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Power to Gas – Potential Markets in Europe

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Abstract

The main objective of this paper is to identify potential markets in the European Union with the best perspectives for a future development of the Power to Gas technology concept.

To ensure easy and quick access to the major findings, a market analysis tool is developed which takes into account various factors to assess the markets regarding their future business opportunity of an installation of Power to Gas plants. The assessed factors majorly analyze the fields of legal and economic influences, but also take into account technological aspects and social engagement. The use of essential external factors creates an understanding for potential market growth or decline, the market size or the competitive situation of power to gas when compared to other technologies.

The developed market analysis tool with integrated rating scale provides comparable results of an initial market analysis and enables a quick understanding of where the core challenges of each market are. Furthermore, it can be adapted to other markets, providing the basis for future market analysis.

Keywords: Power to Gas, Market Analysis

Introduction

This paper focuses on the evaluation of potential future markets for Power to Gas (PtG) in the EU. It is to be seen as an initial assessment and guideline to understand which of the European markets should be chosen for in-depth analysis regarding their future need for PtG.

At first, the current situation of PtG in the EU is summarized using technical and economic aspects and the increasing need for flexibility options, such as energy storage, which have been pointed out in previous chapters. Subsequently, a series of factors is analyzed on their current situation and, if applicable, their hypothetical future development to derive the role of PtG in the transition towards a more sustainable energy system within countries in the EU.

As a conclusion and to increase utilization of the results from the factor assessments, an overall rating shows which of the analyzed markets is seen to promise the most potential for the development of PTG.

To achieve a better understanding on how certain factors influence the development of PtG, three exemplary markets in the EU have been chosen for this analysis. All three markets show promising characterizations regarding PtG but greatly vary in their market design. The main arguments speaking for the selection were their differences in share and absolute numbers of intermittent power from RE, the energy market size, and the geographic location within the EU. The result for each analyzed factor shall be seen as an indicator for how to assess other markets regarding PtG, which show similar factor characteristics. Nevertheless, it is strongly advised to not conclude from the results from one market to another. A country specific analysis either for initial assessment or in-depth analysis is always required to specify the potential of PtG.

1 Power to Gas

PtG is a sustainable technology concept that enables long-term energy storage and facilitates the integration of fluctuating renewable energy (RE) in the energy system. It converts excess power from intermittent RE through electrolysis to hydrogen and respectively through methanation to methane. Both gases can be stored in the gas infrastructure and used at required time in a variety of fields of applications, such as mobility, industrial, heat supply and power generation applications. This multi-system use makes PtG a unique energy storage concept, bringing the energy transition from the power system to all other energy systems (Deutsche Energie Agentur, 2014).

Figure 1.1.1 illustrates the PtG concept. The three processes that define an energy storage system are the charge of the energy storage by converting power to gas, the storage, for example in the gas infrastructure and the use of the gas in one of the various fields of applications of PtG.

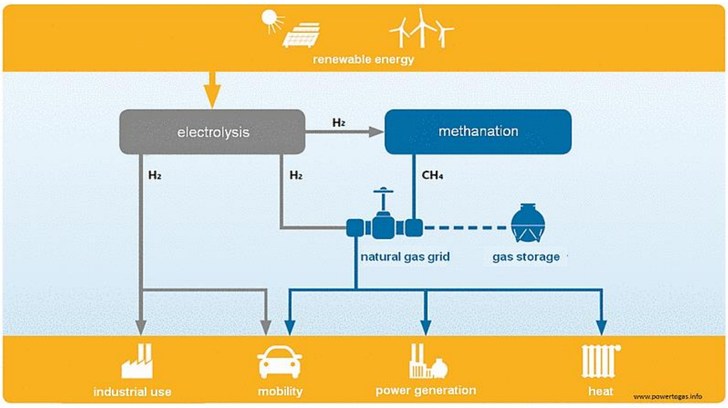

Figure 1.1 Power to Gas concept (Deutsche Energie Agentur, 2014)

In principle, the PtG concept can be differentiated regarding its produced gases, hydrogen and methane. The characteristics of both gases cause differences in the energy storage and in the fields of application.

2 Current Situation in the EU

PtG as a technology is functioning and ready for market introduction from a technical stand point. However, currently there is no realistic scenario where costs of hydrogen or methane from the PtG concept can compete against costs from traditional fuels or biogas. In fact, the costs of gas from PtG are for the most part several times higher (von Hausen, 2015).

The currently unfavorable economic and competitive situation of PtG is predicted to greatly improve over the next decades. The main arguments speaking for this development are the predicted decrease in technology installation and operational costs, the development of more favorable legal framework conditions, and increasing prices for fossil fuels.

The installation costs are predicted to decrease, especially once market launch for PtG occurs and series production of PtG plants starts. The decrease in operational costs of PtG stands in direct relation to the increase of the share of intermittent power supply. The EU climate and energy targets for 2020 and 2030 can only be reached if the massive increase in installations of RE systems continues. This pressures national government to further develop installation of wind and solar power and results in an increasing amount of intermittent power and times of overcapacities. The operational costs that are mainly affected by the amount of full load hours and the price of power purchase will therefore decrease over time (Sterner & Stadler, 2014).

However, the use of flexibility options, which adjust power supply, power demand, increase the electricity transportation capacity or enable energy storage, can strongly affect the described development of increasing overcapacities. To which extent they will be used in future in each country depends on technology, economic and legal framework conditions, such as the cost and price for the provided flexibility. Hence, their development is one factor of uncertainty for the further development of PtG and strongly depends on national government decisions (Sterner & Stadler, 2014).

A driver for PtG is the adjustment of legal framework conditions, such as taxation and remuneration of hydrogen and methane from renewable energy sources (RES). Higher sales prices and lower taxation could compensate the higher production costs for the gases and therefore, lead to an increasing use of the PtG concept. This is of importance when considering that the EU targets also count for other sectors, such as industry, heat and transport sector. Especially the development of reaching the 2020 sub-targets in the transport sector, shows deficits in most countries at the moment. The use of green gases, either as fuel or as component in the conventional fuel production, could be one way to easily implement the use of RE in the transport sector. Furthermore, there are indications that transportation, out of all sectors, offers the best economic framework conditions for PtG and is seen as potential area for market launch (von Hausen, 2015). The state and development of the framework conditions regarding PtG are different for each country and therefore require an individual analysis.

Finally, the future development of PtG is dependent on the development of fossil fuel pricing and availability, as well as increasing prices for carbon dioxide emissions rights or the creation of a carbon dioxide tax (ECN & DNV-GL, 2014). Many predictions, suggest an increase in prices for fossil fuels and carbon dioxide rights. This development would increase the costs and prices for fossil fuel using applications and therefore help improve the economic competitiveness of the PtG concept.

3 Factor Analysis for Exemplary Markets

In the following, three markets will be analyzed for seven factors regarding their suitability for the PtG concept. The exemplary markets chosen are Denmark, Portugal and Germany.

Portugal is a typical example for a peripheral state with high potential for RE, such as intermittent power from wind and solar, which has a small energy market size and little potential for interconnectivity to other markets. Germany and Denmark are examples for centrally located states with high potential for interconnectivity. Germany, on the one hand, is the biggest energy market in the EU, whereas Denmark is a small energy market but has the highest share of intermittent power in the EU. All countries have plenty of options to provide the flexibility needed to enable an increasing use of intermittent power sources. However, country specific differences for chosen flexibility options are discussed to assess the potential of PtG.

Share of Intermittent Power from Renewable Energy

The share of intermittent power from RES strongly affects the operating hours and costs of PtG plants. As described before, an increase in numbers of overcapacities has immediate effect on the economics of the PtG concept because it increases the full load hours and lowers the power purchase costs.

Starting at a level of above 25 % of intermittent RE sources, the operation of these sources has to be curtailed during times of low consumption to avoid grid perturbation and congestion (European Commission, 2013). Before that share, the grid operator is able to compensate the intermittency. Alternatively to curtailment, flexibility options can help balancing power demand and supply.

Figure 3.1 shows the composition of the non-carbon electricity supply and breaks down all forms of RE sources. Excluding nuclear power, which is not a type of RE, the countries in the EU with the highest share of electricity from RES are Austria, Sweden and Latvia, which have vast access to hydro power. Countries with power that majorly comes from hydro power have a very stable power supply. Incase power supply does not match demand; hydro power plants can quickly adjust to the requirements. This also facilitates the integration of intermittent power sources.

Most new power plant installations in recent years were wind and solar power plants, which produce intermittent power. As Figure 3.1 shows for 2012, Denmark has the highest share of wind and solar power combined with circa 33 % wind and 1 % solar power, followed by Portugal with circa 22 % wind and 2 % solar power. Germany has the fifth biggest share in the EU with 7.4 % wind and 4.5 % solar power. If the given shares in 3.1 are compared to Figure 3.2, the strong growth of wind and solar power installation since 2002 becomes visible (US Energy Information Administration & International Energy Statistics, 2014).

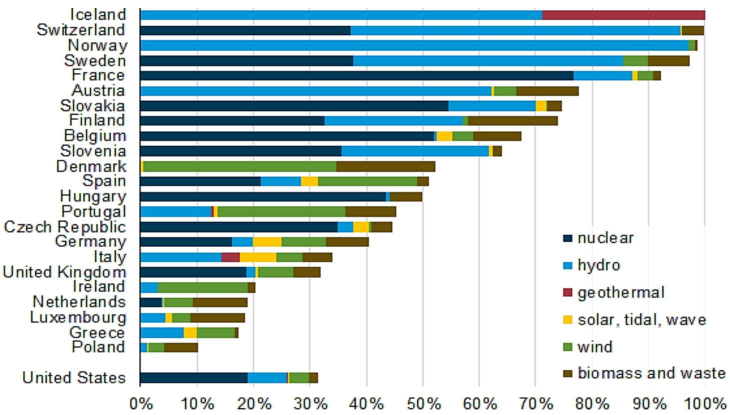

Figure 3.1 No-carbon electricity share of total generation in European Countries and the United States in 2012 (US Energy Information Administration & International Energy Statistics, 2014)

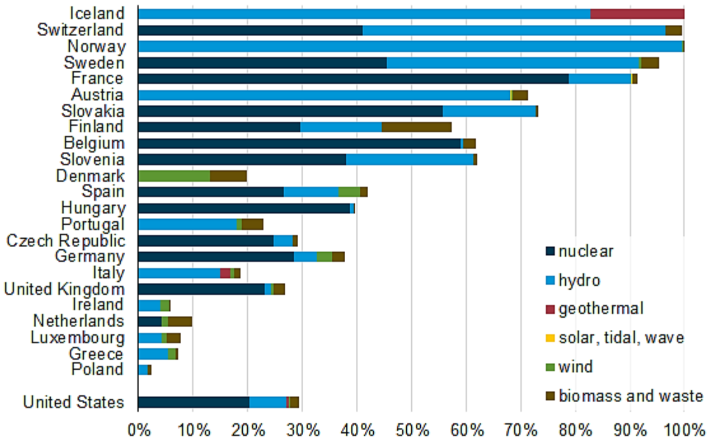

Figure 2.2 No-carbon electricity share of total generation in European Countries and the United States in 2002 (US Energy Information Administration & International Energy Statistics, 2014)

The strong growth of wind and solar power is predicted to continue in future, especially in Denmark as forerunner. Denmark aims for 50 % intermittent power from RE in 2020 and up to 84 % of power from wind turbines in 2035 (Danish Wind Industry Association, 2014). Germany aims for 26 % of power from solar and wind sources combined in 2020 (UBA, 2015) and approximately 80 % in 2050 (SRU, 2011). Portugal aims for circa 27 % of power from solar and wind in 2020 (European Renewable Energy Council, 2011). Further figures for Portugal were not accessible, but a continuing increase is seen as likely.

In Future, Denmark will remain leader in the share of intermittent power production, if the growth continues as projected. Portugal, on the other hand, seems to experience slower growth rates until 2020, whereas the German average growth remains relatively constant in absolute terms. Nevertheless, Portugal's geographically isolated location and its vast wind and solar potential promises to enable a continuing future growth of installations of solar and wind power plants.

One crucial difference of the three markets is the distribution of the solar and wind power plants. Whereas plants in Portugal and Denmark are more or less evenly distributed over the entire country, with a concentration in coastal areas, Germany has the major part of wind power installations in the north and solar power installations in the south. This uneven distribution results in even higher shares of intermittent power in certain regions than expressed in the averaged national level (VKU, 2013).

Energy Market Size

The energy market size is considered in order to gain a basic understanding for how much energy is consumed as electricity and gas in each country. Both energy forms play an important role in the PtG concept. Furthermore, the amount of electricity consumed helps to see the significance of intermittent power from RES in absolute terms.

Table 3.1 shows that Germany is more than 10 times bigger than Denmark or Portugal when comparing the total energy and electricity consumption and approximately 20 times bigger when comparing the gas consumption.

Since the electricity market is much bigger in Germany, this also means that there is the highest amount of intermittent power generation in absolute terms. Taking into account the uneven distribution of intermittent power generation, mentioned in the previous chapter, this signifies that there are potential regions which already have much higher shares of solar or wind power in absolute terms and as percentage and hence require earlier implementation of flexibility options.

Table 3.1 Energy market size in 2012 (EIA, 2013)

market size [TWh]	Denmark	Portugal	Germany
total primary energy consumption	216	287	3949
electricity consumption	32	47	540
gas consumption	40	47	944
energy consumption transport sector [%]	31	33	30

The gas consumption and the energy consumption in the transport sector are also much bigger in Germany. This means, if PtG is considered for gas production, or respectively for fuel production for the transport sector, Germany would be the biggest sales market, as well as buyer market for intermittent power. Portugal, however, has the strongest growth of primary energy, electricity and gas consumption, if the development of the past decade continues (EIA, 2013). Another argument speaking for Portugal regarding market size potential is that the country is the furthest away from reaching the EU sub-target of RE in transportation, and so could use PtG to catch up on it.

Storage Potential in the Gas Grid

The storage potential for hydrogen or methane in the gas grid is an indicator for how much energy can be stored when using the PtG concept to convert electric power to gas.

The potential storage capacity in the gas grid is indicated in Table 3.2. Germany has a more than twentyfold higher storage capacity for methane than Denmark and more than a hundredfold higher storage capacity when compared to Portugal. It also has vast storage capacities under construction and in planning, which will further extend the storage capacity (ZSW, IHS, IER, 2012). For example, when considering a methane to power conversion with an electric efficiency of 60 %, approximately 6.48 TWh and hence 20.25 % of the Danish electricity demand could be stored for long-term in the gas grid. In Germany, circa 24.11 % and in Portugal only circa 2.43 % of the yearly demand for electricity could be stored as methane in the gas grid (own calculations based on ZSW, HIS, IER, 2012 and IEA, 2013).

Table 3.2 Storage Potential in the gas grid (eurogas, 2013) (ZSW, IHS, IER, 2012)

storage size [TWh]	Denmark	Portugal	Germany
CH_4 storage existent	10.8	1.9	217
CH_4 storage under construction or in planning	n.a.	n.a.	163
H_2 as share in CH_4 storage (assuming max. 2% H_2)	~ 0.15	~ 0.03	~ 3.00

When considering the admixture of hydrogen with natural gas in the grid, the German maximum is 2 % hydrogen, cf. DIN EN 51624 (Dena, 2014). This figure has been adopted for Denmark and Portugal due to lack of information. Therefore, hydrogen storage capacity is much smaller than the methane storage capacity but still is in the multiple digit Gigawatt hour range. For example, when considering hydrogen to power conversion with an electric efficiency of 60 %, approximately 0.09 TWh and hence 0.28 % of the Danish electricity demand could be stored for long-term in the gas grid. In Germany, circa 0.33 % and in Portugal only circa 0.04 % of the yearly demand of electricity could be stored as hydrogen in the gas grid (own calculations based on ZSW, IHS, IER, 2012 and EIA, 2013).

Technology Alternatives

When considering technology alternatives to the PtG concept, all potential functions of PtG have to be taken into account, the feed-in of intermittent power, the long-term energy storage of high energy capacities, and the feed-out of green gas such as hydrogen or methane with its various fields for application. In the following, the potential of the three exemplary alternatives which can substitute some of the functions of PtG is briefly explained. The examples are interconnectivity of national power grids, extension of pumped hydro storage and heat storage. All examples can technically and economically impact the PtG development. Besides the given examples, there are other options to substitute functions of PtG but shall not be part of further discussion in this thesis.

The extension and modernization of the power grid is important to enable the distribution of locally generated power to the demand location and also to enable the transmission over long distances. Hence, it compensates supply and demand differences over distance and therefore helps balance intermittent power. When comparing Denmark, Portugal and Germany in terms of the ability to interconnect their markets with other markets, Portugal shows the least favorable characteristics. Its isolated location in Europe leaves only Spain as a potential market for interconnectivity, limiting the ability to transport excess energy or to compensate for undersupply. Denmark and Germany, on the other hand, are surrounded by neighboring countries and have high potential for interconnectivity. Additionally, their geographic location enables the connection to the vast hydro power potential as energy storage which is mainly located in the Alps and Scandinavian mountains. Norway, for example, could develop storage capacities of up to 84 TWh and Sweden 34 TWh (Czisch, 2000). Germany and Denmark both plan to increase or already have interconnectivity with Norway to sell their excess power (WIP Renewable Energies, 2014).

To lower fluctuations and to store energy, national available pumped hydro energy storages can be used. Their availability depends on the prevalent topographic characteristics. Table 3.3 shows that pumped hydro storage has no relevance in Denmark but is of importance in Germany and Portugal. The expected power capacity of pumped hydro storage is expected to grow quickly in Portugal until 2015 (European Commission, 2013). Furthermore, (eurelectric, 2011) suggests that Portugal has the technically feasible potential to increase its use of hydro power, including pumped hydro, to up to 25 TWh. This would be enough to cover half of the country's yearly electricity consumption and can also be used to increase flexibility in the grid. For Germany, the increase in pumped hydro storage capacity is limited. Current storage capacity of circa 0.04 TWh is expected to double by 2040. Still, it can only cover a fraction of the yearly storage need, which is projected to be in the range of 20 TWh to 40 TWh in 2040 (ZSW, IHS, IER, 2012).

Table 3.3 Installed pumped hydro storage power capacity in Europe (European Commission, 2013)

	Pumped Hydro (MW installed end 2010)	Pumped Hydro (MW to be installed 2011-2015)
Italy	8,895	
Germany	7,326	74
Spain	5,657	1,270
France	5,229	
Austria	3,774	1,027
UK	3,251	
Switzerland	2,729	1,628
Poland	1,948	
Norway	1,690	
Bulgaria	1,330	
Czech Republic	1,239	
Belgium	1,186	
Luxembourg	1,146	200
Portugal	968	1,660
Slovakia	968	
Lithuania	820	
Greece	729	
Ireland	594	
Turkey	500	
Sweden	466	
Romania	378	
Slovenia	185	
Finland	0	
Latvia	0	
Hungary	0	
Netherlands	0	
Denmark	0	
Cyprus	0	
Estonia	0	
Malta	0	
Total EU-27 plus Norway, Switzerland, Turkey	**51,008 MW**	**5,859 MW**

Another alternative to lower fluctuations in the grid and to store energy is to convert power to heat. When considering Germany, Portugal and Denmark for heat applications, Portugal shows the smallest heat demand due to its mild climate (IEA, 2014). In geographic locations with seasonal and daily demand for heat, such as Germany and Denmark, converting power to heat could be an alternative to lower fluctuations in the grid and to reduce overcapacities. In Denmark, power conversion to heat is already a common application today (Ostergaard, 2014). However, if there is little heat demand, for example in Portugal, PtG could be of more use because the produced gas can be used for applications in various sectors.

Regulations

At present, most EU countries do not have specific commercial regulations for energy storage (FCH JU, 2015). Therefore, storage systems are treated as a combination of power consumption and generation and as such have to conform to the relevant rules. Regarding PtG, these regulations strongly impact the commercial models. Both, the power purchase and the sale of hydrogen and methane from RES are regulated by different legislations and directives. Creating appropriate market signals to incentivize the building of storage capacity and provision of services are key for a successful market launch of PtG.

Regulations affect the market access and the remuneration of energy storages. Regarding market access, regulations have to be analyzed to understand which applications are allowed, for example, time-shift, frequency reserve, or transmission and distribution referral. Whereas storages can generally access the time-shift market in all EU countries, its ability to provide frequency reserve and transmission and distribution referral is limited to certain countries, for example Germany, for frequency reserve. Regarding remuneration, energy storage may be subject to fees relevant to both operation modes, consumption (feed-in) and generation (feed-out). Furthermore the remuneration can vary dependent on the application of the storage and hence requires individual assessment (FCH JU, 2015).

From the current perspective, Germany has the most developed regulations governing energy storage within the EU. In the following, main characteristic matters are given for Germany regarding PtG. The complexity of influencing regulations shows that country specific analysis is always required. For simplicity reasons and due to little accessibility of information about regulations in Denmark and Portugal, the applicable regulations are only given for Germany. Most regulations are currently under revision for further adjustment regarding PtG and so must be observed continuously to allow an accurate assessment.

In

, all regulations are stated that affect PtG in Germany. A more detailed description is given in the following.

Table 3.4 Regulations in Germany regarding PtG (Dena, 2013)

Regulations in Germany		
Legislations	Directives	technical regulations
Energy industry law (ENWG)	decree for access to the gas grid (GasNZV)	DVGW-G260 regarding gas characteristics
Renewable energy law (EEG)	Decree for gas network charges (GasNEV)	DVGW-G262 regarding use of gas from renewable sources in the gas grid
electricity tax law (StromStG)	Decree for concession fees (KAV)	DIN 51624: 2008 regarding fuels for vehicles - natural gas - requirements and test proceedures
Combined heat and power law (KWKG)		ECE-regulation 110 on the use of compressed natural gas
Energy taxations act (EnergieStG)		DIN EN 437 regarding test gas and test pressure for each category of devices
Federal Immission Control Act (BImSchG)		

First, the power purchased from RES is free of electricity tax (§9 StromStG), EEG levy (§37 EEG), KWK surcharge (§9 KWK), and concession fees (§1 KAV) if the electrolyzer is powered without using the public power grid. Second, if the public power grid is used PtG is exempt from grid usage fees for 20 years (§118 EnWG). If power from renewable sources is stored as gas but reconverted into power, it is free of the EEG levy (§37 EEG). However, if the gas is used for other applications, the EEG levy only decreases by 2 €ct/kWh (§39 EEG) (Dena, 2013). Third, if the electrolyzer is smaller than 2 MW, the purchased power is free of electricity tax (§9 Strom StG). Fourth, hydrogen and methane from a minimum of 80 % power and carbon dioxide from RES count as biogas (§3 EnWG). This increases remuneration, gives priority access to the gas grid, decreases costs for connection (§33 Gas NZV), exempts from feed-in fees (§118 EnWG), and exempts from gas grid costs for

10 years (§20a Gas NEV) (Dena, 2013). Fifth, methane from RES is taxed similarly to natural gas (§1a EnergieStG). Hydrogen as fuel for transportation is free of tax. In case the gas from the PtG concept is reconverted into power, the remuneration is as high as if the power came immediately from the original source, hence from wind or solar power plants. Energy losses due to conversion or storage are not remunerated (Dena, 2013).

Major critics about the regulations regarding PtG argue that the technology is classified as final consumer, and hence electricity tax always applies for the power purchase and the power supply from re-electrification. This, in addition to the non-existent total exemption from the EEG levy in case of other gas applications then re-electrification, is seen as main reason which stops the market launch of the PtG technology (Dena, 2013). To reduce the tax load for other gas applications than re-electrification is of importance because PtG is more economically competitive for applications such as fuels for transportation. The discussion of both, the elimination of electricity tax and EEG levy, is currently ongoing between stakeholders from industry, research and environmental protection on one side and policymakers on the other. It is of high importance because the power purchase costs are affected by the generation costs of about 32 %, the EEG levy of approximately 34 %, the electricity tax for 13 %, power grid usage charges of about 12 %, and a few other minor charges (Eon, 2014). Hence, if EEG levy and power grid fees do not apply, the cost for power purchase reduces to nearly half of the origin costs and therefore decreases the costs for gas from PtG. In contrast, since there is no crediting for hydrogen or methane from RES regarding the biofuel quota (§BImSchG) there is no current incentive to use these gases as fuel or fuel component in transportation because costs remains above market level for conventional fuels (Dena, 2013). This is another integral part of discussion about PtG, because it could enable to reach the targets of RE in transportation.

Regulation regarding PtG in Denmark and Portugal is very scarce. Danish regulations do not mention energy storage but in-directly discriminate their use. One example is the presence of double grid fees which occur because the power to charge the storage is seen as consumption and when the power is released it is seen as new power generation. This is similar to the critical point in Germany that classifies the electrolyzer as end user. However, in Denmark it also applies for the application of PtG if reconverted into power. The storage of natural gas is mentioned in the Danish act on natural gas (Naturgasforsynings loven), but does not indicate any adjustments for PtG (European Commission, 2013). Information on regulations in Portugal was not accessible. It shall be mentioned, though, that in 2013, the Portuguese government announced a tax on all power production, transmission, storage and distribution activities. Because it also counted for all existing operation plants, investors lost their faith in the security of new investments and reduced the numbers of new projects (European Commission, 2014).

All in all, the establishment of a sophisticated legal framework for energy storage systems, with adaptions for PtG, is required to enable a reduction in costs for the production of gas from RE. Since power, as well as gas, is heavily taxed in Germany, Denmark, and Portugal (European Commission, 2014) tax cuts for green gas is one option to promote PtG. This, in addition to, for instance, higher taxation of carbon dioxide emissions or for fossil fuel in general could contribute to a faster market launch of the technology concept PtG. Germany, with its adapted regulations regarding PtG, is the forerunner within the EU and has an ongoing debate on how to further promote the integration of this storage system in its energy supply system.

Prices for Natural Gas and Power

Purchase prices for natural gas and power strongly influence the operating costs of the PtG concept and hence the overall economics. To a large extent, they are dependent on the predominant regulations, mentioned in the chapter above. A high share of the price is due to taxation and grid costs. As described in the regulations in Germany, there are cases where certain tax and grid fees can be reduced or even ceased, for example, if the PtG application involves re-electrification of gas from RE. Therefore, a comparison of power and gas prices, their development and the share of taxation and grid fees is crucial to assess the development of operating costs and potential sales prices for the relevant applications of the PtG concept. Regarding gas prices, Portugal was the least expensive when compared to Germany and Denmark in 2012, cf. Table 3.. It should be noted, though, that the development from 2008 onwards shows a strong increase in price for Portugal, whereas in Germany it remained more or less constant. One factor that could have impacted this strong increase in price is Portugal's growing dependence on LNG imports, which amounted to 46 % in 2014. The increasing use of LNG requires cost intensive investments to build up the required infrastructure, increasing the costs for energy supply (Internationale Energy Agency, 2015). If the development in gas prices continues, Portugal may soon be the market with the highest prices for gas. Taxes and grid costs greatly impact this development. Tax cuts or a reduction in grid fees could be used to promote green gas by reducing their sales price for the end customer, improving competitiveness to conventional natural gas. The biggest potential for these discounts is in Denmark, where the gas price consists to one half from tax and grid fees.

When analyzing the power purchase price in 2012, Denmark had the lowest price, followed by Portugal and Germany. The development from 2008 onwards shows that Denmark's prices slowly decreased whereas the other countries experienced a strong increase. Decreasing power purchase prices lower the operational cost of PtG plants and hence are favorable. When comparing the share of tax and grid costs in the price, Denmark also shows the biggest potential for discounts to promote the use green energy concepts such as PtG.

Table 3.5 Prices development for natural gas and power (European Commission, 2014)

	Denmark	Portugal	Germany
Gas price 2012 [€ct/kWh], for Industry, incl. tax and grid costs	5.8	5.2	5.8
Share of tax and grid costs	48%	37%	31%
Price development 2008-2012	21%	63%	-3%
Power price 2012 [€ct/kWh], for Industry, incl. tax and grid costs	10	12	14.5
Share of tax and grid costs	60%	42%	55%
Price development 2008-2012	-5%	33%	32%

All in all, if the gas and power prices continue to develop similar to the past, Denmark is likely to be most favorable because it offers the potential of decreasing power purchase costs for the PtG plant and further shows increasing sales prices for the produced gas. Additionally, gas and power in Denmark are highly taxed and show high grid fees. Both could be reduced to promote the use of green energy within the PtG concept. These ideas for promoting green energy require an adjustment of the regulatory framework regarding PtG or at least for energy storages and therefore are highly dependent on the future action of each government.

Engagement

When analyzing the current engagement in PtG activities of each country, one can compare the activities in research, the number of pilot testing projects, engaged manufacturers, and operators of pilot plants, as well as the overall intensity of debates between stakeholders and policymakers.

According to participants and performing speakers of the yearly international renewable energy storage conference (IRES) in 2015 (IRES, 2015), as well as the amount of accessible information online, PtG is majorly under discussion in Germany. Most research studies originate from German institutions and universities, amongst others the RWTH Aachen, or the Center for solar energy and hydrogen research Baden-Wuerttenberg. Furthermore, nearly three quarter of all pilot plants are located in Germany. Denmark has one PtG pilot currently in operation, Portugal has none.

The operators of the pilot plants in Germany mainly come from the energy supply industry. Furthermore, research institutions and automotive industry show engagement in PtG activities. Germany has a high number of manufacturers of the main PtG plant component, the electrolyzer. For Denmark or Portugal no manufacturer of electrolyzers was located.

The high engagement in research and testing in Germany is centrally organized in the Power to Gas strategy alliance, a network of international and national companies, mainly from the energy, chemical and automotive industry, and research institutions with the German energy agency as body for external presentation and as contact for policymakers.

4 Conclusion

The overall rating of the market potential of Germany, Denmark, and Portugal is summarized in Table 4.1. It shows the evaluated suitability for future market introduction of the PtG concept for each market. All markets had been classified as examples for promising markets in the EU prior to this assessment.

For the market evaluation, each analyzed factor has been weighted depending on their importance. The share of intermittent power from RES has been evaluated as a main impacting factor and has the highest weighting, followed by market regulations and engagement of stakeholders. Each factor has also been rated regarding its benefit for the PtG technology concept. The rating number “5” stands for highly beneficial for PtG and number “1” for least beneficial. To give the reader a quick and basic understanding, the main influencing characteristics are given for each factor and country. The symbol “+” indicates a positive impact and “-“ a negative.

The result of the market assessment shows similar results for Germany and Denmark, indicating a little higher potential for Germany. Both promise to have potential for using the PtG concept in future. The potential use of PtG in Portugal is evaluated as limited. An in-depth analysis should focus on the other markets first.

When comparing the similar overall rating for Germany and Denmark, one can see that the results for each factor show great differences. Denmark’s targets on wind power installations make a sooner application of PtG than in Germany likely. However, the German market is much bigger and does not evince the regional variations in intermittent power, which potentially leads to an earlier introduction of PtG in the north of the country. Also in absolute numbers, the installation of intermittent power sources in the market is much higher. Furthermore, the much higher storage potential for gas makes Germany technically more favorable for long-term energy storage. Since there is generally much more research and testing activity regarding PtG in Germany, the country already started to adapt regulations to enable a legal framework for PtG. In spite of this, the regulations from current stand point do not favor PtG enough to enable a competitive market launch. Denmark, on the other hand, has not adapted any regulations yet. However, its pricing system for gas and power, with its high tax and grid fees, shows off the highest potential for discounts to enable a decrease in operational costs and a more competitive sales price for green gas from the PtG process.

All in all, the performed market evaluation is to be seen as initial assessment to gain an overview of how to evaluate the PtG potential in markets in the EU. It shows off the factors that have been identified as majorly impacting and demonstrates their variations in the markets of Germany, Denmark and Portugal. Germany and Denmark have been identified as the most favorable markets. For deeper understanding, and to evaluate if a PtG plant can operate competitively in one of these markets in the future, an in-depth analysis should be undertaken. By taking into account additional factors or weighting each factor differently, the results of a subsequent analysis can greatly vary from the results in this thesis performed initial assessment.

Table 4.1 Market potential of Germany, Denmark and Portugal

Factor	Wt.	Country	Germany	Denmark	Portugal
Share of intermittent renewable energy	30%	Rating	**3**	**5**	**3**
		charact-eristics	- 26 % in 2020 + 80 % in 2050 + uneven distribution	+ 50 % in 2020 + 84 % in 2035	- 27 % in 2020
Energy market size	10%	Rating	**5**	**2**	**3**
		charact-eristics	+ highest consumption of total primary energy electricity and gas	- lowest consumption	+ strongest growth in energy consumption over the past decade
Storage potential in the gas grid	5%	Rating	**5**	**3**	**1**
		charact-eristics	+ 217 TWh CH4 + high extension potential	+ 10.8 TWh CH4	- 1.9 TWh CH4
Technology alternatives	10%	Rating	**3**	**2**	**3**
		charact-eristics	- interconnection to skandianvian or alpine hydro power possible + little pumped hydro potential - high potential for power to heat storage	- closest distance to skandinavian hydro power for storage + no pumped hydro potential - high potential for power to heat storage; already in use	+ low power grid interconnectivity to other markets - highest extension potential for hydro power for storage
Regulations	20%	Rating	**3**	**2**	**1**
		charact-eristics	+ forerunner regarding adaption of legal framework for PtG	- double grid fees	- tax on power production, transmssion, storage and distribution
Prices for natural gas and power	10%	Rating	**2**	**5**	**3**
		charact-eristics	+ potential for green energy discounts, especially power	+ high gas price + low power purchase price + high potential for green energy discounts	+ strongly increasing
Engagement	15%	Rating	**5**	**2**	**1**
		charact-eristics	+ PtG strategy alliance + majority of pilot projects + high activities in research, manufacturing and industry involvement	+ one pilot project	- no pilot projects
Overall rating when considering all factors			**3.50**	**3.25**	**2.20**

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