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Power-to-Gas via Biological Catalysis

WP9 – Market Analysis

Preface

This report is made as a part of the project: "Power-to-Gas via Biological Catalysis" that analyses and demonstrates commercial operation of a 1 MW P2G facility producing pipeline ready biomethane. The analyses and report are conducted by Lasse Helleskov Ravn, Neas Energy, in 2014. Neas Energy is responsible for WP9 – "Market analysis & Trading strategy" and the report covers the first part (market analysis) of the WP9.

The demonstration project is supported by the ForskEL program, which administered by Energinet.dk. The partners in the project are:

- Electrochaea (Project coordinator)
- Hydrogenics
- Audi
- Energinet.dk
- Neas Energy
- HMN Gashandel
- SVC Avedøre
- Insero Business Services

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1. Value source identification and quantification – electricity markets

This chapter contains a brief description of how the energy system will develop and how it may influence the balancing needs. Furthermore, it contains a description of the different electricity markets, in which physically electricity is traded: Elspot, Elbas, Regulating power market and Reserve markets.

1.1 Future energy system and balancing needs

The Danish Government strives to achieve an energy system that is independent of fossil fuels in 2050. The Danish Energy Agency has, May 20th 2014, published a report concerning the challenges related to replacing fossil fuels with renewable energy towards 2050. In the report four scenarios are presented. In two of the scenarios, the energy system is highly electrified and primarily supplied by wind turbines whereas the other two scenarios are combustion based and primarily supplied by biomass (Danish Energy Agency, 2014). According to the Danish Energy Agency it should be decided, shortly after 2020, which strategy to prioritize.

Regardless of strategy, the wind power capacity will increase towards 2050 to a minimum of 7000 MW (2020 level) in all four scenarios. A minimum of 12,000 MW wind capacity will additionally be installed towards 2050 according to the wind scenarios. Furthermore, 2000 MW PV is expected in the system by 2050 (Danish Energy Agency, 2014). The question is how to secure security of supple in the electricity sector if the capacity of fluctuating renewables is going to increase significantly in the future.

September 12th, Energinet.dk published their strategy plan for 2015 to 2017, in which Energinet.dk states the importance of procuring flexibility to adapt to the increasing share of fluctuating renewables. Furthermore, Energinet.dk writes in the strategy plan that the current market model does not provide the right incentive to act flexible or invest in flexible production or consumption units. Therefore, the market needs to be adjusted to secure domestic flexibility. Clear price signals should reflect the system needs and provide the right incentive for operate flexible. (Energinet.dk, A, 2014)

Larger price variations will increase the economic incentive to provide flexibility and Energinet.dk will support the transition of a market model with larger but manageable price variations (Energinet.dk, A, 2014). However, no concrete initiatives that may increase the economic incentive for providing flexibility are described in the report. Energinet.dk has though started a project, in which relevant market actors should identify potential adjustments to the current market model. At the end of the 2017, the project group will outline the adjustments that will be implemented in the long run.

Finally, Energinet.dk also highlight the importance of increasing the capacity of cross boarder interconnections as a part of their strategy to integrate more fluctuating renewables. Here, the initiatives are more concrete with several projects planned e.g. to Holland, Germany and Norway. The short term consequence of increasing the capacity may result in price neutralizing effect between price areas as less bottlenecks occur. The long term effect may be larger price variations when neighbor countries increase their capacity of intermittent renewables as well.

The question is how these things influence the need for balancing in the future. This is difficult to predict but experiences so far may give an indication of what can be expected in the future. In the previous year's more situations where the frequency has dropped below 49.5 Hz and increased above 50.5 Hz, has occurred. It indicates that the need for automatic reserves may increase in the future when more fluctuating renewables will be installed. The need for regulating power (tertiary) has decreased because TSOs has become better to even out imbalances cross border. In a situation where there is a negative balance in one TSO area and a positive imbalance in the neighbor TSO area these imbalances

are evened out before activating regulating power in both areas. Increased production from fluctuating renewables might increase the need for regulating power but as mentioned, this is difficult to predict.

1.2 Elspot market

The Elspot market is the Nordic day-ahead market for trading electricity in the countries: Denmark, Sweden, Norway, Finland, Estonia, Lithuania and Latvia. The liberalized market has around than 370 buyers and sellers that place around 2000 orders every day (Nord Pool Spot, A, u.d.). The market is the largest market in the world in terms of the volume electricity traded. In 2013, 84% of the total power traded in the region was traded on Elspot, which amount to 493 TWh (Nord Pool Spot, B, u.d.).

The Elspot market is day-ahead auction in which contracts between buyers and sellers are formed for the delivery of power the following day. The bids have to be submitted before 12:00 the day before operation and the bids include volume and price, hour by hour. The bids are fed into a computer that based on an advanced algorithm calculates the hourly price for the following day. Simplified, it can be described as the price intersection between the demand and supply curve. The hourly prices for the following day are published at 12:42, which settles the contracts between buyers and sellers meaning that the physical delivery of electricity has to take place. There are different price zones in the region, which are introduced to handle lack of capacity on the interconnections. In case of no bottlenecks on interconnections between price zones a system price is present in the whole Nordic market.

The market is based on a marginal price system meaning that the most expensive production unit that is accepted is the price setting unit. The bids for producers are often related to the short term marginal cost of producing power. In hours with a low demand for electricity, during the night or the summer, it is often base load units that is the price setting unit, while in hours of high demand, daytime or winter, it is often peak capacity units that is price setting (EA Energy Analysis, 2012). As a result, price variations occur during different times of the day and the year. Intermittent renewables do not have any fuel costs related to the power production and will most likely bid in with a low price. Consequently, the intermittent renewables press more expensive production units and reduce the spot price (EA Energy Analysis, 2012). This effect is also called the merit order effect.

The energy system faces changes that will affect future Elspot prices. The increased development of intermittent renewables in Denmark and neighbor countries is expected to contribute to more varying prices (EA Energy Analysis, 2012). Low price periods are expected to occur for longer periods for instance in case of more days with rain and good wind conditions. Such periods can be followed by longer periods of high prices in case low temperatures and no rain (The Energy Political Comittee, 2010). Other factors that will influence the spot price in the future are the increasing electricity demand and the development in fossil fuel- and CO_2 prices.

Significant price variations are not present at the spot market today (The Energy Political Comittee, 2010). Analyses indicates that the prices in 2020 will not vary more than today. However, in 2050, the analysis indicates that price variations will be significant compared to today (EA Energy Analysis, 2012).

Electricity for the P2G operation will be purchased at the spot market in hours where the price is below a certain threshold. Based on fixed operation costs and revenue streams generated from operating the facility a marginal electricity price can be calculated reflecting the purchase bid and the threshold price for when it is profitable to operate the facility.

1.3 Elbas market

The Elbas market is an intraday market in which electricity can be traded within the day of operation until one hour before operation. Besides the Nordic and Baltic region the market covers Germany as well and 123 members are trading on the market (Nord Pool Spot, C, u.d.). In 2013, 4.2 TWh was traded on Elbas (Nord Pool Spot, B, u.d.). The available capacity on the market is published at 14:00 after the spot prices are published. Bids are given as volume and price for the hour in question.

The trade is based on a first-come, first-served principle where the price settlement is based on a pay-as-bid. The volume of power traded at the intraday market is expected to grow in the future when more wind power is implemented in the system (EA Energy Analysis, 2009).

The intraday market offers opportunity for risk reduction and/or additional profit generation. The P2G facility is able to participate in the intraday market by: 1) selling back electricity bought at the spot market, executed by not consuming in the hour in question, and 2) buying electricity in hours where no electricity was bought at the spot market. The marginal electricity price determines when it is profitable to sell and buy electricity at the intraday market.

1.4 The regulating power market

The regulating power market is a common Nordic market. The purpose having the regulating power market is to replace FNR in DK2 and secondary reserves in DK1 and restore the grid frequency. The maximum capacity has to be activated at latest 15 minutes from the activation of the bid (Energinet.dk, 2008).

The individual actor can enter the market through the manual reserve market (see section 1.4.5) or by placing bids at the regulating market. Bids can be submitted until 45 minutes before hour of operation in the size of 10 MW - 50 MW. Furthermore, the bids are given as separated hourly bids for upward- or downward regulation specified in DKK/MWh and the available capacity in MW. The bids can be submitted for a single unit or by pooling a group of smaller units, either production or consumption, to achieve the required capacity (Energinet.dk, 2008).

As for the Elspot market, the last activated unit sets the price for all actors in the market. In case of bottlenecks, different prices will occur based on the activated units in the specific price area (Energinet.dk, 2008). The minimum price for upward regulation and the maximum price for downward regulation is the spot price in the specific price area.

The prices at the regulating power market are more fluctuating than Elspot prices, which benefits the operation of flexible consumption units in a commercial perspective (EA Energy Analysis, 2011). However, the need of regulating power is unknown at the stage of bids for the regulating market is submitted. The minimum bid is -/+ 10 MW, which is more than the capacity rate of the P2G facility in the demonstration project. However, the unit is able to participate in the market provided that the P2G facility is included in a Neas Energy's asset portfolio. It is decided to change the capacity limit to 1 MW (see section 3.2.2).

Up regulation bids can be submitted in hours where:

- Electricity is bought in Elspot or Elbas

Down regulation bids can be submitted in hours where:

- No electricity is bought Elspot or Elbas
- Electricity bought in Elspot but sold back in Elbas

If there is need for regulating power and the unit is accepted a more profitable price can be achieved in the regulating power market compared to the spot market. The marginal costs of the unit determines the up and down regulating bid prices.

1.5 Reserve markets

Imbalances occur due to unexpected changes in production and consumption and Energinet.dk purchases reserve power to secure security of supply. DK1 and DK2 are located within different grid synchronized areas, which is why different ancillary services are required. In DK1 the following ancillary services are procured to maintain the frequency at 50 Hz:

- Primary reserves
- Secondary reserves, LFC (Load Frequency Control)
- Manual reserves

In DK2 the ancillary services are:

- Frequency-controlled disturbance reserve (FDR)
- Frequency-controlled normal operation reserve (FNR)
- LFC
- Manual reserve

Furthermore, Short-circuit power, reactive reserves and voltage control, is provided in both areas but these services are not described in the report. The P2G facility is going to be located in Avedøre and therefore is it only the reserve markets in DK2 that are described.

1.5.1 FNR

FNR is provided by production or consumption units that automatically detects and adjust to frequency deviations in the span of -/+ 100 mHz. The reserve has to be delivered after 150 seconds and has to be provided as a symmetric service i.e. both upward- and downward regulation. More units can be combined to deliver the service but such a system must be verified by Energinet.dk. The minimum bid is 0.3 MW and stated in MW with one decimal. (Energinet.dk, A, 2013).

In cooperation with the Swedish TSO, Energinet.dk buys a total volume of 253 MW (2012), which is auctioned on daily basis in 3-hour or 6-hour blocks. Energinet.dk buys most of the reserves two days (D-2) before day of operation and the rest of reserves the day (D-1) before. The time deadline for submitting bids for D-2 is 15:00 while it is 18:00 for D-1. 6-hour block bids can only be given two days before operation (D-2) and 3-hour blocks one day before (D-1). The bids are given as a payment for disposal in DKK/MW. Accepted bids are paid based on a pay-as-bid principle and in case of activation the actor is paid the regulating power price for the energy delivered. (Energinet.dk, A, 2013)

The fast response time on the electrolyser makes it able to participate on the FNR market. The fact that bids at latest can be submitted at 18:00 for D-1 makes it possible for placing bids at the spot market and thereafter place bids on the FNR market. As FNR is a symmetric service, the P2G facility must be able to up and down regulate at least +/- 0.3 MW. In case of a 0.3 MW bid is won for a 3-hour block, the electrolyser has to operate in the capacity rage of 0.3-0.7 MW in that period. With a capacity of 1 MW, bids of 0.3-0.5 MW can be submitted to the market.

1.5.2 FDR

FDR is automatically activated when the frequency drops below 49.9 Hz. The service includes only upward regulation. It is a fast responding service that has to be fully activated within 25 seconds while 50% of the capacity has to be activated after 5 seconds (Energinet.dk, A, 2013).

In 2012, the volume in the market was 445-465 MW that is bough in cooperation with Svenska Kraftnät on daily auctions. The conditions for bidding and price settlement in FDR are the same as for FNR. The P2G facility is able to respond within required time and therefore able to participate in the market. Up regulation bids in the size of 0.3-1.0 MW can be submitted because the facility has to operate and turn down electricity consumption to provide the service.

1.5.3 LFC

LFC reserves is also going to be procured in DK2 from autumn 2015. The market volume will be up to 30MW and procured as a symmetric service. The reserve has to be delivered after 5 minutes and the minimum bid is 1 MW. Accepted bids are paid an availability payment based on a pay-as-bid principle. Energy delivered for up regulation is settled with the Elspot price + 100 DKK/MW or minimum the up regulation price. Energy delivered for down regulation is settled with the Elspot price – 100 DKK/MW or minimum the down regulation price.

Contracts for delivery will have a duration of 1 year, which is inappropriate for the electrolyser that is not expected to operate all hours in a year.

1.5.4 Manual reserve

The manual reserves are manually activated by Energinet.dk, through the regulating power market, by informing the stakeholders in case of upward or downward regulation is needed. The manual reserves replace LFC in DK1 and FNR in DK2 and restore the grid frequency. The bids for the daily auction are given as upward- or downward regulation, in the size of 10 MW - 50MW, before 09:30 the day before operation. The asset must be able to deliver full capacity after 15 minutes. The stakeholders that participate on the market enter an agreement with Energinet.dk to place bids on the Regulating power market (Energinet.dk, 2008).

In DK2, Energinet.dk has made a five-year agreement with Dong Energy to deliver all the manual reserve until the end of 2015. It is only in case of outage at Dong Energy power plants that Energinet.dk demands manual reserve at the other BRPs, which so far has been a limited number of days. New contracts are signed for the delivery of manual reserves 5 years ahead from 2016.

1.6 Market submission deadlines

One of the important outcomes of this ForskEL project is to demonstrate that the P2G facility can provide the frequency regulation (FNR and/or FDR). But the P2G facility can also be operated in the Elbas market and the regulating power market. Figure 1 illustrates the submission deadlines for making bids in the different markets.

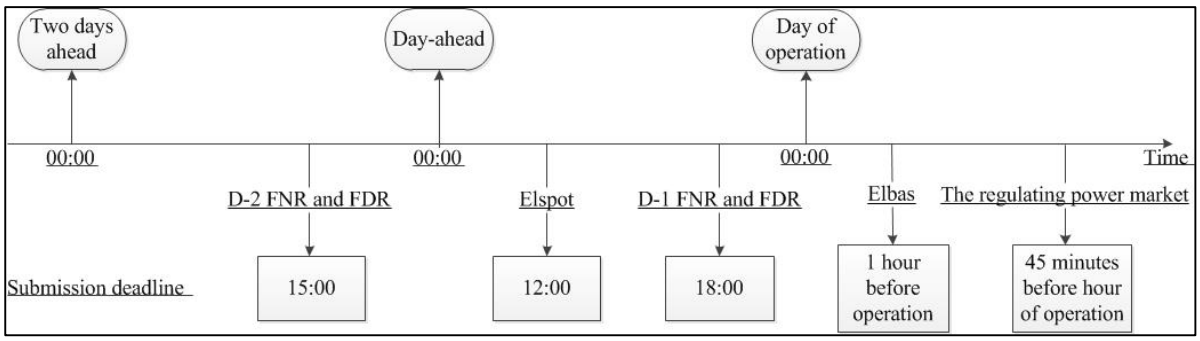

Figure 1: Submission deadlines for making bids at FNR, FDR, Elspot, Elbas and the regulating power market.

2. Value source identification and quantification – gas markets

This section describes the Danish gas markets and the value sources related to the gas market i.e. green certificate scheme.

The volume of traded gas at the European gas exchanges grow within these years. Traditionally, natural gas has been sold at long term contracts at a price closely related to oil prices because gas often is produced in connection with oil production. This correlation is reduced in the recent years and the gas market is starting to become more and more like other energy markets where it is possible to trade different products (Energinet.dk, F, 2013).

2.1 The Danish gas exchange: Gaspoint Nordic

Transport operators trade gas through bilateral contracts and at the Danish gas exchange, Gaspoint Nordic. The majority of the gas is traded through bilateral contracts but the amount of gas traded at the exchange is growing and 25% of the domestic demand was traded at the exchange in 2013 (Gaspoint Nordic A/S, 2014). At Gaspoint Nordic different products can be traded from intraday trading to future contracts.

2.1.1 Day-ahead contracts

Day-ahead contracts represent the majority of the trades (58%) at Gaspoint Nordic in 2013. Contracts can be traded 24/7 on the day before delivery. A gas delivery day is from 06:00 to 06:00, and the physical delivery of gas takes place in these hours. The minimum tick size for a contract is 1 MW. At the end of the trading day a closing price is calculated based on a volume weighed average, which is an indicative price for all accepted contracts for the following operation day. A 1 MW contract results in a physical delivery of 1 MW per hour in the gas day and thereby a total delivery of 24 MWh (Gaspoint Nordic A/S, 2014).

When the biomethane is injected to the grid it can be traded on same conditions as natural gas. Therefore, it is expected to have a value corresponding to the day-ahead gas price at the Danish gas exchange. In 2013, the average price was 27.98 EUR/MWh upper calorific value corresponding to 208 DKK/MWh.

2.2 Green gas certificates in Europe

Today there is not a European certificate scheme but every country has its own scheme. A common European market is still far away. Energinet.dk and six other European certificate administrators have signed a declaration concerning the development of common standards for sustainability and an international market for bio natural certificates (Energinet.dk, F, 2013).

2.2.1 Bio natural certificates in Denmark

In Denmark, Energinet.dk manages a green gas certificate scheme. The owner of a biogas upgrading plant receives 1 certificate per MWh of grid injected biomethane. The certificates can be sold separately of the physical delivery of gas. The consumer that buys the certificate is guaranteed that the same amount of natural gas is substituted by biomethane. The value of the certificate depends completely on supply and demand. Entities that are included in the CO_2 quota settlement are allowed to deduct bio natural gas certificates from their CO_2 accounts. The CO_2 content in natural gas is 205 kg/MWh, which makes 1 certificate worth approximate 11 DKK, assuming a price of 7 EUR/quota.

Dong Energy manages trading of the green certificates for Fredericia Spildevand that owns the first purification plant in Denmark. Dong Energy informs (May 2014) that the demand is very low (Myken, 2014). The market is still young and few trades have been made so far, which makes it difficult to

estimate a market price. In an article from "Ingeniøren", Dong Energy expresses that the selling price of the first certificates is below 1 DKK/m^3 (Wittrup, 2013). It corresponds to a price of < 84 DKK/MWh assuming an upper calorific value of 11.91 kWh/m^3 in the biomethane. However, this price does not necessarily reflect a market price for green certificates. Currently (November 6, 2014), there are only four registered producers of biomethane in Denmark (Energinet.dk, B, 2014).

3. Value source identification and quantification – byproducts

This sections describes how byproducts from the P2G operation may have a value. In the P2G conversion, process heat and oxygen are generated that may have a value. The byproducts will most likely be exploited on site due to the location at the treatment plant.

3.1 Heat production

It is possible to install a heat recovery system and recover waste heat from both the electrolyser and bioreactor. Operation temperature, of app 65°C, are too low to use it directly for district heating but it may be utilized for different purposes. When the facility is located at a sewage treatment plant the heat may be used to pre-heat sludge before digestion and thereby substitute a different heat source. The heat from the P2G facility will have a value equal to the cost of heat source that it substitutes.

3.2 Oxygen production

Oxygen is a byproduct of the electrolysis process and the value of the product depends on it use. For instance, oxygen is used in pharmaceutical industry and other industry. For this type of application, it will require that the oxygen is bottled and transported to the right location. However, the location next to a wastewater treatment plant makes it possible to use the O_2 for the activated sludge treatment process. Air is typically blown to aerate the sludge treatment basins, which is a process driven by electrical ventilators. The use of pure O_2 instead of air will reduce the air volume blown to the basins by 80% (Hofstetter et al., 2014), which will reduce electricity costs for aeration. It is estimated to have a value of approximately 9 DKK/MWh electricity (See Appendix 1).

4. Identification of regulatory aspects that prohibit, inhibit, or support P2G in Denmark

This section describes the grid fees and energy taxes that influences the direct cost of production. Furthermore, the supporting and inhibiting elements are described and discussed.

4.1 Direct cost of production

The major direct cost is electricity cost, which consists of the market electricity price, electricity tax, grid- and PSO tariffs. The grid tariffs include grid- and system tariffs (TSO tariffs), regional grid tariff and local grid tariff (DSO tariffs). Water and nutrients are consumed but the cost of those components is expected to be insignificant compared to the electricity cost (Hofstetter et al., 2014). Additionally, there is a cost related to the volume of biomethane injected to the gas grid.

4.1.1 Electricity tax

The electricity tax is 833 DKK/MWh. A VAT registered company can have almost the full electricity tax compensated if the electricity is considered as process electricity (PWC, 2014):

1) The energy must be consumed by the company

2) The company must be VAT registered
3) The energy cannot be applied in an engine
4) The energy cannot be applied space heating, heating of water or comfort cooling

The Danish tax authority informs that electricity consumed for the P2G production is considered as process electricity (SKAT, 2014). The full electricity price is compensated except from 4 DKK/MWh, which is the minimum payment required by the EU.

4.1.2 TSO tariffs

The system tariff is paid to cover Energinet.dk's expanses to purchase reserve power. The grid tariff is paid to cover O&M costs of the overall grid and the cross boarder interconnections. The size of the tariffs is based on the gross electricity consumption. Net settled own producers[1] are not charged the system and grid tariffs for own consumption.

4.1.3 PSO tariff

Enerigent.dk is obligated to promote environmental friendly electricity production, distributed CHP production, grid connection of wind turbines and research and development for environmental friendly electricity production. The PSO tariff covers Energinet.dk's expenses related to promote these matters. The majority of the PSO means covers the payment to environmental friendly electricity production e.g. subsidy for wind turbines. The PSO tariff is adjusted on quarterly basis in relation to forward prices. In 2014 the average PSO tariff was 216 DKK/MWh and in Q1 2015 the tariff is 211 DKK/MWh.

Net settled consumers are exempted from paying the part of the tariff that concerns promotion of renewable electricity of the own production. Furthermore, a reduced PSO tariff is paid for the electricity consumption above 100 GWh/a (Energinet.dk, D, 2014).

4.1.4 DSO tariffs

Electricity consumers are free to choose among all electricity suppliers in the country but the local grid tariff is paid to the DSO that owns the grid in the area of grid connection. The regional grid tariff is paid for transport of electricity in grids owned by other DSO's. In some cases, it is the local grid owner that owns the regional grid as well, and in that case all expenses for the transport of electricity is paid through the local grid tariff. This is the case for the consumers in Avedøre (The Danish Energy Association, 2013) where Dong Energy Distribution owns the local and regional grid.

The DSO tariff depends on where the consumption unit is connected to the grid. The P2G facility in the demonstration project is going to be connected to a transformer station on the 0.4 kV side. Therefore, the DSO tariff settlement identified to what DONG Energy defines as "B-low hourly settlement". The DSO tariff is a three level time-of-use tariff that is higher during peak hours (DONG Energy, u.d.).

4.1.5 Summary of fixed electricity price components

Figure 8 illustrates the tax and tariffs that are paid (2014) for electricity consumed by the P2G facility in DONG Energy's distribution area. The PSO is the average payment in 2014 and the DSO is the tariff

[1] The majority of the payments to Energinet.dk can be avoided if the consumer owns a production plant and is settled under the net settlement scheme. It is an hourly based settlement of production and consumption: When electricity production is lower than the consumption electricity is supplied from the grid with the normal power costs. If the hourly production is higher than the consumption a price supplement is received for the excess electricity. The size of the production plant is unlimited but it has to be the same legal entity that owns, produce and consume the electricity in order to be net settled (SKAT, u.d.).

paid in Q4, 2014. Additionally, to the fixed components, a price is paid for the raw electricity consumed.

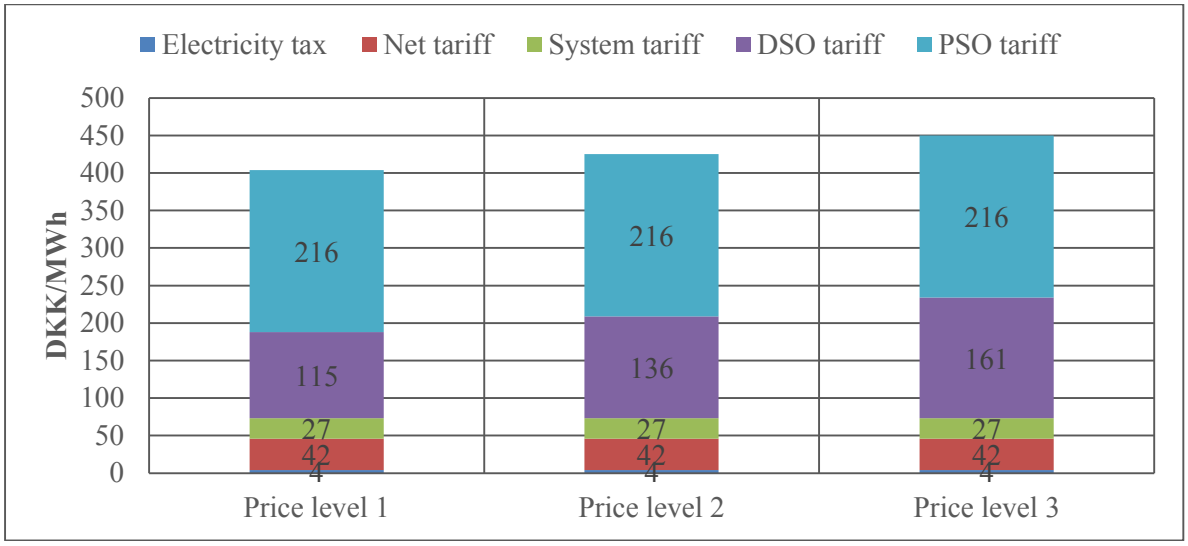

Figure 2: Tax and tariffs paid for consuming electricity in DONG Energy Distribution A/S's grid area.
Price level 1: Week days all year: 21:00-06:00 and weekends and holidays including May 1st, June 5th, December 24th and 31st: entire day
Price level 2: April-September, Monday-Friday: 06:00-08:00 and 12:00-21:00 and October-March, Monday-Friday: 06:00-08:00, 12:00-17:00 and 19:00-21:00
Price level 3: April-September, Monday-Friday: 08:00-12:00 and October-March, Monday-Friday: 08:00-12:00 and 17:00-19:00

4.1.6 Gas grid connection cost

Biomethane must live up to some quality demands regarding regulatory requirements, calorific value, pressure, temperature and additional demands from the grid owner (Energinet.dk, C, 2013). In order to connect a biogas purification plant to the gas grid the owner of the plant must request the gas grid operator in the specific area. The grid operator is obligated to build a grid injection facility but the expenses are transferred to the owner of the biogas purification plant. The two parts enters an agreement for the grid connection that i.e. includes implementation cost, operation costs, amount and quality of delivered gas (Energinet.dk, D, 2013). HMN is grid operator in the area and HMN informs that the expected grid injection payment is 0.6 DKK/Nm^3 biomethane (Rousing, 2014). It corresponds to 50 DKK/MWh upper calorific value.

4.2 Subsidy scheme for upgraded biogas

Subsidy is provided for an owner of a biogas purification plant that supplies upgraded biogas to the natural gas grid. The subsidy consists of three price supplements (Energinet.dk, C, 2014):

Subsidy	2014 (DKK/GJ low)	2014 (DKK/MWh high)
Supplement 1	80.3	261
Supplement 2	15.4	49
Supplement 3	10.0	32
Total	105.8	342

Table 1: Subsidy for provided for injected biomethane in 2014.

The three price components are regulated differently:

Price supplement 1 is regulated based on 60% increase of the difference between the NPI the previous year and the NPI in 2007 and a basis price supplement (Energinet.dk, B, 2013):

$$Price\ supplement_{year} = Basis\ price\ 2008 \times (1 + \frac{0{,}6(NPI_{Previous\ year} - NPI2007)}{NPI2007})$$

Basis price 2008 = 74.2
NPI2007 = 115.4

Price supplement 2 is regulated on basis of the average natural gas price (Danish gas exchange) in the previous year and a basis price of 53.2 DKK/GJ_{low} (Energinet.dk, B, 2013):

- If the average natural gas price is higher than the basis price the difference between the prices is deducted from the price supplement of 26 DKK/GJ_{low} (2012 price supplement).
- If the natural average natural gas price is lower than the basis price the difference between the two prices is added to the price supplement of 26 DKK/GJ_{low} (2012 price supplement).

Price supplement 3 is a fixed value of 10 DKK/GJ_{low} but it is regulated with a price deduction of 2 DKK/GJ starting January 1st 2016. The supplement will disappear after 2019 (Energinet.dk, B, 2013).

4.3 Inhibiting elements in subsidy scheme for upgraded biogas and green certificate scheme

The subsidy scheme for upgraded and grid injected biomethane is not adopted to the P2G technology. The Danish Energy Agency informs that biomethane injected in the gas grid has to originate from a biogas source produced in anaerobe tanks to obtain the subsidy (Harder, 2014) i.e. the methane content in the biogas. The biomethane injected in the gas grid will be produced from the CO_2 contents in the biogas, which currently not legitimate for subsidy. The scheme was introduced before the beginning of the P2G BioCat project and it is, therefore, not designed to include this technology. The Danish Energy Agency is aware of the demonstration project and it is discussed if an exemption for the use of H_2 to produce CH_4 should be implemented in the scheme (Harder, 2014). If the subsidy scheme is not adjusted to include the technology it will decrease the economic potential for operating a P2G facility significantly.

The same applies for the green certificate scheme. It is currently not possible to obtain a biomethane certificate for the biomethane produced at the P2G facility due to the same conditions as described above.

4.4 PSO exemption as supporting element

In the heat sector, electric boilers are exempted from paying the PSO tariff if it is settled from "Elpatronloven" (Skatteministeriet, 2010). A P2G facility is comparable to an electric boiler as a flexible consumption unit. Both technologies operate in case of low electricity prices and is very flexible in terms responding time. Another advantage for both technologies is that fuel is shifted, which is important for implementing more fluctuating renewables.

One can argue that PSO exemption is justified because the operation of a P2G facility similar to the operation an electric boiler. As seen in table xx the PSO tariff is the biggest price component and exemption from PSO will increase the economic potential of P2G significantly.

4.5 Capacity threshold for regulating power market

It is decided to decrease minimum capacity for submitting bids at the regulating power market from 10 MW to 1 MW to encourage smaller consumption units to participate in the market. It might take affect by middle 2016 but it is still uncertain. This change will make it easier for the P2G facility to be operated in the market because it does not have to be pooled with other consumption units.

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Appendix 1 – Value of O_2 production

The electrolyzer produces 90 m^3 O_2/MWh electricity consumed. Electricity consumption for ventilation can be reduced by using O_2 for aeration instead of air. The value of 90 m^3 O_2 is estimated based on the cost savings achieved from reducing the electricity consumption. The estimation is based on average electricity consumption figures provided from SVC Avedøre (Nielsen, 2014).

The annual electricity consumption at SVC Avedøre is 16 GWh whereas 42% is used for air blowers corresponding to 6.72 GWh. Furthermore, 25,000-30,000 m^3/h of air is blown to the aerobe basins. Based on these figures, the hourly electricity consumption for the air blowers is:

$$\frac{6{,}720{,}000\ kWh}{8760\ h} = 767\ kWh/h$$

The electricity consumption per m^3 air is:

$$\frac{767\frac{kWh}{h}}{27500\frac{m^3}{h}} = 0.028\frac{kWh}{m^3}$$

Pure O_2 reduces the volume of air blown to the basins by 80%, which means that 1 m^3 of O_2 corresponds to 5 m^3 of air. 90 m^3 O_2 corresponds to 450 m^3 air of which 360 m^3 of air is replaced. The energy consumption for blowing 360 m^3 of air is:

$$360\ m^3 * 0.028\frac{kWh}{m^3} = 10.04\ kWh$$

10.04 kWh electricity is replaced by using 90 m^3 O_2 to replace 360 m^3 air. SVC Avedøre pays 0.891 DKK/kWh consumed electricity. Therefore, the value of the 90 m^3 O_2 is:

$$10.04\ kWh * 0.891\frac{DKK}{kWh} = 8.95\ DKK$$

The value of 90 m^3 O_2 is estimated to 8.95 DKK.