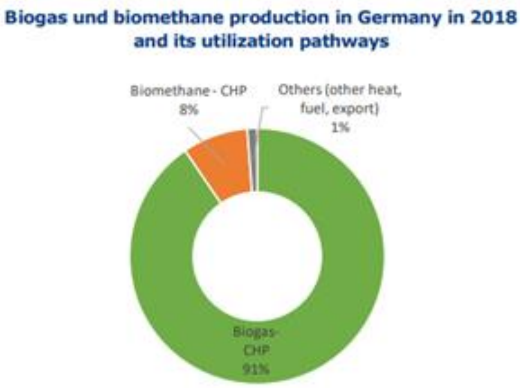

Figure 8. Use of biogas in Germany. [4]

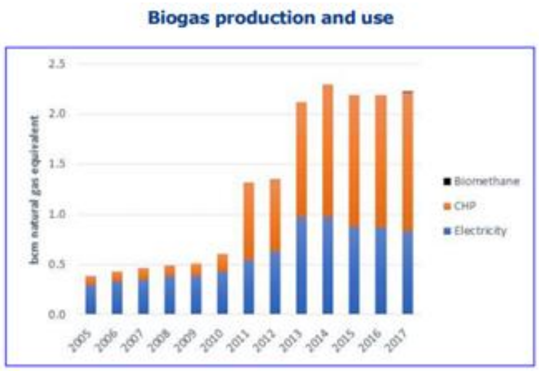

Figure 9. Use of biogas in Italy. [4]

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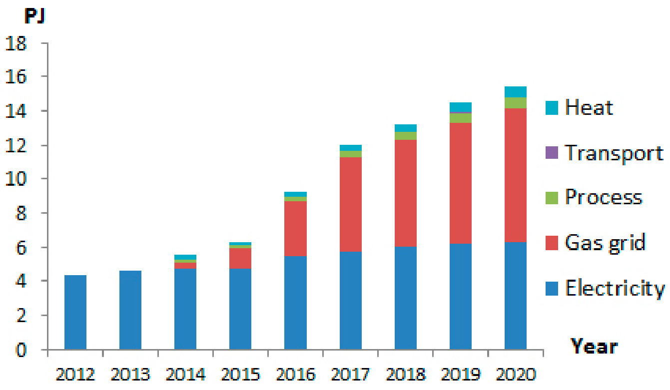

Figure 10. Use of biogas in Denmark. [4]

2. The current certificate regulation framework (mainly biomethane)

The RED II [5] calls for the decarbonisation of other sectors besides electricity. The goal is to reach 32% of renewable energy in the gross final energy consumption by 2030, and particularly 14% in public transport and an annual increase of 1.3% in the heating and cooling sector. Moreover, it states that the current guarantees of origin (GOs) used for electricity should be extended to cover renewable gases, heating and cooling. These GOs must be standardized to 1 MWh of energy produced and shall be valid for 12 months after the production of the relevant energy unit.

In particular, for renewable gases, their injection into a natural gas grid and cross-border trade must be carried out in a mass balance system to ensure the correct accounting of renewable energy and to avoid double incentives. Moreover, the concept of advanced biofuels is introduced as fuels that come from sustainable biomass.

The GO must include at least: the origin, type and capacity of the renewable energy installation, the type of financial aid granted to the production facility (if any), commissioning date of the plant, date and country of issuance, start and end dates of renewable energy production.

Gas certificates in Europe

1. European Renewable Gas Register (ERGaR).

ERGaR is the European organisation responsible for the administration of renewable gases throughout the European natural gas network. It has two renewable gas schemes, the first one is the RED MB where the final instrument is a Proof of Origin (PoO) that includes a Proof of Sustainability (PoS). This scheme is recognised by the European Commission and is intended for biomethane destinated for exportation and used in the transport sector. The second scheme is

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the Certificates of Origin (CoO), which operates under book-and-claim (similar to electricity GOs) and is not recognised by the European Commission.

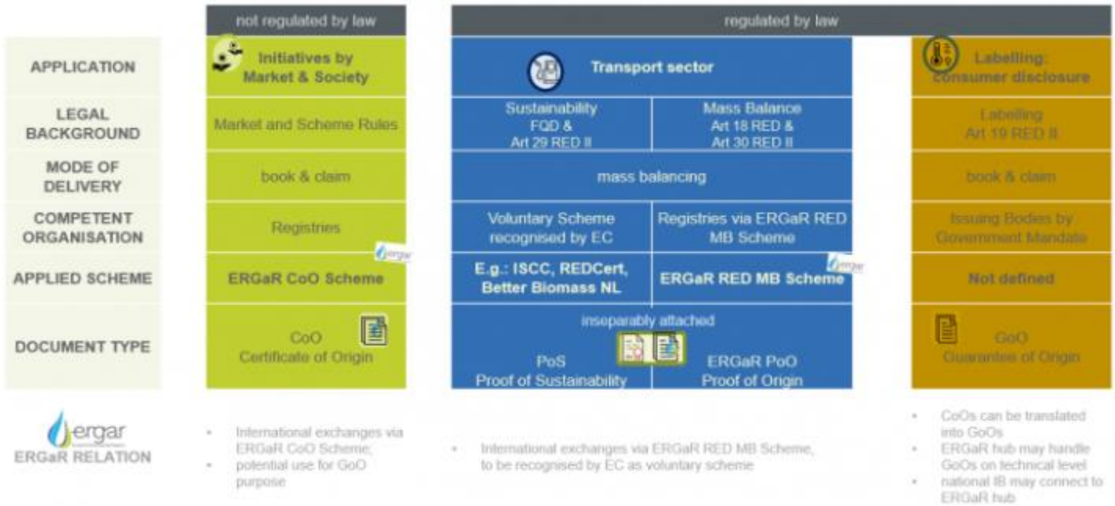

Figure 11. ERGaR operational schemes.[6]

2. Association of Issuing Bodies (AIB)

Through EECS Gas Scheme is designing a GO scheme for gaseous carriers, included hydrogen, and their effective cross border transfer, it will be issued for 1 MWh of energy produced and will provide details of the plant, production process, sustainability of the feedstock, emissions reduced and saved.

3. Certifhy

It is the first initiative for hydrogen guarantees of origin. The project aims to create the path towards EU GOs for hydrogen. It is a pilot project operating in four hydrogen plants in France, Germany, Netherlands and Belgium. The project is financed by the Fuel Cell and Hydrogen Joint Undertaking (FCH JU), the first guarantees of origin have been issued and the registry is now available for all the users. It considers the origin of hydrogen and also the GHG intensity. For the evaluation of the GHG intensity, the GHG intensity of the production of hydrogen from natural gas is considered as a benchmark. Therefore, if the GHG intensity of the hydrogen production process is at least 60% below the intensity of the process using natural gas, then a certificate will be issued.

There are two certificates considered (Figure 12), the first one is the CertifHy Green Hydrogen and is issued in case the hydrogen is made from renewable energy. The second one is CertifHy Low Carbon Hydrogen and is issued for non-renewable technologies, but which have a low GHG intensity, e.g. nuclear and fossil with CCS.

The certificate is managed and operated from a central registry that is in charge of the issuance, transfer and cancellation of the certificates. The cancellation process is done directly on the online platform. The certificates contain information related to the energy source of the hydrogen, information of the plant (location, operator, the start date of operation, etc.), time of

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production of hydrogen, GHG intensity of the hydrogen in an amount of CO2 equivalent per unit of energy and the date of issue of the GO.

Currently, CertifHy has issued more than 75,000 guarantees of origin in 4 pilot projects. The certificates can be traded across the European Economic Area and Switzerland and can be used for any kind of application. The certification management is done through an online stakeholder platform. The main actors involved in the process are shown in Figure 13, the certification body verifies the eligibility and audits the potential account holders. The issuing body supervises the issuing, transfer and cancellation of certificates, this body also supervises the operation of the CertifHy Registry. Finally, the account holder is responsible for requesting any action related to the GO (issuance, transfer or cancellation). The GO last 12 months after the end of the production period. The cancellation of the certificate includes information related to the beneficiary, the location and purpose of cancellation and the period during which the associated hydrogen was consumed.

Figure 12. Certifhy schemes. [32]

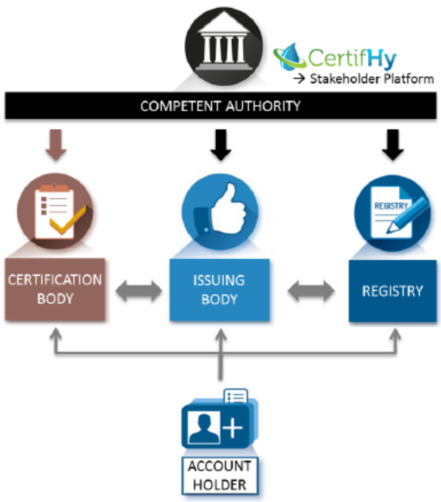

Figure 13. Certifhy main actors. [33]

Comparison among the European gas certificates

The main characteristics of the different Guarantees of Origin can be seen in Table 1 and Table 2. These tables summarize the information found in the D4.2 REGATRACE report on the comparison of biomethane registries [7]. The term RFNBO is referred to renewable fuels of non-biological origin and RCF represents recycled carbon fuels.

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Table 1. Comparison of certificates. Part 1.

Criteria		AIB	CertifHy	ERGaR (CoO)	ERGaR (MB)
Energy carrier	Biomass	Yes	Yes	Yes	No
	RFNBO	Yes	Yes	Only PtG	No
	RCF	Yes	Yes	No	No
	Fossil	Yes	Yes	No	No
	Hydrogen	Yes	Yes	Yes	No
Mass balancing		Yes	Not yet	No	Yes
Sustainability criteria		Yes	No	Optional	Yes
Gas transport	European gas grid	Yes	Yes	Yes	Yes
	Isolated gas grid	Yes	Yes	Yes	No
	Off-grid transport	Yes	Yes	Not yet	No
Financial support		Yes	Not yet	Yes	Yes

Table 2. Comparison of certificates. Part 2.

Criteria	AIB	CertifHy	ERGaR (CoO)	ERGaR (MB)
Methodology on the calculation of sustainability and GHG saving criteria	Under development. Optional for CO2 emissions saved and produced.	Methodology developed following RED II	On voluntary basis	Following one of the voluntary schemes or national systems established under the RED
Geographical scope	EU (future and former members), EFTA	EU, EEA, Switzerland	Countries interconnected to the European gas grid network	EU, EFTA
Countries participating (01/2021)	None, 6 appointed	Only pilot now	Still in process	Not in operation

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National biomethane registries

In all the countries in SuperP2G, only biomethane GOs are currently provided. The operation of the national registries will be described, a final comparison will be made and a conclusion will be drawn on the similarities or differences with the different SuperP2G countries.

Denmark

The certificate system is operated by the National Transmission System Operator (TSO), ENERGINET [8]. The certificates are emitted every 1 MWh of energy produced and can be traded across countries through mass balancing. They state whether or not the plant has received production support and are traded through the online platform system called Certificate register. The GOs are valid for 1 year and do not contain information on raw material and emissions saved.

Austria

The National Energy and Climate Plan state that biogas and renewable hydrogen will be supported by tax exemptions or favourable tax treatment [10]. Moreover, biomethane will be used for the transport sector as well as replace natural gas in the long term in this sector. Also, the renewable gas injected into the natural gas distribution system will be supported by feed-in, for example as a quota system, therefore, guarantees of origin are required. Finally, the Gas Labelling Ordinance [11] describes the implementation of gas labelling information provided by suppliers. It regulates exclusively the labelling of quantities of gas that are fed into or witdrawn from the public gas grid, it includes natural gas as well as renewable gases. This ordinance addresses the origin and, on a voluntary basis, the environmental effects as well as detailed provisions for disclosure of the various primary energy sources.

The national biomethane registry is managed by the gas balance group: AGCS Gas Clearing & Settlement AG [12]. Monthly biomethane GOs are issued, the certificates are not standardised for energy quantity and can be divided up to 1 kWh. Moreover, they do not have an expiration date, however, energy plants that want to apply for feed-in-tariff require an audited certificate with an issue date from the current year. The electricity produced by biomass receives feed-in-tariff, therefore, GOs can be used to prove the origin of the gas. To prevent double-counting, the certificate system operates through mass balancing together with a biofuels registry, where biomethane volumes injected and consumed from the grid are checked.

Italy

Italy has a target of increasing the share of renewables to 22% in the transport sector by 2030 [13]. To achieve this goal, mandatory quotas for biofuels in transport are established and renewable hydrogen was added to the list of biofuels and fuels that can be used for meeting the quotas.

The Italian biomethane registry is managed by the energy service system operator: the Gestore dei Servizi Energetici [15]. The GOs are incompatible with any other support and sold through bilateral contracts or the Italian Power Exchange (exchange for spot trading of electricity and natural gas in Italy). There are two schemes, the first one are the Certificates of supply for

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consumption (CICs) or Certificati di Immissione in Consumo di biocarburanti. They are issued every month for biomethane destined to the transport sector. The certificate lasts 20 years and covers 10 GCal (11.62 MWh). The second scheme is CICs for advanced biomethane, these are issued every 5 GCal (5.81 MWh) for sustainable feedstock that does not change land use. The incentive lasts 10 years and the GOs can be sold through the GSE who will pay the monthly average spot price for gas minus 5% and also 375 EUR per CIC.

Germany

The German Biogas register is managed by the German Energy Agency (DENA). Biomethane is subsidised through different policies. To get the benefits, the origin and quality of biomethane must be verified through the German biogas register by neutral auditors. There are two types of certificates, Type I refers to the statement on the biogas delivery. It requires mass balancing since the quantity will be transported from the plant to the end consumer directly. The second type refers to the statement on the biogas guarantee of origin. In this case, mass balancing is not required since the gas property is separated from the other biogenic properties during the transport, later the properties are connected upon arrival to the consumer.

Netherlands

The National Energy and Climate Plan in the Netherlands [16] states that renewable gases will be used in the transport, electricity and industrial sector. The GOs are managed by Vertogas and are standardized to 1 MWh of energy produced. The sustainability of biomass can be detailed in the certificate but is not mandatory. The certificate can be sold through bilateral contracts, exchanged with other traders, sold to the final users or transported to renewable fuel units (HBEs) for transportation.

Conclusion

The Biomethane registries and guarantees of origin are usually managed by the National Transmission System Operators. These entities are in charge of setting the rules, issuing and cancelling the certificates. However, the certificate is not standardized in all the countries, in most cases, they are accounting for 1 MWh of energy produced, but in Italy, it is different. Moreover, the expiration period varies significantly from one country to another as well as the information provided on each certification.

3. Biomethane trade and certificate market

Figure 14 shows the international biomethane transfers in 2019 in Europe. The biggest drivers for the biomethane market are Switzerland and Sweden since most of the transactions have as destination these countries. Imports to Switzerland represented 536 GWh in 2019 mainly from Denmark, Germany and to a lesser extent from Great Britain. Imports to Sweden accounted for 1400 GWh in 2019 and are from Denmark. Germany is the second-largest importer with 155 GWh, these biomethane quantities are mainly from Denmark and Great Britain and to a lesser extent from the Netherlands. Therefore, Denmark is the biggest exporter, it exported 1772 GWh in 2019.

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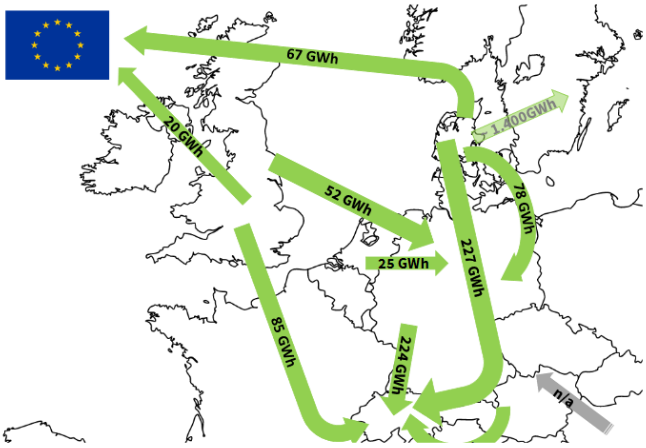

Figure 14. Biomethane transfers in the EU level, 2019. [18]

Figure 15 shows the Danish biomethane transfers in previous years. Danish certificates are issued per every MWh of energy delivered; thus, the number of certificates corresponds to the quantity of energy produced in MWh. Denmark has increased its biomethane market in the last years, the number of certificates issued increased from 2.2 million in 2018 to **4.2 million in 2020.** In 2020, 1.4 million certificates were cancelled on the border with Sweden, 180.3 thousand on the border with Germany, 714.2 thousand were transferred to DENA and only 598.9 thousand were sold in Denmark. This indicates that 80% of the cancelled certificates are exported to other countries and only a fifth are sold nationally.

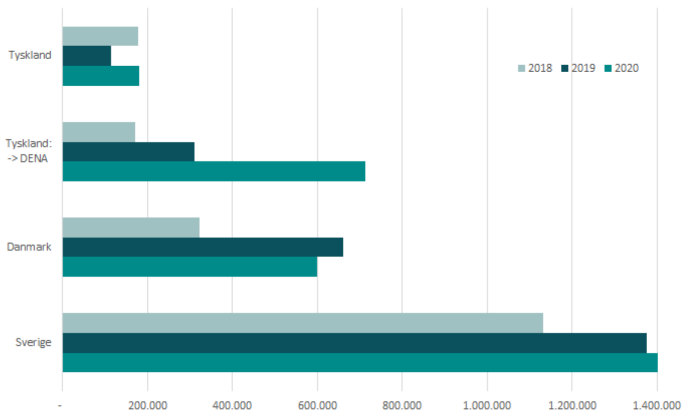

Figure 15. Biomethane certificate trade in Denmark. [19]

Figure 16 refers to gas certificates for Austria, the quantity of biomethane in MWh injected in the grid (blue) and the biomethane for which certificates were issued (grey) are also depicted in the figure. Austrian certificates are not standardised to 1 MWh; thus, the amount of energy does not correspond to the number of certificates. Compared to the Danish market, the Austrian one is smaller, in 2020 137.69 GWh of biomethane were injected into the gas grid, being January the

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month with the biggest production. From the figure, it can be concluded that almost all the biomethane injected into the grid has a guarantee of origin certification.

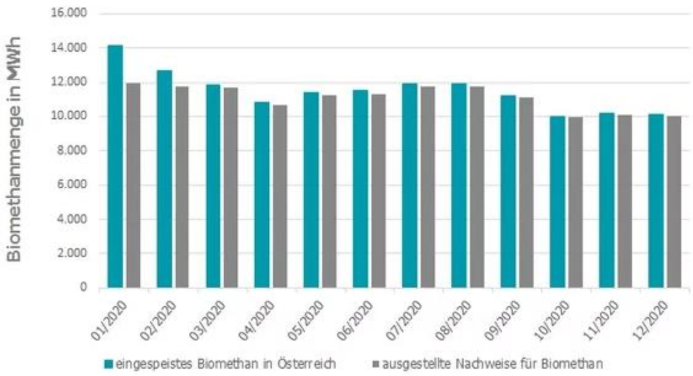

Figure 16. Biomethane certificates volume in Austria. [20]

Vertogas is the entity that manages the Guarantees of Origin for green gases in the Netherlands, its development in the last two years is depicted in Figure 17. The Dutch GO are standardised for every MWh of energy produced, therefore, the amount of energy delivered corresponds to the number of certificates. The market for green gas certificates increased significantly from 2019 to 2020. The issued certificates increased by 70% approximately, while the traded and cancelled certificates increased in a lower proportion. Most of the transactions are due to trading, however, it is not specified if the trade is occurring at a national or international level. The transferred certificates to the Dutch Emission Authority (NEa, Nederlandse Emissieautoriteit) are relatively low with 0.4 million approximately. The NEa oversees the registration of certificates for compliance with a specific quota.

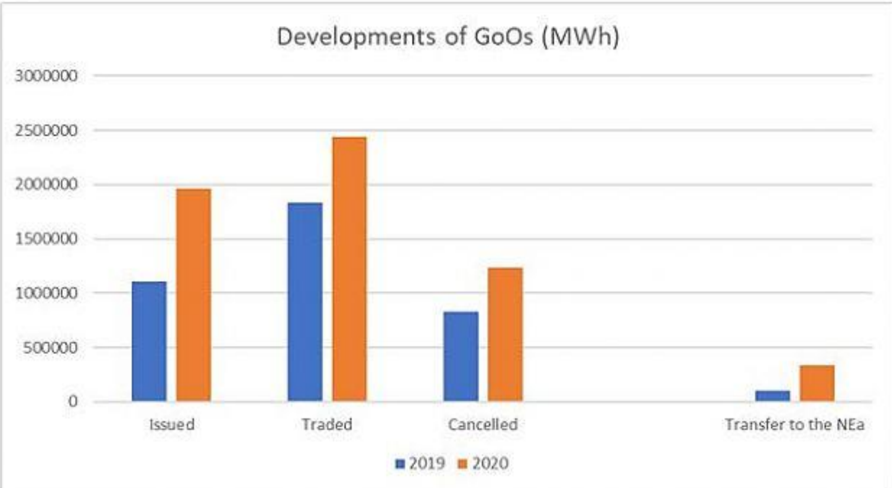

Figure 17. Biomethane certificates in the Netherlands. [21]

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4. Electricity certificates development and comparison to gas certificates

Electricity certificates are widely used and traded in Europe today and the development of this market can serve as an example of how renewable gas certificates may develop in the future. It also illustrates the benefits and drawbacks of the design of certification schemes as well as possible trading volumes and price intervals.

The guarantees of origin for electricity were introduced for the Renewable Energy Directive 2009/28/CE (RED I). The purpose of these is to prove the origin of the energy consumed, particularly that electricity has been produced by renewable energy sources. There is a certificate for all the country members of the European Union, together with Switzerland and Norway. The online registry is managed by the Association of Issuing Bodies (AIB) through the European Energy Certificate System (EECS). The certificates are issued every month for each MWh of electrical energy produced and expired after 1 year. There is no a fixed price for each GO and its price depend on market demand and supply. In addition, to avoid the use of the term residual mix, certificates are issued for all types of energy, so that anyone can know where the energy comes from.

The following terms are used by the AIB to classify the certificates [22]:

- Issue: GOs created in a month for electricity produced in an earlier month.
- Transfer: GOs transferred within a country or region.
- Cancel: GOs which have been made non-transferable by the holder of the account in which they reside (or its agent).
- Export: GOs transferred to another country.
- Import: GOs transferred from another country.
- Expire: GOs which relate to electricity produced more than a year ago, and which have consequently been cancelled.

Figure 18 shows the transactions of GOs per country in 2020. Norway is the country with the most certificates emitted with 132 million GOs issued. Other countries with important contributions are Spain, Netherlands, Italy, France, Sweden, Switzerland and Austria. Norway is also the largest exporter and importer of certificates. In general, most of the certificates are transferred within the same country, however, Norway, Netherlands, Finland, Denmark and Belgium imported more GOs than the transferred. Imports and exports are the most common transactions on the certificates, they represent 30% of the total transactions. Finally, only 2% of the GOs expired.

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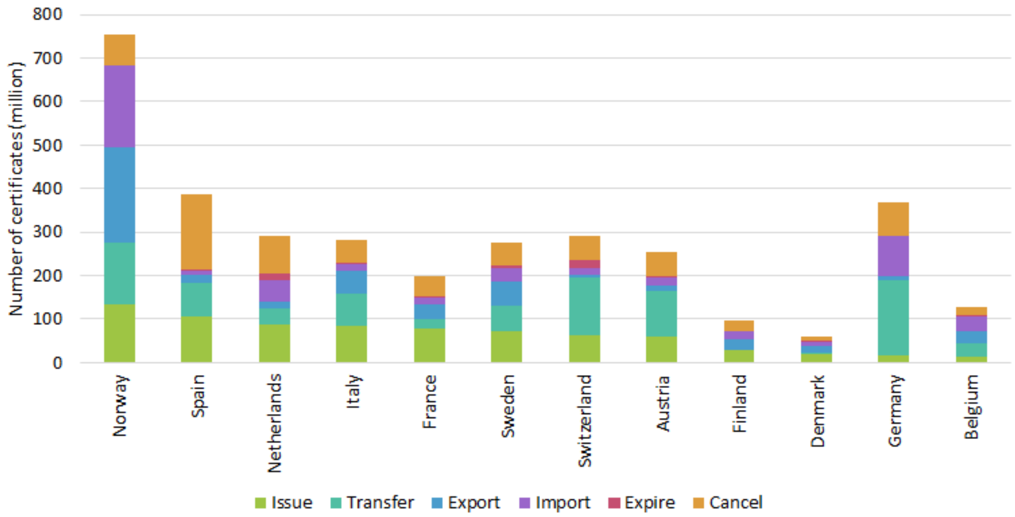

Figure 18. EECS transactions in 2020 per country. Own elaboration with data from [22]

Most of the certificate market is due to electricity production from hydro energy (Figure 19) which coincides with the last plot, where Norway was the bigger market player. More than half of issued certificates are from hydro or marine energy, 20% from wind energy; while solar and biomass represent a smaller share of GOs with 4% and 6% respectively. Nuclear only accounts for 4.37% of the issued certificates and fossil fuels represent almost 9%, of which 86% are certificates from natural gas. The high share of natural gas GOs confirms the need for green certificates for the gas industry.

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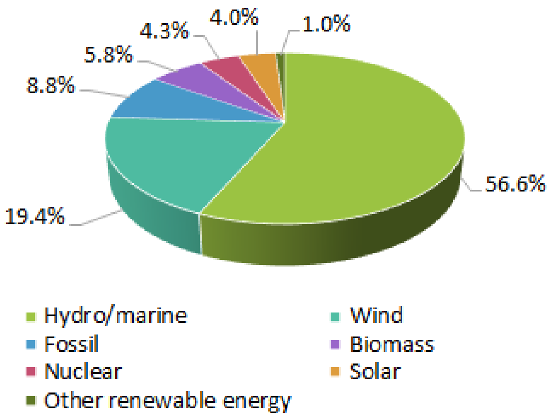

Figure 19. Share of technology on the issued certificates. . Own elaboration with data from [22]

The certificates per transaction in the European Union are depicted in Figure 20. Most of the transactions are due to transfer, issuance and cancellation. Only 2% expires and the imports/exports account for 30% of the transactions. The share of technology in all the transactions is similar: hydro is the dominant one with more than half of the certificates, followed by wind, biomass and solar. Nuclear and fossil fuels certificates are mainly transferred and cancelled within the same country or region.

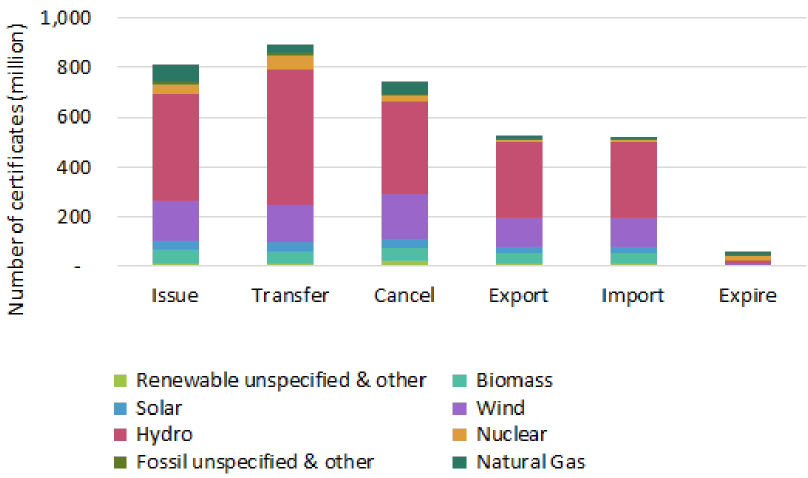

Figure 20. Certificates per transaction and source 2020 EU. . Own elaboration with data from [22]

The certificates for the countries belonging to the SuperP2G project are shown in Figure 21. The transactions in 2020 are depicted as well as the energy carrier associated with the transaction. Germany is by far the biggest market participant, most of its certificates are due to hydro energy and are transferred within the same country or region. Hydro energy represents also most of the Austrian certificates and in less proportion to wind and fossil fuels. The Netherlands is

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dominated by wind and natural gas certificates, most of which were issued and cancelled in 2020, this country also imports a large quantity, mainly wind energy. Italy has the largest share of its market in hydroelectric power and a smaller share in wind, solar and biomass. Finally, Denmark is dominated by wind energy and its share of imports/exports is bigger than any other transaction.

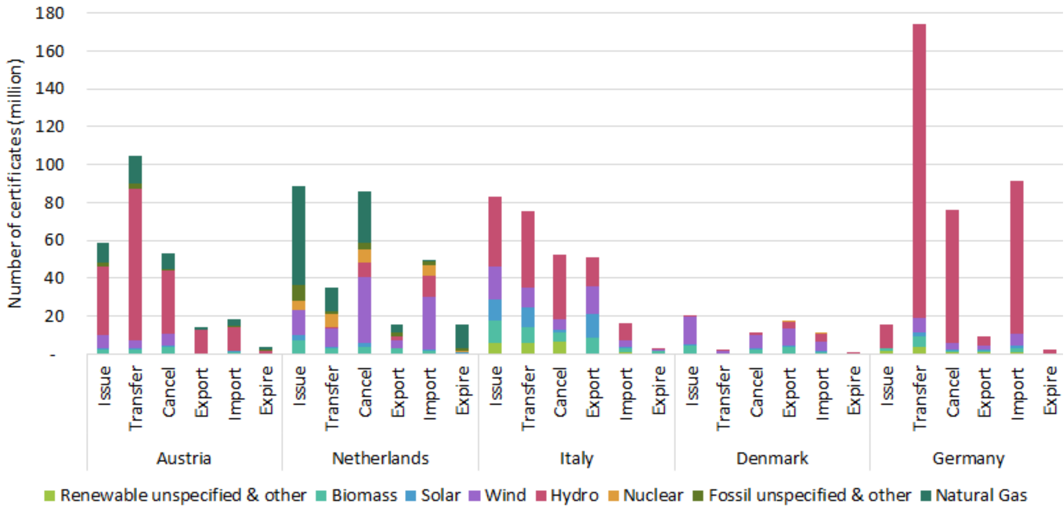

Figure 21. Electricity certificates countries of interest 2020. . Own elaboration with data from [22].

The demand for green certificates for electricity has increased considerably during the last 5 years (Figure 22). The first certificate was emitted in 2001, the first years, few countries made use of the certificate, mostly Austria, Finland, Norway and Sweden. The demand for certificates increased slowly during the first 6 years and from 2007, the certificate demand doubled the one in 2006. The year with the biggest number of certificates issued was 2019 with almost 800 million, in 2020 the demand decreased by 12%. If the renewable certificates are expected to have a similar evolution, the market for a renewable gas certificate has a big potential.

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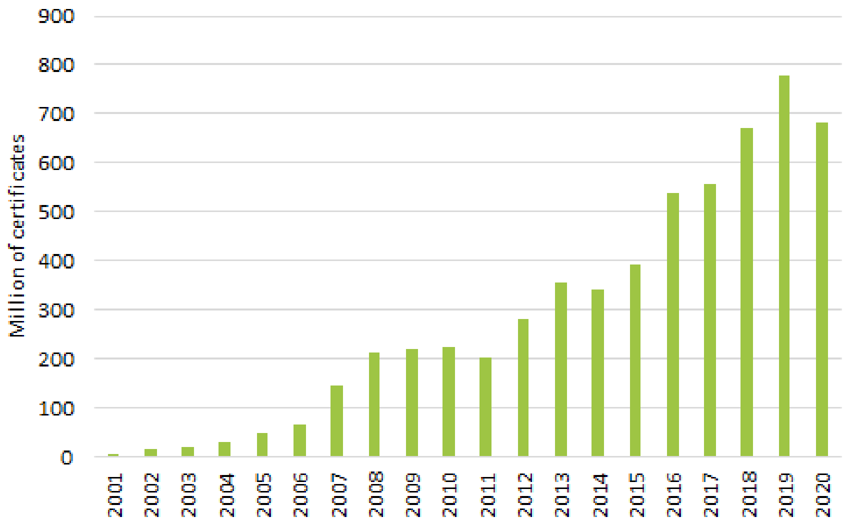

Figure 22. Development of green certificates for electricity generation. . Own elaboration with data from [22]

Price of certificates traded today and future uncertainty

Prices for electricity certificates are available and the market is relatively transparent in providing volumes and prices. This is not the case for the much smaller biomethane certificate market, where prices are highly uncertain.

Electricity certificate prices

The prices of renewable energy certificates are not regulated and they are not set at one particular market. Prices vary according to the supply and demand and are affected by the national tax schemes and renewable obligations as well as changes in businesses ambitions to transform to green energy profiles. Moreover, prices are often negotiated through power purchase agreements between the producer and the final user. In 2018, certificates were traded between 1 and 2.5 EUR/MWh. However, due to an increase in the traded volumes in 2019 the prices dropped. Thus, the wholesale prices were between 0.4 and 0.5 EUR/MWh in 2019 and 0.75-0.85 EUR/MWh in 2020 [23].

Prices are influenced by annual supply changes due to climate variations (sun and precipitation), but also by the variations of an additional renewable generation coming on line each year. The demand side of certificates is also affected by their use to obtain other supports such as feed-in or compliance with specific quotas.

Prices of biomethane certificates

There are no statistics available on biomethane certificate prices. Price levels are expected to be slightly higher than for electricity certificates, but as the volume is not large and specific trading partners predominate, this is highly uncertain. Therefore, no price can be used as an indicator for broader trading of biomethane certificates in the future.

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5. Potential for future trade in renewable gas and green hydrogen certificates

Biomethane certificate trade will continue to develop gradually. The potential is *less* than for hydrogen in the long term as hydrogen will be the first (main) product before used for methanation or liquid biofuels. Biomethane will mainly substitute natural gas, but this will compete with the electrification of heat supply and the electrification of industrial process energy demand. If electrification is very competitive, the potential for biomethane growth will be limited and thereby also the expansion of biomethane certificate markets.

For hydrogen certificates, it was considered only the trade in green hydrogen certificates and exclude the specific blue hydrogen certificate options. However, the modelling approach illustrated below using Balmorel includes the blue and grey hydrogen production option.

Difference in production cost and demand levels for hydrogen between countries will drive trade patterns

Hydrogen production cost depends highly on natural gas prices for grey and blue hydrogen. For green hydrogen, differences in production cost are related to the availability of cheap average electricity prices, which is observed in Europe, although interconnection capacity is reducing price differences. Demand for conventional hydrogen as industrial feedstock is relatively high in areas that have higher electricity prices. The degree that this will lead to hydrogen trade flows depend on the costs of electricity transmission relative to costs of hydrogen transmission/transport. These relationships are included in the modelling illustration.

Hydrogen production cost differentials

Natural gas costs are only modestly different within the European natural gas network. Costs will be moderately lower at the entry points from Norway, Russia and Algeria, but not substantially lower. Resources outside Europe may be considerably cheaper and that may create hydrogen import by shipping, but this option will not be covered here.

The cost of electricity is the main cost component that differs regionally within Europe, apart from the cost of labour. Hydrogen production is very capital intensive relative to labour, so labour cost is not very relevant to total production costs.

Cheap renewable electricity exists in low price markets like Norway (Nordic area). Future expansion of renewables in the north (mainly North Sea wind or onshore wind and PV) will provide lower hydrogen production costs here compared to cental European markets. Similar cheap PV may develop in the south but this is a bit more uncertain as the existing electricity demand may absorb this easier without a large electricity price impact. The average electricity price is the most important since electrolysers will need a substantial amount of producing hours to cover investment costs. However, the profile of electricity prices also matter and 4000-6000

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hours annually with moderate prices may be sufficient to make green hydrogen competitive in 2030 even though average electricity price is not much lower than for other regions.

Hydrogen production may take place where there is cheap electricity and at the same time direct uptake for hydrogen in the natural gas grid or specific local fuel demand (direct transport or advanced fuels). If the local hydrogen demand does not benefit from/require the renewable certificate to receive support (or demand is conditional on that) then there may be excess certificates for sale. That will be one possible driver for trade-in hydrogen certificates.

An illustration of future certificate trade potential using an exogenous projection for total hydrogen demand in each country

This illustration will be based on the energy system model Balmorel focusing on the power and heat sector in most European countries divided into a larger number of power market areas.

The main driver for certificate trade is the aggregated demand for hydrogen. This illustration chooses to use an exogenous demand projection for total hydrogen including both conventional feedstock demand and demand for energy purposes.

Future hydrogen demand

The future of hydrogen demand is uncertain, it is not clear to what extent it will replace natural gas and how it will be compared to biomethane. The hydrogen roadmap Europe [24] presents different scenarios on future hydrogen demand per sector. It is expected that in 2030, some grey and blue hydrogen will remain, but by 2050, most of the hydrogen will be green from central and regional electrolyzers. We focus on the 2030 projection and its possible implications on certificate trade.

The European hydrogen demand in a business-as-usual scenario is projected to be 481 TWh in 2030 and 780 TWh in 2050. Therefore, this demand is considered for the model assuming the same share per country as it is now. Figure 23 shows the future hydrogen demand per area, Germany is the country with the highest demand with 107 TWh in 2030 and 174 TWh in 2050, however this demand is distributed among the 4 regions. The second largest demand is from the Netherlands with 69 TWh in 2030, followed by France and Belgium. The rest of the countries have significantly lower demand. Moreover, the 10 countries in this study account for the 60% of the total hydrogen demand in Europe.

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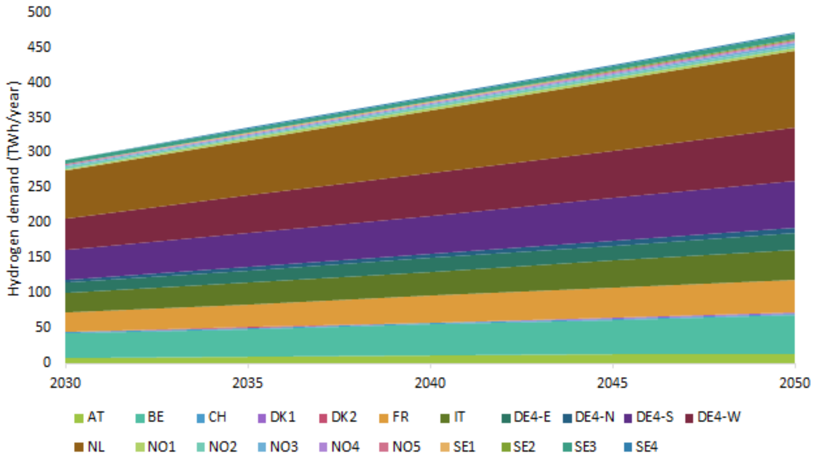

Figure 23. Future hydrogen demand. Own projection based on [24].

Modelling future hydrogen and biomethane trade flows with Balmorel

The hydrogen model was set up in the energy system model Balmorel, where the electricity and heating sectors are modelled for European regions. The countries included in the model are the countries of the SuperP2G project and neighbouring countries: Austria, Denmark, Germany, Italy, Netherlands, Belgium, France, Norway, Sweden and Switzerland. For modelling purposes, the countries are divided in different regions as seen in Table 3. The model simulations are performed for 4 representative weeks in different seasons for 2030.

Table 3. Regions in the Balmorel model used

Country	Regions	Country	Regions
Austria	AT	Belgium	BE
Denmark	DK1, DK2	France	FR
Germany	DE4-N,DE4-S, DE4-W, DE4-E	Norway	NO1, NO2, NO3, NO4, NO5
Italy	IT	Sweden	SE1, SE2, SE3, SE4, SE5
Netherlands	NL	Switzerland	CH

The model use the total hydrogen demand in Figure 23 as an input and determines the supply technology mix (grey, blue and green hydrogen) based on production costs. The production location is optimised based on transmission costs (distances) and production cost including endogenously computed electricity costs for the green hydrogen.

Reference scenario for 2030 with environmental tax (CO_2) and fuel taxes on heating fuels

The reference scenario uses the hydrogen demand projection and projections on final demand for electricity and heat as inputs. An environmental tax, in the form of a CO2 tax, is included

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representing the EU ETS quota price. For fuels used in heat and electricity production, fuel taxes corresponding to the average level in 2020 are used. The grey hydrogen technology option capacity is constrained at the level of 2019 consumption for each country. The production capacity for blue and green hydrogen is not constrained. For a more detailed coverage of assumptions and Balmorel modelling see Appendix D. Main assumptions in the Balmorel model and the MSc thesis Modelling of regulation and certificates for hydrogen and renewable gases [25].

For hydrogen production Figure 24 shows that production in the countries depends mainly on the domestic demand. Germany has the highest production followed by the Netherlands.

Only a smaller fraction of hydrogen production remain grey hydrogen as seen in Germany and the Netherlands. This illustrates that imposing the environmental tax also on grey hydrogen and exempting (nearly) the blue hydrogen from this tax will make blue hydrogen competitive versus grey hydrogen in 2030 for the reference scenario. The reference scenario does not consider specific country wise targets for green hydrogen or existing regulation banning CCS that could effectively block blue hydrogen as for instance is the case for Austria. The composition of hydrogen production mix is based on technology competitiveness that is influenced by many parameters including EU-wide taxes and ETS prices.

Green hydrogen is produced in Norway, Sweden and France driven by lower power prices in these countries. Green hydrogen and blue hydrogen is competing closely and where power prices are low green hydrogen substitute the blue hydrogen. Gas transmission costs are also affecting green hydrogen from Norway and Sweden, it limits the green hydrogen production in the Nordic countries as exports are not yet competitive versus blue hydrogen in export markets.

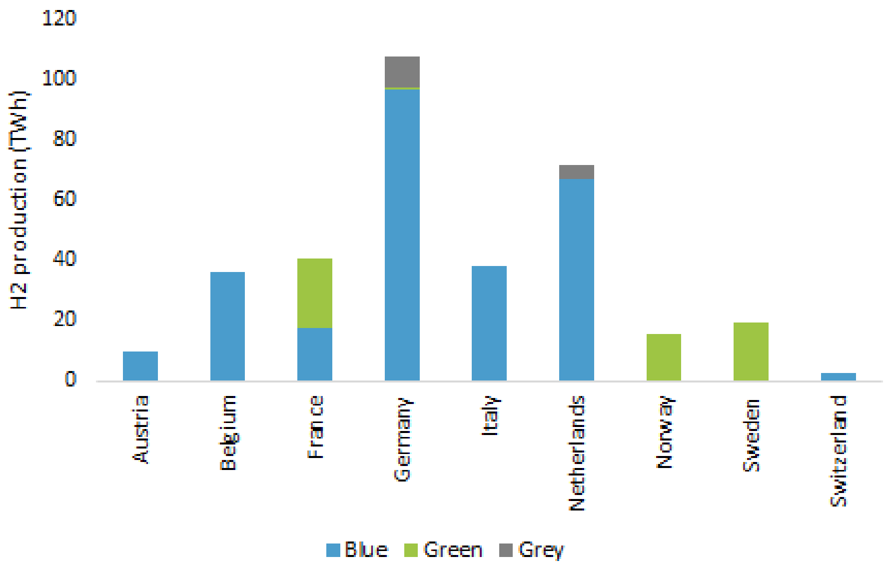

Figure 24. Hydrogen production mix in 2030 for reference case with taxes. [25]

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The production mix is sensitive to a number of key parameters and this apply to both reference scenario and the following certificate scenario. Therefore sensitivity analysis has been carried out for natural gas price, CO_2 price, hydrogen pipeline (transmission) cost and green hydrogen certificates. For results of this sensitivity for the green hydrogen certificates see (Itzel Thesis, section 6.1). Additional parameters would also impact the production mix including electricity prices, capacity costs and efficiencies of hydrogen technologies. Lastly the actual emissions including methane from grey and blue hydrogen production is uncertain and could impact the reference scenario production mix.

The hydrogen transmission flows in 2030 resulted to be 73 TWh, however, most of these were at a national level from one region to another. The cross-border trade is illustrated in Figure 25, the net flows account for 15.5 TWh (21%) of the total flows. Only green hydrogen is traded between Norway and Sweden and then these go from Sweden to Denmark and Germany. Denmark has no hydrogen production in the reference scenario. This may not fully correspond to present day natural gas connections, but these are the net flows.

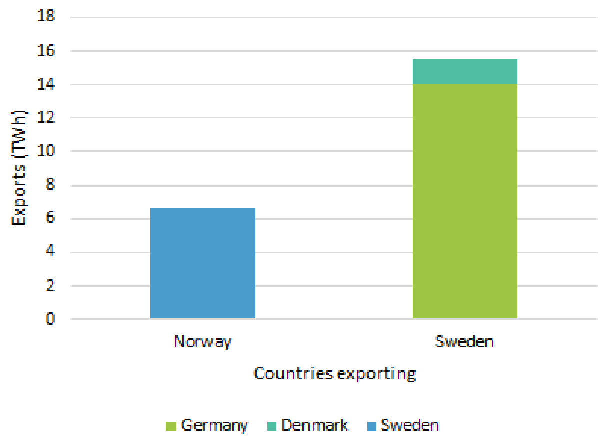

Figure 25. Hydrogen transmission flows in 2030 for reference case with taxes. [25]

Hydrogen certificate scenario

To illustrate the effects of using a certificate price as a subsidy to support green hydrogen production we simulate a certificate with a price of 2 €/MWh. This simulation is based on the reference scenario and adding certificates by reducing the operational cost of green hydrogen production by 2 €/MWh. The production cost of blue and grey hydrogen remain unchanged.

The certificate scenario (Figure 26) shows that the production composition among the countries changes and the composition of technologies within countries also change. Total hydrogen production is increased in France, Sweden and Norway. Production decrease in Netherlands and

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Belgium, the values for all countries can be found in Appendix E. Hydrogen production mix under different scenarios.

Green hydrogen production dominates total hydrogen production with Norway, Sweden and Denmark producing only green hydrogen, France also produces almost only green. Only Italy, Austria and the Netherlands maintain blue hydrogen dominance and Germany maintain a smaller share for blue hydrogen.

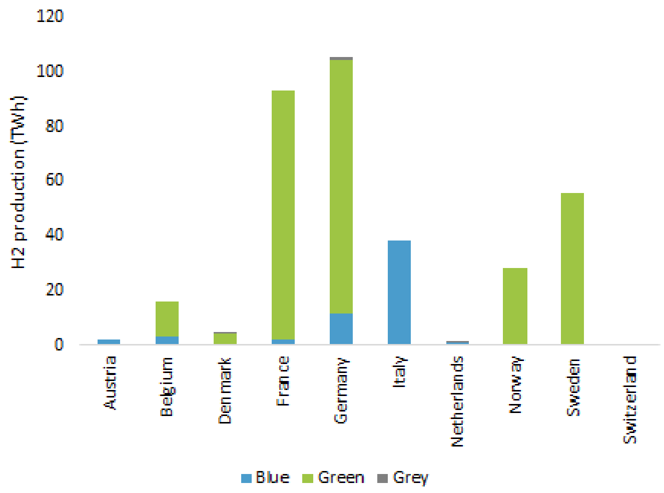

Figure 26. Hydrogen production mix in 2030 scenario with taxes and certificates. [25]

Hydrogen transmission flows are increased considerably with excess production in Norway, Sweden and France. The Netherlands will be importing a large share of domestic consumption as will Austria and Belgium will increase imports considerably. Italy is still producing corresponding to domestic demand, but here the blue hydrogen is still competitive versus the green hydrogen. This result is depending on the assumptions for PV production costs in Italy and the amount of additional PV installation required to really affect the average power prices. Denmark is producing little green hydrogen but serves as a transit country now for the gas as reflected in the flows in Figure 27. The shorter gas transmission distance is not sufficiently reducing the cost to balance the effect of somewhat higher electricity prices than in some of the other Scandinavian regions.

The electricity price differences are driving the competitiveness of hydrogen and an illustration of how hourly prices for some illustrative weeks influence the mix between green and blue hydrogen production is included in Figure 28. It illustrates the hourly variation on blue and green hydrogen production during week 1 of 2030. Blue hydrogen peaks coincide with high electricity prices and zero green hydrogen production.

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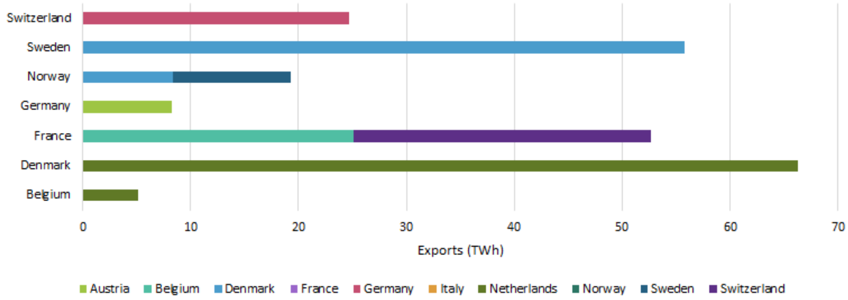

Figure 27. Hydrogen transmission flows (gross numbers) in 2030 scenario with taxes and certificates. [25]

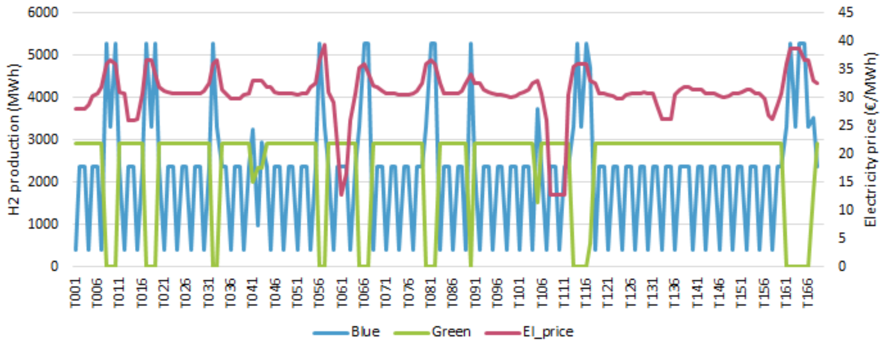

Figure 28. Hourly electricity prices and hydrogen production in France in 2030 . [25]

In this scenario, it is shown that green hydrogen competitiveness and thereby hydrogen trade flows are sensitive to adding a certificate subsidy of moderate size. Sensitivity of the impact of alternative certificate prices is illustrated in the master thesis [25]. The finding is that the certificate level affects the share of green hydrogen, with a certificate price of 0.5 €/MWh the share is 27%, this increases to 40% with a certificate of 1 €/MWh. The maximum impact of the certificate price will be around 2-3 €/MWh, where the green hydrogen share is 83-94%. After this level, the share does not increase a lot.

Moreover, certificates also drive transmission flows and trade between countries. At a certificate price of 0.5 €/MWh, net exports are only 22 TWh, however when the price increases to 1 €/MWh, exports increase to 36 TWh. This factor corresponds to 110 and 112 TWh with certificate prices of 2 and 3 €/MWh respectively. After this certificate price, the trade does not increase but remain constant at around 115 TWh.

Results are also influenced by the natural gas price, CO_2 tax (ETS price), gas transmission costs and the investment costs of green and blue hydrogen technologies. For further sensitivity on a number of these assumptions see [25], chapter 6.

An alternative illustration of the potential for certificate trade was considered. It is possible to use the maximum certificate export shares for biomethane observed today and assume that similar levels for export/import share of the total production of green hydrogen can be achieved in 2030. Using the same overall hydrogen demand projection as in the Balmorel simulations would give a very high estimate of potential green hydrogen certificate trade in 2030. The first

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solution based on trade flows in Balmorel simulations is considered the best option and numbers for the alternative is not presented in this report.

Concluding remarks

This report covers the present situation in renewable gas and hydrogen demand and production in Europe with a focus on project partner countries. Furthermore, the design and regulation of gas and electricity certificates are outlined. This leads to an overview of the present biomethane certificate trade and a comparison with the development in electricity certificate markets.

The second part illustrates the possibility for the trade of hydrogen in Europe among the partner countries and neighbouring countries assuming that the trade going on in 2030 will be based on green hydrogen production. Using the Balmorel model we hereby provide an illustration of possible certificate trade flows in 2030. Some key results are:

- Current biomethane production is less than existing conventional hydrogen production and quite marginal compared to natural gas consumption.
- Biogas production is somewhat larger than biomethane and only for Denmark and Netherlands a considerable share is upgraded to biomethane. Germany has a large biogas production of which a smaller share is upgraded to biomethane.
- Certificate registries and designs for renewable gas certificates exist, but there is no uniform EU level registry or market platform.
- Certificate trade today is mainly seen in biomethane certificates and dominated by relatively few countries in particular Denmark. There is so far almost no trade in other renewable gas or hydrogen certificates. Certificate trade is among other factors triggered by energy tax exemptions in consuming countries and they are not a major driver for investment in biomethane production capacity.
- Electricity certificates issuing have grown a lot and are now widely used and traded but at quite modest price levels ranging from 0.5€/MWh to 2€/MWh in recent years corresponding to 2-3% of electricity wholesale prices. The market is several times larger than the biomethane certificate market, but renewable gas certificate markets have the potential to develop in the same way as has been seen for electricity certificates.
- A potential illustration for 2030 based on aggregate European hydrogen demand projection and using the Balmorel model show that among other key parameters also certificate prices could play a key role in increasing the share of green hydrogen production and not only in the areas that have the largest hydrogen demand.
- A reference scenario using exogenous projection of hydrogen demand in the modelled countries illustrate that already in 2030 a large part of grey hydrogen production may be substituted with mainly blue hydrogen and to a smaller extent green hydrogen. This

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scenario does not consider specific country wise targets for green hydrogen or effects from regulation banning CCS as for instance is the case for Austria.

- Hydrogen certificates may be switching the competitiveness of green hydrogen relative to blue hydrogen as illustrated in the certificate scenario, drastically reducing the share of blue hydrogen produced in 2030. The effect on international certificate trade could be quite large in that situation as the hydrogen transmission costs are overcome by the lower green hydrogen production costs in regions with relatively lower electricity prices.

- Norway, Sweden and France may become exporters of green hydrogen and Germany and Netherlands importers and thereby certificate buyers. Italy will not import due to high gas transmission costs and will mainly use domestic blue hydrogen. The results are based on assumptions in the illustrated certificate scenario and trade flows are sensitive to a number of parameters including natural gas prices and the CO_2- tax level (ETS prices).

- The potential for green hydrogen certificate trade found in the scenario with taxes and certificates is around 110 TWh in 2030. This potential varies depending on the specific scenario assumptions for the countries covered in the Balmorel modelling.

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Appendix A. Overview of main documents on regulation of renewable gases used as a source.

Renewable gas and regulation overview [26]

- There is no current EU regulation for hydrogen that applies to all countries.
- ACER has the task to check and ensure a well-functioning internal energy market within the European Union + ENTSOE and ENTSOG.
- Renewable gases mix of commodity-based and destination bases, most likely the last one.

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- Certificates are available only in some countries, mostly for biomethane.
  Some price base and some quantity base.
- Currently, hydrogen has a small share (less than 10%).
- Biogas supported by different mechanisms mainly for electricity purposes.

Rules for biomethane certificates. ENERGINET [27]

- Definitions for biomethane certificates.
- Detailed the process on how to register and ask for a certificate, how the assessment of a facility is done.
- Describes how the process of registering a certificate and cancellation of it is done, its lifetime and how to transfer it.

Future markets for renewable gases and hydrogen. [28]

- Information on national registries for biomethane.
- Cost of natural gas 20 EUR/MWh, renewable gases from 40 to 120 approx. EUR/MWh.
- Sustainable bio-methane potential only covers 25% of the EU demand.
- Gas certificate system based on voluntary agreements. Electricity has European Energy Certificate System (EECS).
- Mass balancing, only between countries with physical frontiers. This approach is used in the gas market because of the European Renewable Energy Directive and the Fuel Quality Directive, which only recognise international trade in certified liquid and gaseous biofuels when the physical transfer is coupled to the trade in the certificates.
- Each country has their own regulatory body with very particular characteristics. In report only stated Netherlands, Germany and Italy.
- ERGAR (European Renewable Gas Registry) to facilitate the trade through Guarantees of Origin.
- Need of certificates, but not describe the precise design of the scheme. Thus, need for international standardisation and public ownership.
- Need of imposing renewable gas obligations on retailers and priority access to the grid.
- Recommendation on EU targets:
    a. Biomethane: 10% for 2030 and 25% for 2050.
    b. Hydrogen: 100% of the current demand must be neutral CO2 hydrogen (with CCS).

2. Support level for bio-methane of around 30-200 €/MWh depending on the externalities considered. For hydrogen, the support should be between 50-200 €/MWh.

Appendix B. The Hydrogen Act

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The "Hydrogen Act" is a document published by Hydrogen Europe and includes the existing framework to harmonise and integrate all hydrogen actions and legislation. This document sets the actions to follow in the next 30 years divided into 3 periods or phases with two main topics (Figure 0.2). The first topic (blue) is related first to infrastructure and the second (green) to market growth. During the ramp-up phase, between 2025 and 2035, most of the regulatory aspects will be set, both, support mechanisms (tariffs, quotas, investment support, tax relief) and guarantees of origin. It is expected that most hydrogen production will achieve commercial competitiveness by 2035. After 2035, it is expected that the hydrogen market will be liquid and new market rules will be required to avoid failures. Moreover, the guarantees of origin will be a tradable commodity, as green GO for electricity.

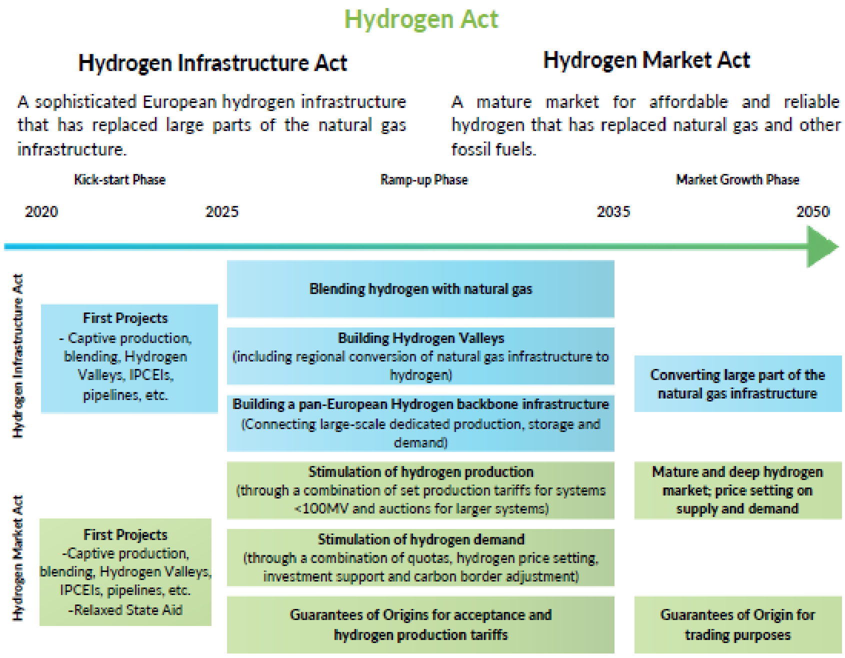

Figure 29. The hydrogen act. [29]

Guarantees of origin are also addressed by the hydrogen act, some of the main aspects are:

- Since the objective is to decarbonise all the energy sectors, a special focus should be on the carbon content of the energy careers used for hydrogen production, even for renewable technologies.
- It should be included whether the hydrogen meets certain criteria to be blended with natural gas or to be injected into the hydrogen grid.
- As for biomethane, the GO must be issued at the time of production. It could be transferred directly from the producer to a consumer without being injected into the grid.
- The national TSOs/DSOs will be responsible for the administration of the natural gas grid and the hydrogen grid.
- After 2035, green hydrogen can be traded, therefore common criteria and platforms for all Europe are necessary.

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- The same benchmarks for the carbon content of the molecules and sustainability criteria should be applied to all countries to facilitate imports and exports.
- Imports from other Non-EU countries will be possible through a validation process by an EU body at the EU point of entry.
- When the tariff/auction system for hydrogen starts, but the market is not developed, bilateral agreements with neighbouring countries could agree on annual volumes and prices.
- It is expected to have hydrogen quotas, which can be fulfilled by using the Hydrogen Guarantees of Origin (HGOs).

Appendix C. National Energy and Climate Strategies

Austria [10]

- Reduction of GHG emissions by 36% compared to 2005.
- Renewable energy in the gross final energy consumption of 46-50% and 100% in electricity.
- The Penta countries will examine possible common approaches for guarantees of origin, cross-border infrastructure, the role of TSO and DSOs and standards for hydrogen blending, as well as support schemes for hydrogen and innovation projects.

Denmark [30]

- 70% reduction in greenhouse gas emissions in 2030 compared to 1990 levels.
- 55% of renewable energy in gross final consumption in 2030.
- Specifies target for electricity, but not for gas.
- Power-to-X is only mentioned as alternative fuels mostly for the transport sector.

Germany [31]

- Reduction of 55% greenhouse gases emissions by 2030 compared to 1990
- 30% share of renewable energy in the gross final energy consumption.
- Renewable gases will help as base demand electricity, transport and the industrial sector.
- No additional support for first-generation biofuels based on food crops.
- The future production of biofuels will be based on waste materials and residues (advanced biofuels). A specific quota for advanced biofuels will be introduced.

Italy [13]

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- Increase of renewable energy up to 30% of the gross final energy consumption by 2030, particularly 22% of the gross final consumption in the transport sector.
- Renewable gases help in transport and high intense industries in the medium term.

Netherlands [16]

- Reduction of 49% greenhouse gases emissions by 2030 compared to 1990
- Electricity target share of 27%
- The target for renewable gas in the transport sector of 1.1%.
- Renewable gases will help in the transport, electricity and industrial sector

Appendix D. Main assumptions in the Balmorel model

The level of taxation implemented in the model is shown in Figure 30, this corresponds to the future carbon price. Taxes are represented in euros per tonne of CO_2 emitted. The current level is 25 EUR/ton CO_2 and it increases constantly up to 2050. The CO CO_2 price is uncertain, in this study a carbon price of 50 25 EUR/ton CO_2 was considered in 2030. In 2050, the carbon price increases to 100 EUR/ton $CO_{2.}$ The carbon price increases constantly from 2021 to 2050. Also, to account for the CO_2 emitted by grey hydrogen production, the CO_2 cost was added to the fuel cost of grey hydrogen, this corresponds to 2.5 EUR/GJ in 2030 and 5.1 in 2050.

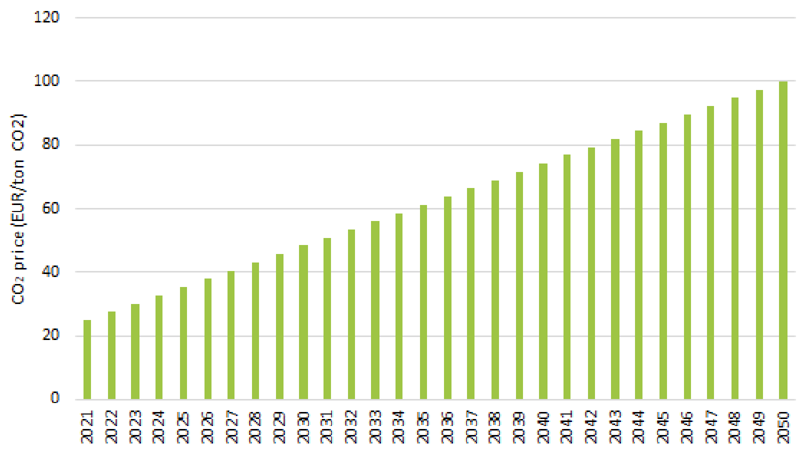

Figure 30. Environmental tax level.

When analyzing the level of taxes in previous years, it was found that countries have different levels of taxes (Figure 31), their development in recent years has also been different from one country to another. Therefore, to model the future development of fuel taxes, it was considered that in 2030 all the countries will unify their tax levels. Thus, in 2030, all EU countries have the

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same tax level, for natural gas corresponds to 2.9 and 3.7 EUR/GJ for heating and electricity respectively.

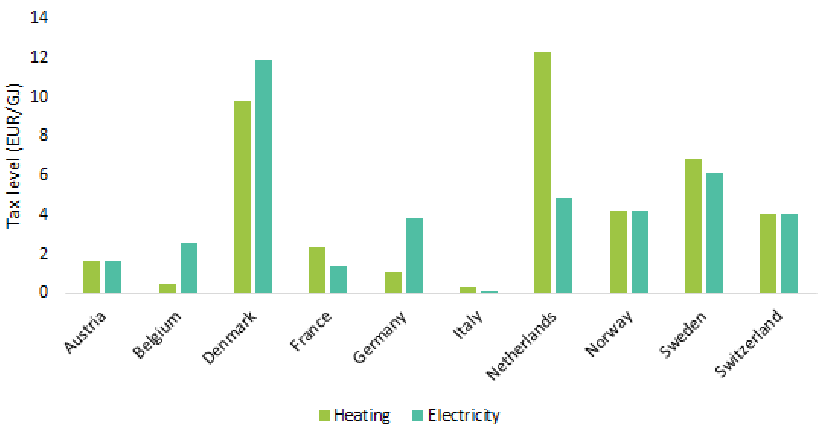

Figure 31. Fuel tax level for heating and electricity 2021.

Appendix E. Hydrogen production mix under different scenarios.

Table 4. Hydrogen production mix in 2030 for reference case with taxes.

	Blue	Green	Grey
Austria	9.91		
Belgium	35.93		
France	17.52	22.93	
Germany	96.94	0.47	10.53
Italy	38.31		
Netherlands	67.35		4.42
Norway		15.70	
Sweden		19.48	
Switzerland	2.85		

Table 5. Hydrogen production mix in 2030 for scenario with taxes and certificates.

	Blue	Green	Grey
Austria	1.70		
Belgium	3.36	12.89	
Denmark	0.01	4.23	0.01
France	1.91	91.15	
Germany	11.45	92.99	1.46
Italy	38.31		

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Netherlands	1.06		0.05
Norway		28.31	
Sweden		55.52	
Switzerland	0.11		
Total	57.91	285.09	1.52

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