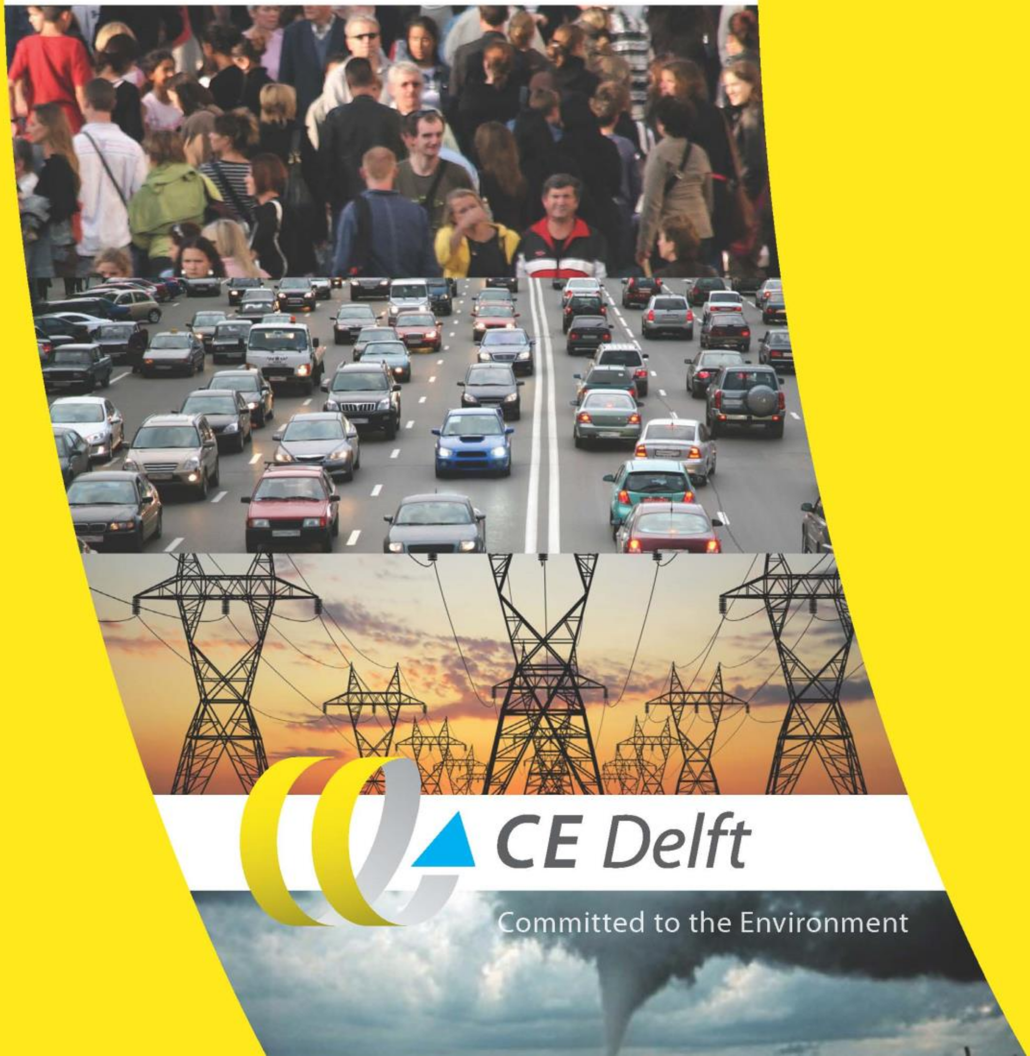
Potential for Power-to-Heat in the Netherlands



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Potential for Power-to-Heat in the Netherlands

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Summary

Electricity markets in Northwest Europe show strong signs of transformation. The introduction of substantial amounts of variable renewable energy sources induce new dynamics in the supply of electricity and create significant price pressure. This offers new opportunities for cost-effective deployment of electricity. Power-to-Heat, the application of electricity for heating purposes through industrial electric boilers, is one of the more promising examples explored in various Northwest European Member States. This report presents a high-level investment outlook for Power-to-Heat applications driven by day-ahead electricity pricing in the Dutch energy system.

Frequent occurrence of low electricity prices

In order to develop a realistic outlook on the opportunities for application of Power-to-Heat in the Dutch context the assessment sets off with a characterisation of the electricity price developments in the Netherlands and Northwest Europe and an outlook on future trends in the run-up to 2020-2023, as driven by the Dutch Energy Agreement on Sustainable Growth.
The assessment concludes that opportunities for Power-to-Heat applications mainly occur during periods of low electricity pricing resulting from temporarily high contributions from (a) wind during off-peak hours in winter and (b) solar PV during peak hours in summer. Therefore, low-cost electricity occurrences should be expected in all seasons.

Market for Power-to-Heat

The electricity market outlook suggests that significant cost benefits can be attained through application of Power-to-Heat. To assess this, we first evaluate the technical potential for the application of Power-to-Heat in the Netherlands using a sectorial characterization of the type of heat demand that can technically be served by industrial electric boilers. This potential is offered by large-scale generation of heat below 260°C for industrial purposes, district heating and horticulture.

Technical potential of 3-6 GW in industry and 95MW to 475 MW in district heating

Characterizing the potential for low-cost electricity deployment in the Dutch industry conservatively on the basis of heat demand below 200°C, suggests an hourly potential of approximately 5.5 GW in winter and 3 GW in summer.
Heat demand for district heating is more sensitive to outdoor temperatures. For large-scale systems, in summer only some 95 MW of Power-to-Heat may be deployed while this may run up to 475 MW in winter. In horticulture, heat demand typically involves smaller-scales, temperatures below 100°C and varies more heftily between day and night as well as from summer to winter. The technical potential therefore is not included in the assessment, though it may prove sizeable for smaller-scale Power-to-Heat applications.

Business case under electricity market simulations

The business case for Power-to-Heat in the Netherlands is based on an evaluation of costs and benefits and estimated return-on-investment in today's market as well as for 2023 market simulations, assuming incremental levels of installed Power-to-Heat capacity. Since a sizable segment of the investment costs involve costs for grid connection, the evaluation distinguishes between the situation where a new grid connection is required, as well as the situation where a grid connection is present for existing Combined-heat-and-power installations. The results indicate that the case is highly constrained under current conditions. In case no grid connection is present, costs for Power-to-Heat applications are likely to outstrip the benefits.

Power-to-Heat and Combined-heat-and-power

Only marginal investment in Power-to-Heat capacity on sites with existing grid connections for existing Combined-heat-and-power installations may break-even. Only if prices fall well below the simulated prices, can the investment be expected to be profitable.

Table 1 Technical and economic potential for Power-to-Heat application by 2023 in the Netherlands by market segment and season

Sector	Technical Potential Summer	Technical Potential Winter
District Heating	0.1	0.5
Industry	3.0	5.5
Horticulture	n/a	n/a
Total Technical Potential	3.1	6.0

Transmission tariffs impose a barrier

While the benefits relate to savings on costs of natural gas for heat generation, cost components relate to investment, cost of electricity and transmission tariffs. Here, the existing tariff structure shows to impose a relatively significant barrier for infrequent high capacity offtake as it is based on capacity rather than volume. The evaluation presented in this report indicates that the costs saving based on the electricity price simulations with an average price of € 26.50 over some 2,000 hours yearly will not suffice to overcome this barrier, and even lower prices are required.

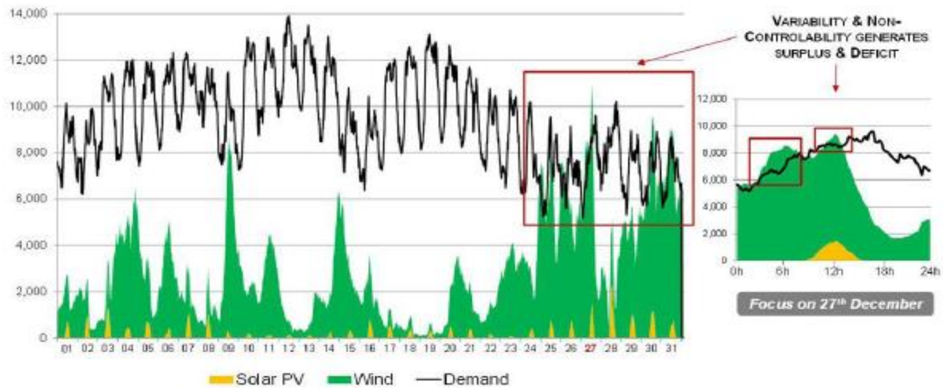
1 Introduction

In recent years the electricity markets in Northwest Europe have shown strong signs of fundamental transformation. Driven by the introduction of substantial amounts of variable renewable energy sources in several European Member States, the rising contributions from these variable sources have altered the supply of electricity and resulted in significant price pressure.

The price pressure exerted by contributions from particularly wind and solar PV is primarily driven by the cost structure of these technologies. Whilst capital expenditures for wind and solar PV installations are relatively high, the cost of operation is very low or even zero. The production of electricity from existing wind and solar PV capacity is therefore mainly driven by the availability of wind and solar irradiance and only to a very limited extent by electricity market prices. Given high levels of installed capacity, production from these resources may even surpass demand, as already occurred in recent years in Eastern Germany. In December 2012, for example, wind and solar energy production exceeded demand levels that were low due to the holiday season (see Figure 1). In such instances market prices for electricity typically reach very low and even negative price levels.

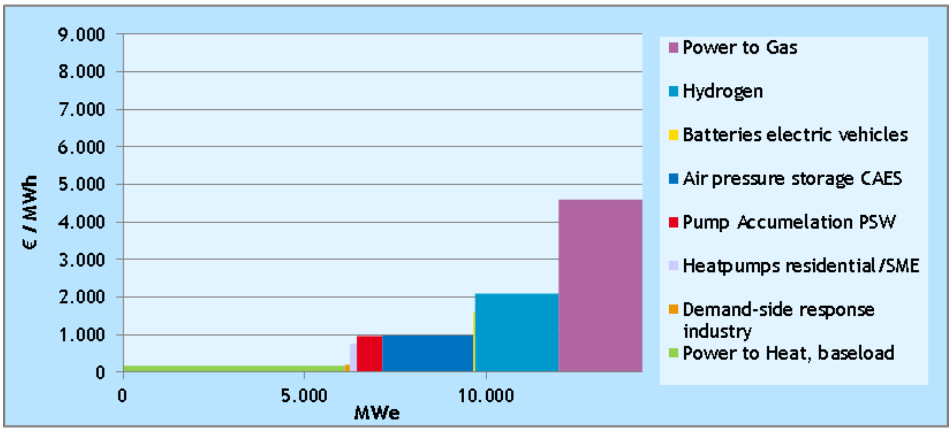
While the generation segments of the electricity supply sector struggle with the new realities in the market place, new opportunities emerge for the deployment of low-cost renewable electricity. The price dynamics recently emergent in the market, are essentially driven by the agenda for further decarbonisation of the European electricity system, and provide for a strong and lasting drive to find new applications of electricity that allow to benefit from low electricity prices. First-movers are EU Member States that lead the energy transition: in countries like Denmark and Germany, market parties have started to explore new applications of low-cost electricity.

Figure 1 Electricity production in Eastern Germany (December 2012)



Source: SBC Energy Institute analysis on 50 hertz data (wind/solar infeed and control load 2012).

Figure 2 Estimates of technical potential for flexible options in the Netherlands to match surplus electricity of wind and solar



Source: (CE Delft, 2014a).

One particularly promising application explored is the use of low-cost electricity for low temperature heat generation through deployment of industrial electric boilers. This technology, often referred to as Power-to-Heat, typically complements existing installations. At instances of low-cost electricity, it provides for an excellent opportunity to reduce costs of low temperature heat generation, while increasing the use of renewable energy and reducing CO_2 emissions.

Preliminary assessments show that a substantial technical potential for Power-to-Heat applications should be expected in the Dutch energy system. The potential relates to low temperature demand in in industry, district heating and horticulture. Further, levelized cost estimation suggests a relatively limited cost level for this potential in comparison to alternative applications of excess (low-cost) electricity (see Figure 2).

An estimate of the technical potential should be seen as a maximum of the technically applicable Power-to-Heat capacity. Up to what point this potential can profitably be realised depends on the business case however. This report presents an evaluation of the business case on a sectorial level.

Aim and outline

This report offers a more detailed evaluation of the potential for Power-to-Heat applications in the Dutch market. The aim is to investigate what the potential is for Power-to-Heat applications in the Dutch energy system, given observed and expected developments in electricity markets.

The report is structured as follows:

- The assessment sets off with an evaluation of the current and future developments in the Northwest European electricity markets, as electricity prices are a critical driver of the business case (Chapter 2).
- Then a more detailed assessment of the technical potential for Power-to-Heat applications in the Dutch context follows (Chapter 3).
- Finally, an evaluation of costs and benefits of Power-to-Heat applications in the Dutch context is presented, with estimates for return on investment in current and future electricity markets, for different alternate means of heat production (Chapter 4).

2 Northwest European Electricity Markets

2.1 Introduction

With the European Union's Third Energy Package that entered into force on the 3rd of September 2009 the European Union set off to initiate an energy transition on the pathway to decarbonise the European economy. Among a broad set of measures, the package includes a series of ambitious energy policy targets for 2020 also known as the 20-20-20 targets. These targets involve a 20% greenhouse gas emission reduction, meeting 20% of energy needs by renewables and a 20% increase in energy efficiency by 2020. The European Commission reaffirmed its commitment to further decarbonisation efforts with the Commission's recent statement on 2030 energy and climate policy proposing an overall 27% EU target for renewable energy.

The European electricity sector is set to play a pivotal role in the realisation of the targets for renewable energy sources (RES). A share of approximately 34% RES deployment in the electricity sector was derived from the 2020 targets, while the recent proposal for 2030 has been estimated to translate to a share of 43 to 47%[1] of RES deployment in the European electricity sector. National energy policies of European member states however show strong differences in approach, design, implementation and success. In the Northwest European context, Denmark and Germany appear to have taken the lead, followed by France, the United Kingdom, Belgium and the Netherlands (see Table 2).

In a recent effort to align interests and efforts with regard to the Dutch energy transition by form of a *Dutch Energy Agreement*[2] the Dutch government recommitted to the 14% target for 2020 as well as a 16% target for 2023. The agreement commits to 10.45 GW of installed wind capacity by 2023 against current levels of 2.5 GW. For solar PV no explicit targets were formulated but Dutch DSO's expect realizations of 1 to 6 GW by 2020.[3]

Table 2 Renewable energy consumption as share of gross inland energy consumption and share of electricity generated from renewable sources in NW Europe in 2012

	Share of renewable energy consumption (%)	Electricity generated from renewable sources (%)
Belgium	5.9	11.1
Denmark	23.3	38.7
Germany	10.4	23.6
France	8.2	16.6
The Netherlands	4.3	10.5
United Kingdom	4.1	10.8

Source: Eurostat.

1 EC (2014). Impact Assessment Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030.

2 SER, Energy Agreement for Sustainable Growth, 6-9-2013. The agreement was facilitated by the Social Economic Council (SER), www.energieakkoordser.nl .

3 TenneT, Visie op productie- en belastingontwikkelingen in de elektriciteitssector, I. Janssen-Visschers, G. van der Lee, 30 October 2013.

In summary, renewable energy sources will play a major role in the transition to a diversified, low carbon energy system in (Northwest) Europe and the Netherlands. While some member states already show significant levels of integration of renewables in the electricity system, others are bound to step-up efforts to expand the renewable energy resource base. Hence, the contribution of renewable energy technologies to the electricity production is set to show a forceful expansion.

2.2 Changing Dynamics in Electricity Pricing

The outlook on increasing contributions from variable renewable energy sources (VRES) should be expected to have a significant impact on the electricity markets. In order to assess the consequences of large-scale integration of VRES, one may turn to the electricity systems that already show relatively high levels of VRES penetration. In particular the Danish and German electricity system, with penetration levels running up to over 30 and 25% respectively, illustrate the consequences of the limited price responsiveness of these resources. The German electricity market is a critical segment of the Northwest European context, both due to its size as well as its central position. The German market also has a large impact on the Dutch market. For the purpose of this review, developments in the German market will be taken as a benchmark for future developments.

Germany is Europe's largest wind energy market with a total capacity of about 31 GW by the end of 2012. Further, Germany was the world's top PV market, with 7.6 GW of newly connected systems in 2012, ending the year with a total of about 32 GW (EPIA, 2013). Globally, Germany ranks third in terms of overall capacity, after China and the US (GWEC, 2013).

Figure 3 EPEX Spot auction Germany/Austria (Phelix): Peak/base price 01/09/2008 and 01/09/2014

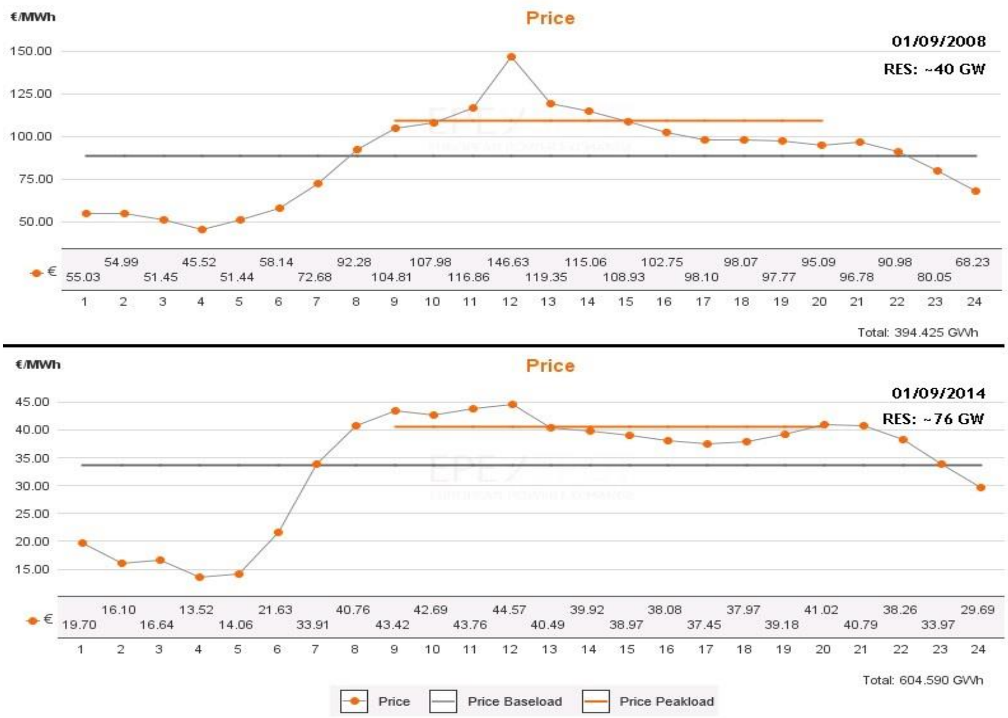
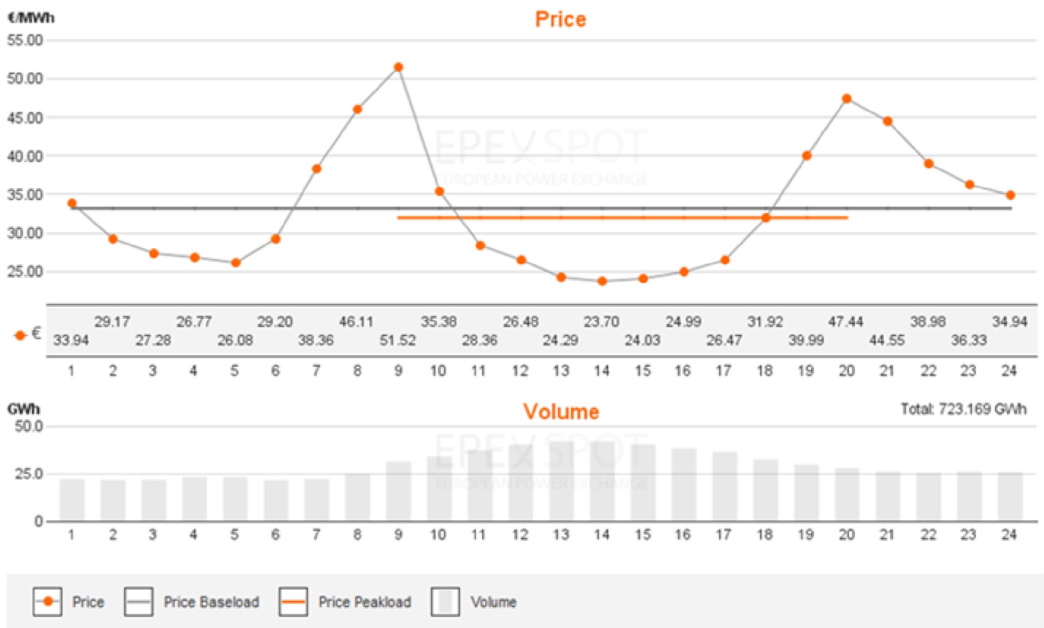


Figure 4 EPEX Spot auction Germany/Austria (Phelix): negative wholesale power prices in winter 13/14

The large-scale integration of renewable energy sources in Germany has had a significant impact on German electricity pricing. As load is served by the production facilities with lowest marginal cost of deployment, these costs increase with demand. Hence, classically, daily price profiles largely reflected underlying demand profiles. Increasingly however price dynamics are reflecting the contributions from wind and solar PV. On the whole, day-ahead market prices have been declining markedly over the past years as illustrated in Figure 3. The figure presents the day-ahead price profile at EPEX[4] in Germany/Austria on Monday the first of September 2008 and 2014 respectively, while the respective average RES contributions are indicated on the upper right-hand side. The figure illustrates that while the RES contribution on September 1st in 2014 was roughly double the level of 40GW attained in 2008, the baseload price was slightly below 35 €/MWh compared to some 85 €/MWh in 2008.

Figure 5 EPEX Spot auction Germany/Austria (Phelix): Peak/base price 17/04/2014



4 The spot market for electricity is operated by EPEX SPOT, a joint venture owned by German EEX AG and the French Powernext SA. The index for the German/Austrian market is called the Physical Electricity Index, or PHELIX.

The impact of large-scale introduction of wind on German prices emerged already in the last decade, during periods of strong winds at times of low demand, typically in the German winter off-peak. Such events resulted in extremely low and even negative prices, driven by the opportunity costs associated with de-commitment of conventional facilities the feed-in tariff for VRES. Ever since the first occurrence of negative prices in October 2008, the EEX (and later EPEX) closed at negative prices occasionally as illustrated in Figure 4.

Figure 5 presents the day-ahead market price profile at EPEX in Germany/ Austria on Thursday the seventeenth of April 2014. This figure illustrates the full extent of large contributions of solar PV. In this case, solar PV clearly resulted in a strong decline of the peak prices classically observed in electricity markets and even a reversal of the classic structure of the spread between peak and baseload prices

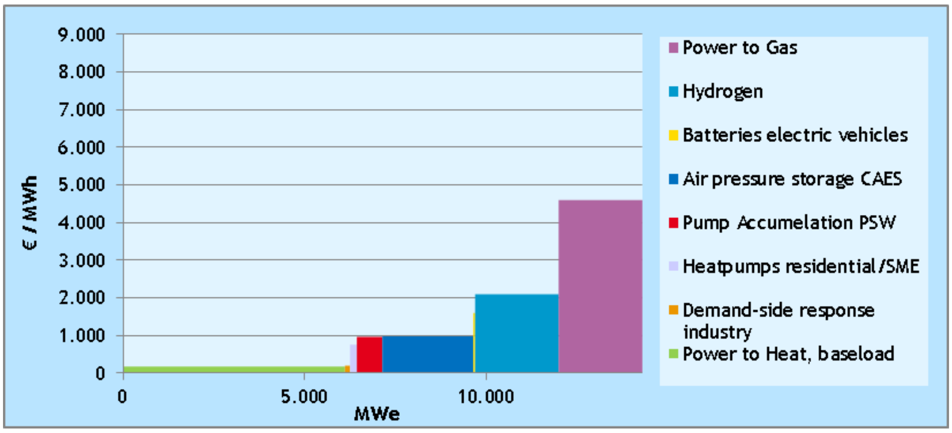
In summary, while VRES exerts a downward price pressure on electricity prices, a marked impact of wind and solar PV can be found for specific segments of the electricity price profiles:
- in summertime the new dynamics result in declining electricity price levels during daytime due to contributions from solar PV;
- in wintertime the impact of wind results in increasing price volatility, particularly when large wind volumes occur when demand is low.

In such instances provide an opportunity for flexible demand options to benefit from low electricity pricing.

2.3 Balancing Variable Renewable Power Generation

With increasing penetration of variable renewable energy resources on the grids, a greater need for flexibility to maintain reliable supply arises. Conventional production facilities must be rapidly ramped up and down over short periods of time in order to compensate for these fluctuations, but the previous Section illustrates that this ability falls short in case of large VRES contributions. Inability to do so will lead to curtailment of wind and solar energy, with the associated opportunity costs on a system level.

Figure 6 Flexibility options, suitable to match surplus electricity of wind and solar



Source: (CE Delft, 2014a).

Flexibility options in electricity systems that have the ability to respond quickly in order to balance supply and demand, particularly in situations of oversupply should therefore be expected to benefit. Flexibility can be realized in various ways:

1. Demand: electricity demand is increased price-responsively at times of wind and solar surpluses.
2. Production: at times when there is no renewable electricity available, electricity production shifts to other resources.
3. Storage: mechanical (pumped storage, compressed air, flywheels) or chemical (hydrogen, synthetic natural gas, battery systems) storage creates a buffer capacity when there is a mismatch between supply and demand, the stored electricity can be used at a different place and/or at time.
4. Enabling technologies, e.g. smart grids, to efficiently manage above mentioned techniques.

In a recent first-order assessment, CE Delft has evaluated a series of flexibility options covering respective technical potential and levelized costs for the Netherlands (CE Delft, 2014a). Figure 6 illustrates the technical potential and associated costs of flexible options to match surplus electricity of wind and solar in the Netherlands. The least-cost technology of the flexibility options is the application of Power-to-Heat. This technology has a substantial technical potential in the Netherlands, at relatively low cost.

Within the context of this assessment, Power-to-Heat refers to heat generation from electricity through electric boilers on an industrial scale. The technology is mature, offers an excellent opportunity to benefit from low and declining electricity prices and therefore shows increasing levels of application in countries with large-scale VRES deployment like Denmark and Germany. Once the limits of Power-to-Heat are in sight, other more expensive technologies may come into play. Some of these offer only limited volumes, other show relatively high costs. Power-to-Gas, for example, is a promising technology as gas can be stored and transported over long distances, but Power-to-Gas technology is still in a pilot phase and costs are currently relatively high.

2.4 Conclusions

In summary, current and prospective EU energy policy sets ambitious targets for renewable energy deployment in the European economy and the European electricity sector in particular. These targets are bound to incentivise member states to assure the large-scale introduction and deployment of VRES.
The European framework leaves substantial room for national support mechanisms on a member state level, and practical mechanisms vary accordingly. Several member states, such as Denmark and Germany, already show relatively high penetration levels of renewables in the electricity system. Other member states, amongst which the Netherlands, face a significant challenge to meet the EU 20-20-20 targets. The Dutch government has therefore stepped up the efforts for renewable support and set out an ambitious agenda for renewable development and deployment up to 2023. These developments should be expected to significantly affect the Dutch and Northwest European electricity markets.

A closer look at the dynamics of the electricity supply in the German market offers insights on the impact of increasing levels of renewables deployment for electricity generation. The system dynamics show that VRES can severely disrupt the overall supply and demand balance. Since VRES, notably wind and solar PV, run at very little marginal cost, their deployment is essentially driven by weather conditions. At times of low wind and solar input, VRES offer little electricity production and require alternative production facilities to meet demand. In case of large wind and/or solar production at levels meeting demand or beyond, temporary oversupply situations would occur and conventional assets in the system are unable to complement.
These contributions put significant pressure on the electricity prices. While a general downward trend in electricity prices can be observed in Germany, and hence its neighbouring markets, particularly summer peak prices are heavily depressed by the impact of solar PV. Also wind energy increasingly shows a more pronounced price impact, most notably resulting in extremely low prices in wintertime at times when strong windy conditions coincide with low levels of demand.

Low or negative electricity prices will provide opportunities for electricity consumers. The ability to respond quickly to market conditions, flexibility, is a prerequisite to reap the benefits of low/negative prices. Several categories of flexibility were identified. Here a mature technique, referred to as Power-to-Heat, seems to offer significant technical potential in the Netherlands at relatively low cost. The technique involves deployment of industrial electric boilers for the purpose of heat generation. In the following chapter, a more detailed assessment of the technical potential of Power-to-Heat in the Netherlands is presented. The assessment is followed by an analysis of the costs and benefits of Power-to-Heat applications in industrial context.

3 Technical Potential Power-to-Heat

3.1 Introduction

In the previous chapter Power-to-Heat was shown to be an excellent opportunity to benefit from declining electricity prices. Power-to-Heat can be utilised to convert short-term surplus electricity from solar and wind power into steam in an electric boiler. Within the context of this report, Power-to-Heat refers to heat generation by application of an industrial electric boiler, of the type ‘high voltage electrode boilers’. Such installations are currently commercially available, typically with capacities of up to 50–70 MW and a steam output up to 45 bar at 260˚C. In addition, such installations can be operated flexibly, with ramp rates from zero to full output within 3 to 10 minutes timeframes (see Annex B for further specifications of electric boilers)[5].

For the particular case of process industries with high demand for heat and district heating, Power-to-Heat may provide for an attractive opportunity to reduce the costs for heat generation. In these cases, heat generation is typically provided by gas-fired boilers or Combined-heat-and-power installations (gas engine, gas turbine, or combined cycle gas turbine). These installations may be complemented with high voltage electrode boiler(s) that should be seen as an ‘economiser’ installed to benefit as much as possible from low electricity prices, when and as long as prices are sufficiently low. Heat generation reverts back to the conventional heat source when electricity prices are high.

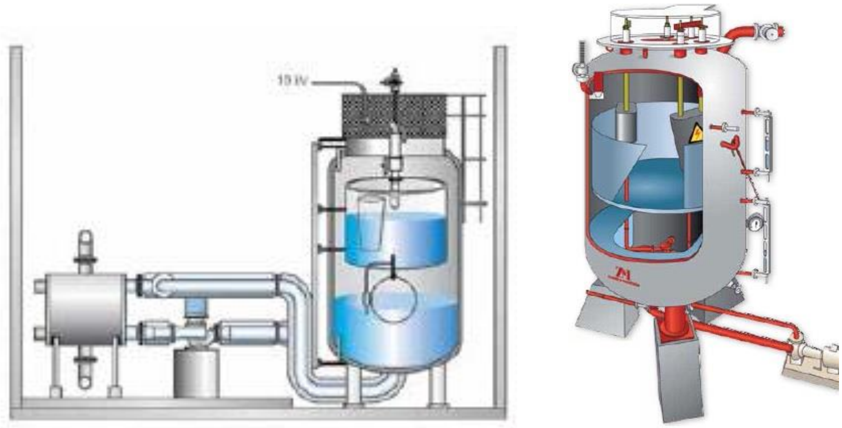
In countries with high levels of renewable penetration, notably Denmark and Germany, increasing numbers of Power-to-Heat projects have been realised in recent years. These projects involve large energy consumers in Denmark and Germany as well as municipal utility companies. Stadtwerke Flensburg, for example, is one of the pioneers seeking to profit from price fluctuations in the electricity market.

5 An alternative technology that utilizes electricity to generate heat is provided by heat pumps. Heat requirements exceeding +/- 100˚C are generally too high for the currently available heat pumps however.

Figure 7 **An industrial electric boiler on transport**

Source: VAPEC.

Figure 8 **Hot water electric boiler with circulation pump and heat exchanger (left) and electrode steam boiler (right)**

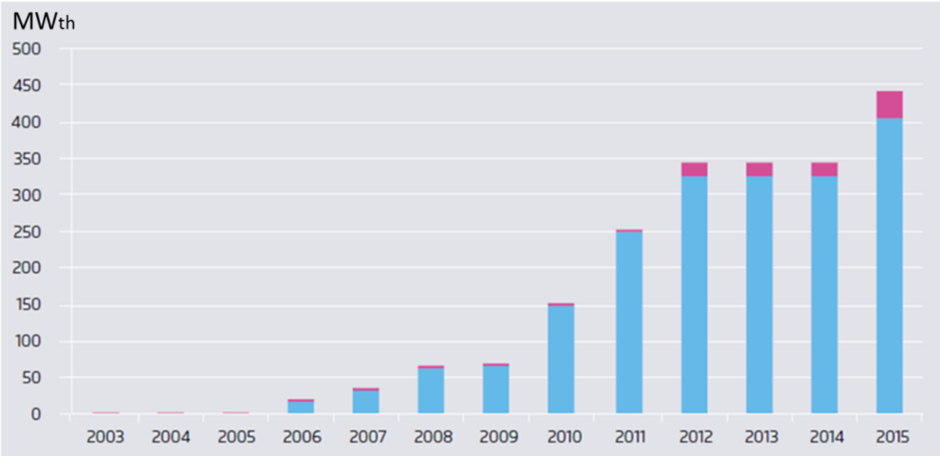


Source: Zeta.se.

The city of Flensburg is located in Northern Germany near the border with Denmark. In this region wind energy plays a major role in the electricity system. In addition, 98% of the Flensburg residents is connected to the district heating system, one of the largest in Germany.

In January 2013, Stadtwerke Flensburg commissioned a large electric boiler with a capacity of 30 MW ((Brandt, et al., 2013). Six large electric immersion heaters use surplus electricity (low price) from renewable production to heat up the district heating water to 100°C. This is then fed into a buffer containing 29 million litres of water, to circulate in the district heating grid. Herewith, Stadtwerke Flensburg seeks to produce heat at a very favourable cost, while offering a flexible response to the intermittent renewable electricity production. A recent study on opportunities for Power-to-Heat commissioned by Agora Energiewende reports that the initiative does not stand on its own. In Denmark, for example, some 44 Power-to-Heat installations have been commissioned in recent years and by 2015 over 400 MWe of installed capacity is expected (See also Figure 9 and Annex A).

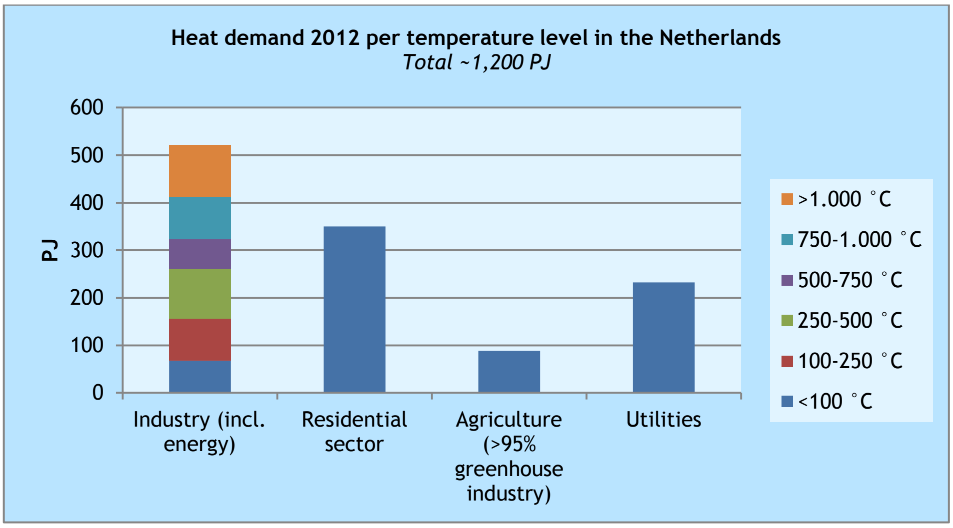
Figure 9 Installed Power-to-Heat capacity electric boilers (blue) and heat-pumps (red) in Denmark



Source: Agora, 2014.

3.2 Technical Potential in the Netherlands

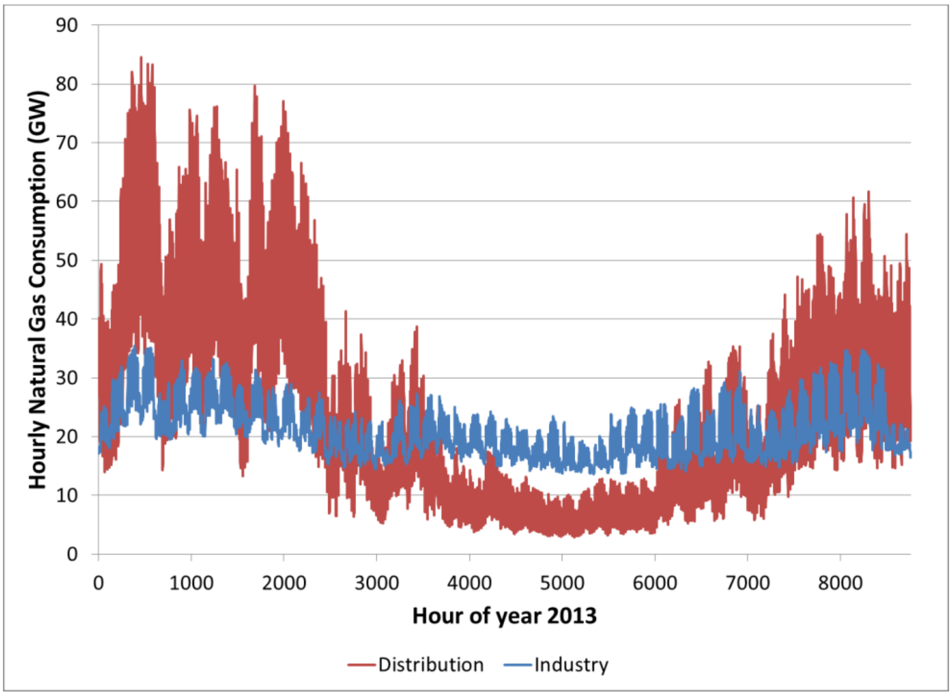
Figure 10 Heat demand 2012 per sector in the Netherlands



Source: CE Delft, 2014b.

Whether Power-to-Heat also provides for good opportunities in the Netherlands depends on the technical potential for Power-to-Heat in the Netherlands. Some 40% of the total energy consumption in the Netherlands relates to heating. Figure 10 presents an estimate for the total heat demand in the Netherlands per temperature category and sector in 2014 (CE Delft, 2014b), based on total heat demand reported by CBS in 2012 and an assessment of the distribution per temperature category and sector by Expertisecentrum Warmte/ECN in 2006 (ECN, 2010). The total heat demand in the Netherlands is estimated measure between 1,100-1,200 PJ (306-333 TWh). The majority of total heat demand involves low-grade heat of ≤100°C.

Figure 11 Hourly consumption of natural gas in the Dutch residential sector and industry in 2013



Source: GTS, 2014.

The residential sector accounts for about half of low-grade heat demand, while utility demand captures about 30% thereof, and horticulture about 14%. High-grade heat demand is dominated by the industry.

Figure 11 presents the hourly natural gas demand for these segments in 2013. Here one may note that demand for natural gas in the industry shows a relatively stable pattern throughout the year, while natural gas demand in the residential sector is heavily affected by the seasonal impact of outdoor temperature. It should be noted that this pattern will be highly dependent on the actual outdoor temperature profile. In the case of 2013, the year was characterized by a lengthy cold season in the first months of 2013 largely in absence of very cold days. The winter of 2013/2014, on the other hand, was characterized by very mild temperatures resulting in relatively low natural gas demand in the residential sector.

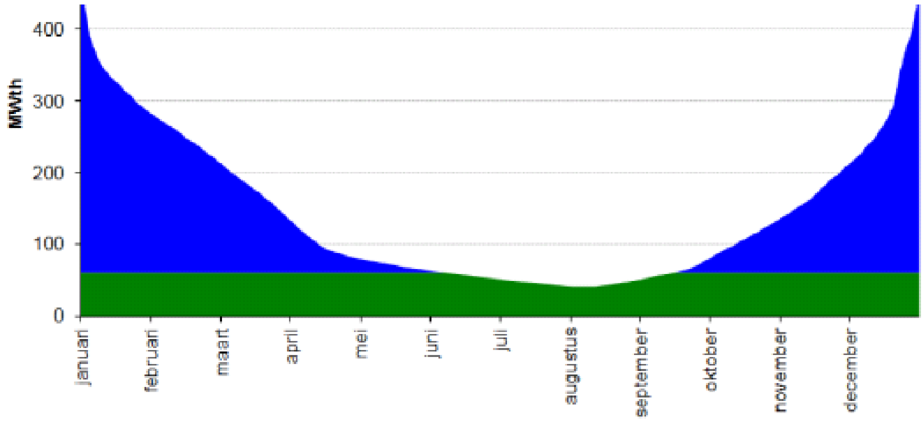
In the following, a more detailed assessment of the technical potential in terms of heat demand is presented, including qualification of the required heat in terms of low- and high-grade temperatures.

3.2.1 District Heating

Total heat demand for the residential sector and utility in the Netherlands was estimated to measure ~550 PJ/y (see Figure 10), corresponding to 17.4GW. About 5-10% of the total heat demand for the residential sector and utilities is estimated to be accountable to district heating, including collective heating for large flats. The yearly heat demand for district heating then results to range from 28-55 PJ/y. A more conservative estimate for the technical potential for Power-to-Heat may be provided by heat generation by large-scale district heating systems. In this case, only some 15 PJ/y or 475 MW_{th} of gas-fired heat generation may be substituted by on average Power-to-Heat (see also (CE Delft, 2009).

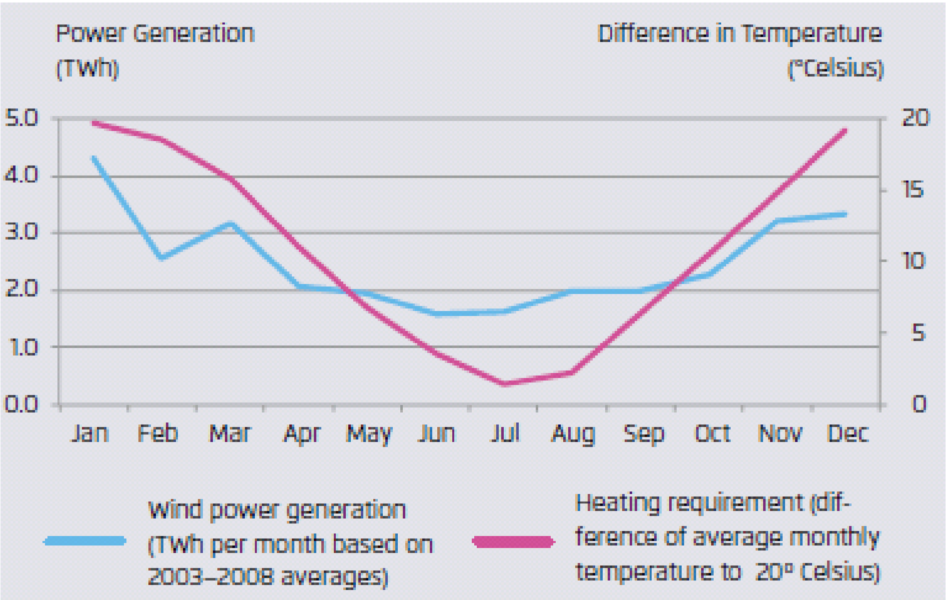
In the Netherlands most heating needs arise from October to April driven by outdoor temperatures. Accordingly, in winter heat demand reaches its peak, while in summer the heat demand attains minimum levels. For a typical district heating such as that of Utrecht and Nieuwegein, heat demand shows a base load demand for heat of about 15% of peak demand (see Figure 12).

Figure 12 Annual course of heat demand for Lage weide/Nieuwegein



Source: MER NUON Groene Weide.

Figure 13 Heat requirement and wind power generation in Germany per month



Source: Agora Energiewende, 2013.

The remaining 80% of the heat demand varies greatly depending on season (i.e. outdoor temperature). Therefore the potential to exploit low electricity prices year-round is estimated to be limited to some 20% of peak demand. This leads to a technical potential for Power-to-Heat of around 3,0 PJ/y or about 95 MW hourly year-round.

It may be noted though that the contributions of wind energy are highest during winter time, corresponding to highest demand for heat in district heating (see Figure 13). This correlation is highly advantageous for matching heat demand with (abundant) wind energy supply.

Accordingly, higher levels of technical potential may apply, running up to the aforementioned 475 MW_{th} during winter peak.

3.2.2 Industrial Heat Demand

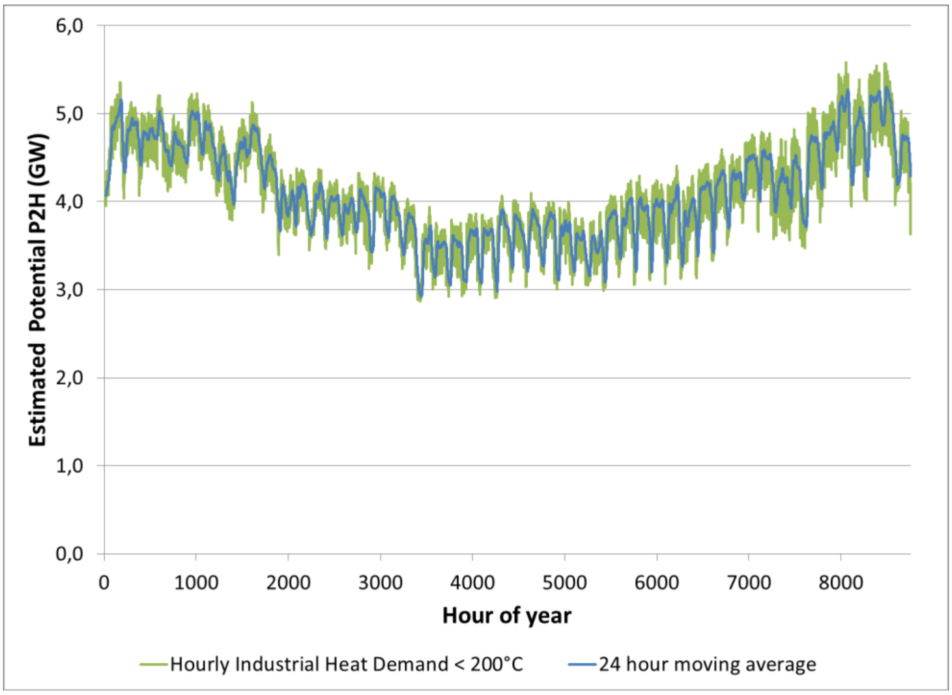
The Dutch industrial sector accounts for a sizable segment of national heat demand. Temperature requirements show a broad range however, while Power-to-Heat is applicable only for relative low temperatures of ≤260°C. Based on the estimates in Figure 10, the technical potential for Power-to-Heat in 2012 130 PJ/y or 36 TWh/y. Here, medium/high temperature industries which operate at >250°C such as steel production, foundries, and glass manufacturers are excluded.

Table 3 Heat demand in main industrial sectors differentiated by temperature category

		< 100°C	100-200°C	200-400°C	> 400°C	Total
2012	Industry	-	133	147	118	399
	- refining	-	20	100	14	134
	- food & beverage*	-	20	-	-	20
	- chemical	-	83	47	104	234
	- paper	-	10	-	-	11
2020	Industry	1	127	147	113	387
	- refining	-	20	100	14	134
	- food & beverage*	-	20	-	-	326
	- chemical	-	77	46	99	222
	- paper	1	10	1	-	12

Source: Davidse Consultancy, 2012 and *ECN, 2010.

Figure 14 Estimated hourly industrial natural gas consumption profile scaled to industrial heat demand <200°C



A more detailed evaluation of heat demand in the industry has been compiled by Davidse Consultancy, 2012. The analysis includes coverage of heat demand for several industries in 2012, segmented for several temperature ranges on the basis of an industry survey. In addition the survey included an outlook for 2020. Table 3 presents the main results of the inquiry with regard to heat demand, combined with data on food & beverage derived from (ECN, 2010). The combined industrial demand for heat below 200°C on the basis of this assessment adds up to 128 PJ/y or 36 TWh/y for 2020 and aligns with the previous estimate. It may however be noted that this would entail a conservative estimate of the potential for Power-to-Heat applications in the Dutch industry, since electric boilers can produce steam at temperatures up to 260°C.

Assuming this heat to be delivered during the minimum number of operating hours of combined cycle gas turbines and gas turbines with waste heat recovery, one may use the number of full load hours per year and the total number of hours per year to derive the upside of the technical potential for substitution of heat generation by Power-to-Heat. The number of full load hours per year typically was around 6,000 hours/year in the last decade, while the total number of hours per year is 8,670 (non-leap years). Hence the technical potential of Power-to-Heat may be estimated to be lie between 6 GW for at least 6,000 hours yearly and 4.1 GW year-round.

Alternatively, the industrial demand profile for natural gas may be scaled using previously derived yearly heat demand at temperatures <200°C. This approach implicitly assumes heat demand at temperatures below 200°C to follow the same course as overall industrial heat demand. In Figure 14 the hourly industrial heat demand excluding send-out to power plants in 2010[6], and its 24 hour moving average, scaled to a yearly demand of 128 PJ or 36 TWh is presented. As can be observed, the estimated demand profile varies roughly between 5.5 and 3 GW yearly, with clear declines during weekends and a seasonal decline in summer.

3.2.3 Horticulture

The horticulture has also a significant heat demand of ~100 PJ (Figure 10). Heat demand in horticulture is of a pronouncedly different nature compared to industrial heat demand. First, the heat demand is of a lower temperature range: up to 100°C. Second, the heat demand has strong seasonal and daily variations. The profile can be characterised as large heat demand occurring in the night (year-round but stronger in the winter months), and limited heat demand during daytime (none in summertime, limited in spring and autumn, larger in winter).

Due to the different nature, we will not include horticulture within the scope of the technical potential of heat demand. Having said this, there is certainly a sizeable potential for the application of Power-to-Heat in horticulture. Strengths of the sector include a strong investment climate (innovativeness, involvement in energy markets, within scope of environmental permits), physical space to accommodate boiler installations, presence of a sufficiently strong grid connection (due to the presence of Combined-heat-and-power), local distribution grid can accommodate significant energy flows, presence of heat buffers that are sized to provide heat demand over a number of days. Due to the presence of the large heat buffers, the typical profile of horticulture heat demand can arguably be overcome.

6 Based on Gasunie Transport Services reports 2010.

3.3 Local Infrastructure and Embedding

In the context of each of the previously discussed segments of the Dutch market for heat demand often local heat demand is served with Combined-heat-and-power facilities and/or (additional) gas-fired boilers. In 2012 some 23% of industrial heat demand was served with Combined-heat-and-power, while 48% was served with gas-fired boilers. For 2020 a decline of the contribution of Combined-heat-and-power installations to 18% is expected which will largely be compensated by increase of the contribution by gas-fired boilers to 52% (Davidse Consultancy, 2012). Table 4 summarizes the installed Combined-heat-and-power capacity by early 2014, spanning some 2.8 GW_e industrial Combined-heat-and-power capacity and an additional 3GW_e and 3GW_e in horticulture and built environment (CE Delft ; DNV GL, 2014).
In principle the Combined-heat-and-power facility offers the opportunity to serve local heat demand, while producing electricity either for (partial) local use as well, or to generate additional financial benefits by offering the electricity on the power market.

Table 4 Installed capacity Combined-heat-and-power per 01/01/2014 in MWe (excl. coal)

	Internal combustion/ gas motor	*CCGT*	*Gas turbine*	*Steam turbine*	**Total**
Industry	-	2,316	373	174	2,863
- refining	-	667	21	24	712
- food & beverage	-	147	117	62	326
- chemical	-	1,006	153	74	1,233
- paper	-	208	4	6	218
- other	-	288	78	8	374
Horticulture	3,060	-	-	-	3,060
Built Environment	580	2,055	-	321[7]	2,956
Total	***3,640***	***4,371***	***373***	***495***	***8,879***

Source: Energy Matters, 2014.

Since Combined-heat-and-power facilities typically have shown declining returns due to increasing pressure on electricity prices in recent years, an electric boiler set to benefit from lower electricity prices may provide for a natural fit in an effort to minimize the cost of heat generation. In addition, the parts of (electricity) infrastructure will be available already in case a Combined-heat-and-power installation is on-site. Here one should particularly think of the grid connection that should be in place for the Combined-heat-and-power installation, which is also required for an electric boiler. Hence, on top of synergies in deployment strategies a relative cost advantage for deployment of Power-to-Heat in combination with an existing Combined-heat-and-power installation may be expected. On the other hand, a Combined-heat-and-power /boiler strategy will require flexible deployment of the Combined-heat-and-power installation. Though many installations in the Netherlands already show differing degrees of flexibility, additional adjustments of the Combined-heat-and-power installation may be required.

7 Excluding the coal-fired Amercentrale of 600 MWe.

In case a gas-fired boiler is in place, a Power-to-Heat installation may complement the installation in order to exploit low electricity prices, while reversing to gas-fired operation at times of high electricity prices. In this case, a new grid connection may be required however.

3.4 Conclusions

This chapter set out with a brief introduction to the technical background of Power-to-Heat indicating the suitability of the technique to exploit short-term electricity price drops due to contributions from intermittent resources. This starting point was followed by a brief review of Power-to-Heat developments in Denmark and Germany, the EU member states that may be taken to be leading the energy transition in the sense that relatively large shares of VRES have already been introduced in these markets. In both countries application of Power-to-Heat is on the rise, particularly within the context of the process industry and district heating.

Further, a closer look at the technical potential for Power-to-Heat applications in the Dutch market was presented. Also in the case of the Netherlands substantial volumes of heat demand in the industry and district heating jointly with the existing infrastructure provides for a sound basis for such applications.
The potential for Power-to-Heat applications in the context of district heating is significantly affected by the demand profile as heat demand varies heavily over the course of the year. The resulting conservative estimate of the technical potential, based on the baseload heat demand adds up to some 0.1 GW year-round running up 0.5 GW during the winter peak.
The relatively stable levels of heat demand in industry provide for a significant potential for Power-to-Heat applications to generate low temperature below 200°C steam, conservatively estimated to offer a technical potential in the order of some 3 GW year-round, running up to some 5.5 GW in winter.
This estimate of demand for steam below 200°C should be taken as a conservative estimate as Power-to-Heat may service steam demand up to 260°C. As such, the technical potential in the Dutch industry suggests a solid technical potential for Power-to-Heat applications.

Local circumstances will significantly affect the technical potential for application of Power-to-Heat. Typically, a Power-to-Heat installation will be combined with an existing Combined-heat-and-power installation or a gas-fired boiler, either of these cases may prove to have a positive business case.
There can very well be additional synergies in combining Power-to-Heat with a Combined-heat-and-power installation due to the electrical capacity of the grid connection already present. In the following chapter, a more detail assessment of the costs and benefits of Power-to-Heat applications is presented.

4 Costs and Benefits of Power-to-Heat

This chapter presents an assessment of costs and benefits of Power-to-Heat applications in the Netherlands. Costs for this assessment are based on literature and relate to the investment costs for installation of an electric boiler and operating costs. These costs represent the actual costs involved with investment in the industrial boiler, investment in grid connection and finally boiler operation and maintenance costs and electricity consumed. Benefits of Power-to-Heat applications mainly relate to the potential cost savings associated with heat generation with an electric boiler at times of low electricity prices. Hence, benefits cover fuel savings resulting from a the fuel switch allowed by Power-to-Heat applications alongside a gas-fired boiler. Since these savings are largely driven by electricity prices, this assessment has been carried out for a number of price ranges; we present results based on actual APX prices in recent years, as well as simulated APX prices for 2023, given developments in the Dutch and Northwest European electricity markets (scenario for growth of variable renewable energy contributions).

This chapter concludes with an outlook on the return on investment in Power-to-Heat in terms of Return on Investment (ROI) and Return on Equity (ROE).

4.1 Cost structure of Power-to-Heat

Investment in Power-to-Heat involves several cost components. The main components relate to the investment cost for the high voltage electrode boiler, including cables, installation and grid connection costs, jointly entailing the CAPEX of a project. Furthermore, an investor should account for fixed and variable operating and maintenance (O&M) costs of the electrical boiler, which form the OPEX. For the purpose of this assessment, estimates regarding CAPEX and OPEX are based on Energienet (2012) as shown in Table 5. Further details can be found in Annex B.

Table 5 Assumed cost structure for a 20 MW Power-to-Heat installation

Parameter	Value	Unit	Description
Investment cost electric boiler incl. cables, installation and grid connection cost	190,000	€/MW	0.06 mln average cost for a 20 MW electric boiler and 0.13 mln €/MW for grid connection
Investment cost electric boiler incl. cables and installation	60,000	€/MW	0.06 mln average cost for a 20 MW electric boiler
Fixed O&M	1,100	€/MW/y	-
Variable O&M	0.5	€/MWh	-

Source: Energinet, 2012.

The nominal investment costs of a 20 MW high voltage electrode boiler for industrial purposes including cabling and installation range from 50 to 70 k€/MW. For this assessment, average investment costs of 60 k€/MW are assumed. For certain industrial processes high purity steam, or high pressure and temperature are required, which would result in differing investment costs. In addition, site specific circumstances can also influence investment cost. These process- and site-specific estimates have not been carried out in this assessment.

An additional cost of 130 k€/MW is reported to be required for grid connection costs, in case limited connection capacity is present on site. These costs relate to strengthening the local grid and transformer station. In case a grid connection is in place, notably in case a Combined-heat-and-power installation is already present on site, these grid connection costs can be avoided. Such a grid connection should be expected to be sized to either feed the Combined-heat-and-power electricity to the grid or, alternatively, to accommodate an on-site demand for electricity in case the Combined-heat-and-power installation is not in working order.

Summarising, estimates of total CAPEX for the investment run up to 190 k€/MW for a 20 MW industrial installation in case of an insufficient grid connection, and a lower amount of 60 k€/MW in case additional grid connection costs are not applicable.

Regarding the OPEX, a fixed O&M cost of 1,100 €/MW/y and an additional variable O&M cost of 0.5 €/MWh is assumed. In additional yearly cost of 23 k€/MW for transmission of the electricity consumed needs to be accounted for (see text box).

Transmission Tariffs
A transport tariff for electricity consumption applies to the electricity consumed for the deployment of an industrial boiler. Costs for year-round transport in the Netherlands range from 20 k€/MW tot 25 k€/MW yearly depending on the region. About half of this tariff involves a yearly tariff for contracted grid capacity, while the reminder involves a variable tariff component. The variable component is a monthly tariff depending on monthly peak consumption. In case consumption only takes place in a limited number of months, these costs decline accordingly. The existing structure for transport tariffs result in high costs per MWh in case of infrequent high capacity consumption as it is based on peak consumption rather than volume. High infrequent peak consumption results in transportation costs ranging from at least 10 €/MWh for 2,000 hours up to 30 €/MWh for 600 hours of offtake yearly.[8] Grid connection represents option value as it allows to operator to arbitrate between electricity and gas.

4.2 Benefits of Power-to-Heat

The benefits of Power-to-Heat applications are expected to be offered by the potential savings on costs for lower temperature heat generation for industrial purposes. These savings involve the opportunity cost of alternative means of heat generation, and in the Dutch industrial context typically the cost of heat generation with a gas-fired boiler or conceivably a Combined-heat-and-power installation. Additionally attainable benefits, for example resulting from more advanced deployment strategies for balancing services, have been disregarded here.[9]

8 For an offtake below 600 hours yearly, a 50% reduction of the variable component and a 25% reduction of the total network charges applies

9 An elaborate assessment of such benefits in the German market is offered by recent publication of an assessment committed by Agora Energiewende (see (Agora Energiewende, 2014).

The potential savings with heat generation through Power-to-Heat concepts are therefore largely driven by the cost difference between heat generation with natural gas on the one hand and heat generation with electricity on the other. The cost difference is driven by prices of natural gas, European Union CO_2 Emission Allowances (EUAs) and electricity respectively.

Table 6 **Natural gas - and European Emission Allowance prices assumed in this study**

Parameter	Value	Unit	Description
Price natural gas 2010-2013	8.5	€/GJ	IEA WEO, 2013
Price natural gas 2023	8.8	€/GJ	*New Policies Scenario*, IEA WEO, 2013
European Emission Allowances (EUA) - CO_2 costs 2010-2013	8	€/tonne	IEA WEO, 2013
European Emission Allowances (EUA) - CO_2 costs 2023	18	€/tonne	*New Policies Scenario*, IEA WEO, 2013

Source: WEO, 2013.

For the purpose of this analysis, both the benefits in recent years are assessed, as well as an estimation of the potential savings on the timeline as laid down in the Dutch Energy Agreement running up to 2023[10].

Prices of natural gas and EUAs assumed for this analysis are based on an averages of prices in recent years. Prices for the 2023 analysis are based on the New Policies Scenario in the World Energy Outlook (WEO) 2013 by the International Energy Agency (See Table 6).

Assuming a 90% efficient gas-fired boiler as alternative heat supply (the reference) implies that for heat production and an emission rate of 0.0561 tonne CO_2/GJ, the costs of natural gas and EUAs jointly imply a *cut-off price* for electricity. Below this cut-off level, a 99% efficient electric boiler will produce heat at lower costs than the reference, above this level the Power-to-Heat installation will not achieve lower costs. Table 7 presents a range of cut-off prices for differing cost-levels of natural gas and EUA's.

The price levels assumed for natural gas and EUA's in this analyses imply an opportunity cost level of 9.2 €/GJ in 2010-2013 and 9.8 in 2023, corresponding to a cut-off price range between 37 and 40 €/MWh for electricity. As lower estimate of the cut-off range, in the subsequent analysis 35 €/MWh will be taken as the cut-off price for Power-to-Heat activation. The price level of 35 €/MWh is also expected to be below typical cost levels of industrial Combined-heat-and-power installations, so that Power-to-Heat deployment for heat generation may complement Combined-heat-and-power deployment in a strategy seeking increase flexibility and ultimately reduce costs for heat generation.

The heating cost savings resulting from deployment of Power-to-Heat below this cut-off electricity price is estimated for both 2010-2013 and 2023 in the following sections.

10 A target of 16% renewable energy supply as a share of final energy demand, by 2023.

Table 7 **Cut-off rates for activation of Power-to-Heat given by opportunity cost levels of heat production with gas-fired boilers for differing levels of natural gas and EUA cost**

	Cost level						
Cost of natural gas + EUA: [€/GJ]	6	7	8	9	10	11	12
Cut-off price APX [€/MWh]	24	28	32	36	40	44	48

4.2.1 Heat Generation Cost Savings 2010-2013

For the estimation of the heating costs savings that would have been attainable through Power-to-Heat deployment over the timespan 2010-2013, the hours of Power-to-Heat, hourly cost savings and yearly cost savings are calculated in Table 8.

The results indicate that over this timespan, Power-to-Heat deployment would have run up to some 1,000–1,500 hours yearly, with the exception of 2011. During these hours an average electricity price of some 25-30 €/MWh applied, so that typically the hourly savings would have run up to some 10 €/MWh_{th}.

Table 8 **Hours of Power-to-Heat deployment (assuming an activation price of 35 €/MWh) and associated hourly and yearly heating cost savings per MW Power-to-Heat capacity**

Installed capacity Power-to-Heat (GW)	2010	2011	2012	2013
Number of hours with APX price <= 35 €/MWh	1,773	589	1,573	1,101
Average cost of electricity <= 35 €/MWh [€/MWh]	26.9	25.4	28.7	30.3
Hourly savings [€/MWh_{th}]	9.40	10.90	7.60	6.00
Yearly savings [€/MW_{th}]	16,689	6,427	11,975	6,620

4.2.2 Heat Generation Cost Savings 2023

For the purpose of this evaluation a simulation of the Dutch electricity market in 2023 is developed. The simulation is based on a stylized model of the Dutch electricity market, offering a detailed reflection of the marginal cost of electricity generation in Dutch system on a unit-by-unit basis and an hourly projection of demand and generation from variable renewable energy sources. Surrounding markets are simulated through simplified representation by form of a system marginal cost curve and hourly projection of demand and generation from variable renewable energy sources as well. The result of the simulation is an hourly electricity price curve for the Dutch day-ahead electricity market, the APX. More details can be found in Annex C.

Table 9 **Results for the APX price simulation for 2023 for current and projected levels of installed wind capacity and solar PV**

	Baseload €/MWh	Offpeak €/MWh	Peak €/MWh
Simulation 2023 (2.5 GW wind, 0.35 GW solar PV)	50.5	45.6	59.2
Simulation 2023 (10 GW wind, 0.35 GW solar PV)	45.7	39.1	57.6
Simulation 2023 (2.5 GW wind, 4 GW solar PV)	49.6	45.2	57.5

The model offers a simplified representation of the electricity market, disregarding a variety of dynamic restrictions like minimum up- and down-time of generation units, ramp rate restrictions and start costs. As such, it offers an outlook on price developments in terms of order of magnitude and provides an indicative outlook on the potential for Power-to-Heat applications for heat generation as a cost-efficient alternative to gas-fired boilers, given the underlying scenario assumptions (see the following textbox).

Electricity Market Scenario Assumptions
The scenario for Dutch electricity supply in 2023 was developed on the basis of the commitments as laid down in the National Energy Agreement. It aligns with the *Duurzaam Beleid Scenario*[11] as presented in the Quality and Capacity Plan 2013 (QCP, 2013) by TenneT. This Scenario reflects the relevant objectives in the Dutch Energy Agreement, combined with information on decommissioning and mothballing as announced to TenneT and finally expert judgment on announced new builds in order to attain an internally consistent scenario.
This scenario was validated through consultation of a broad panel of domain experts from stakeholders in the Dutch electricity market.

Foreign developments are based the *Scenario B* and *Vision 3* developed by ENTSO-E[12], that represent a 'best estimate' until 2020 and an 'on-track' scenario for the European 2050 energy roadmap goals, respectively.

Fuel prices were adopted from the *New Policies Scenario* as presented in the World Energy Outlook (WEO) 2013 by the International Energy Agency (IEA). This Scenario accounts for existing policy commitments and assumes that those recently announced are implemented, be it cautiously.

Table 9 presents the price results for three simulations, reflecting both today's level of installed wind power and solar PV capacity as well as the projected levels of installed capacity in 2023 on the basis of the National Energy Agreement and QCP 2013.

From these simulations it may be concluded that the future development of wind power and to a lesser extent solar PV capacity is a critical element in the price simulation.

In order to account for secondary effects of Power-to-Heat instalment, a series of price simulations for varying levels of installed Power-to-Heat was developed, ranging from virtual absence of Power-to-Heat up to an installed capacity of 5 GW in the Netherlands covering the range of estimated potential for Power-to-Heat.

For each of these simulations, the heating cost savings attainable through Power-to-Heat deployment in 2023 is estimated by calculating the hours of Power-to-Heat deployment, the hourly cost savings and yearly cost savings. The results are presented in Table 10.

The results suggest a substantial potential for Power-to-Heat deployment, up to 2,200 hours yearly. However, increasing levels of Power-to-Heat capacity will affect this potential significantly, depressing the potential deployment with some 15 to 30% per GW of installed capacity. During these hours an average electricity price of some 25–30 €/MWh occurs, so that typically the hourly savings run up to some 8 €/MWh.

[11] This may be translated as the *Sustainability Policy scenario*.

[12] See Scenario Outlook and Adequacy Forecast 2013–2030, ENTSO-E, 2013.

Table 10 **Hours of deployment and associated average cost of electricity for differing levels of penetration of Power-to-Heat assuming an activation price of 35 €/MWh**

Installed Capacity Power-to-Heat (GW)	0	0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0
APX price <= 35 €/MWh	2,170	1,820	1,520	1,230	990	840	700	570	460	350	250
Average cost of electricity €/MWh	26.50	26.90	27.40	27.80	28.20	28.70	29.30	29.70	30.10	30.40	30.60
Hourly savings €/MW Power-to-Heat	8.50	8.10	7.60	7.20	6.80	6.30	5.70	5.30	4.90	4.60	4.40
Yearly savings €/MW Power-to-Heat	18,445	14,742	11,467	8,856	6,732	5,292	3,990	3,021	2,254	1,610	1,100

Note: Hourly and yearly savings are calculated for the full installed capacity, given in row 1. For no installed capacity, we have calculated a marginal Power-to-Heat yield figure the first MW of Power-to-Heat realised).

4.3 Investment Outlook Power-to-Heat in the Netherlands

Table 11 **Basic assumptions on the capital structure for Power-to-Heat investments**

Parameter	Value	Description
Debt/Equity	80%/20%	The assumed ratio of debt/equity
Interest [%]	5.5%	-
Required return on equity [%]	15%	A 15% ROE is customary in project finance, as a benchmark for the opportunity cost of investment
Economic lifetime [years]	15	Economic lifetime of the asset is taken as a basis for the loan and depreciation

For the investment outlook for Power-to-Heat in industrial context in the Netherlands this section combines costs and benefits of Power-to-Heat as calculated above and presents the resulting investment outlook by form of return on investment (ROI) and return on equity (ROE). For these calculations, several basic assumptions regarding the capital structure as presented in Table 10 were applied.

Figure 15 presents the ROI and ROE for a Power-to-Heat project for each of the years 2010-2013. These four assessments assume that the electricity price dynamics as observed in each of the years 2010-2013 will consistently hold over the full economic lifetime of the asset. The evaluation distinguishes between the case that a new grid connection is required for the project, and the case that the grid connection capacity is adequate (reflecting for example the situation that a Combined-heat-and-power installation is already present on the site).

Both in case of a Power-to-Heat project in the situation where a new grid connection is required, as well as in presence of adequate grid connection, the ROE fails to meet the 15% requirement for each of the years and fails to achieve a positive ROI. Further, year-on-year the returns may differ substantially, reflecting a significant volume risk.

Figure 15 Return on investment (ROI) and return on equity (ROE) for a Power-to-Heat project for the actual APX realisations in 2010-2013, including and excluding grid connection costs respectively

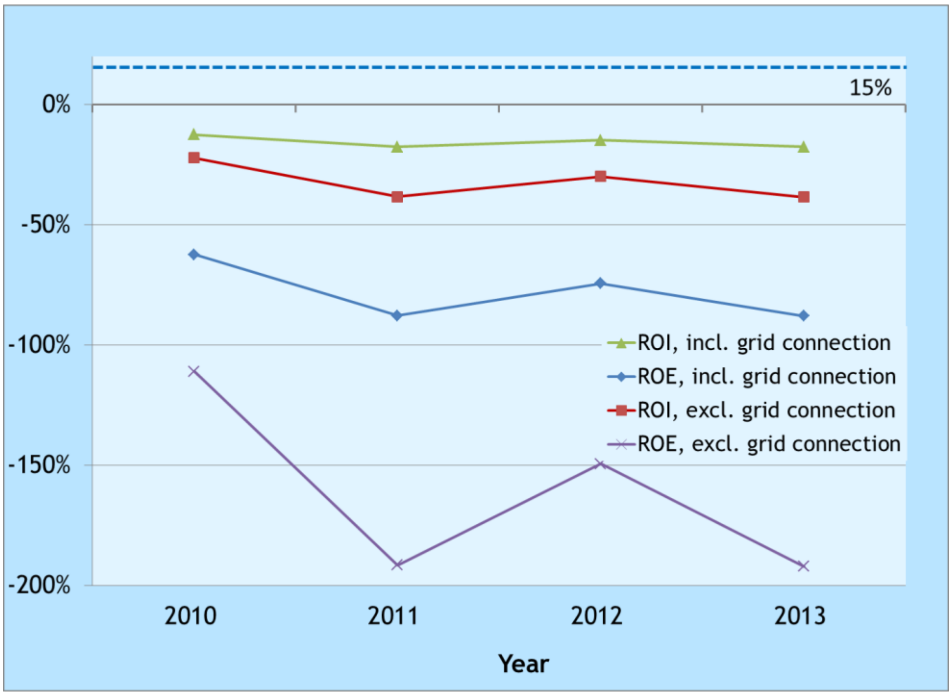
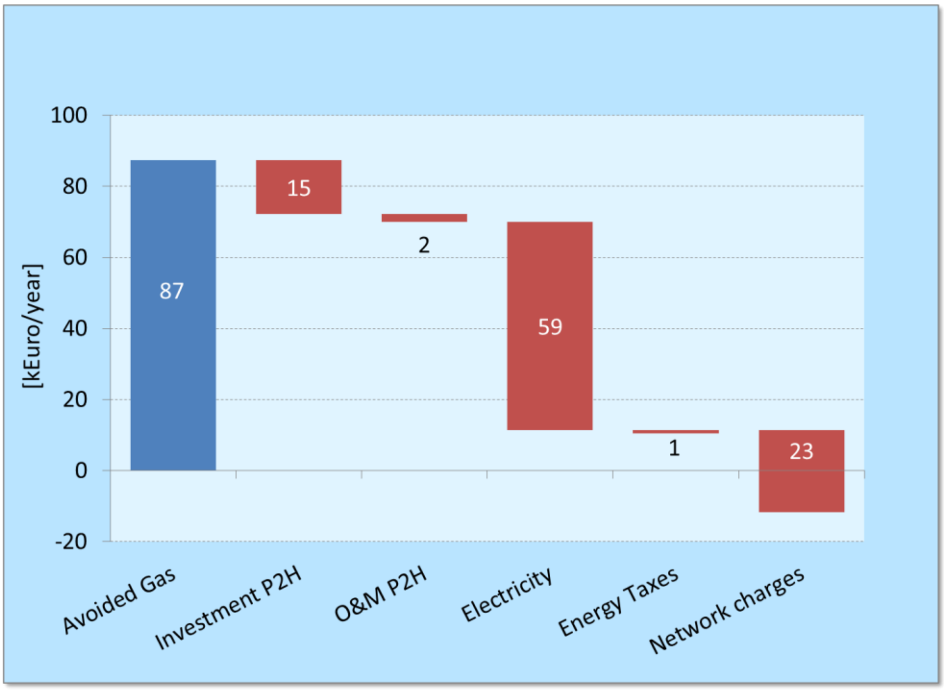


Figure 16 Yearly costs and benefits of 1MW of Power-to-Heat capacity for electricity price simulations for 2023, assuming a new grid connection is required (top) and assuming a grid connection is in place due to presence of a Combined-heat-and-power installation (bottom)



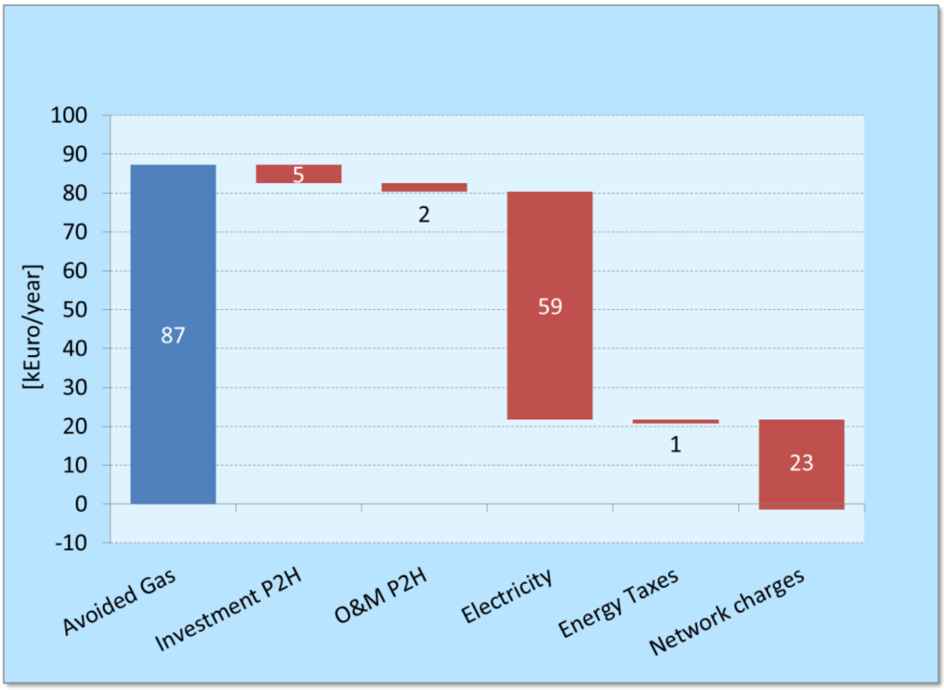


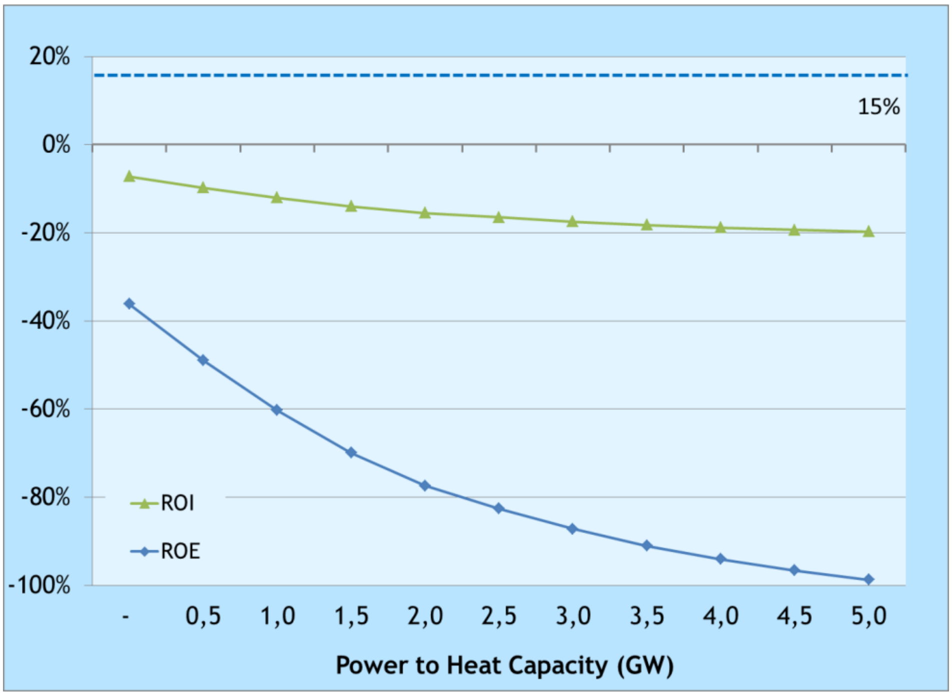
Figure 16 presents the costs and benefits per MW Power-to-Heat capacity for low levels of installed Power-to-Heat capacity (or assuming no impact on electricity pricing) on the basis of the previously presented simulations of the electricity market in 2023. As before, the evaluation distinguishes between the case that a new grid connection is required for the project (
Figure 16, top), and the case that an adequate grid connection is already available reflecting the situation that a Combined-heat-and-power installation is already on-site (Figure 17, bottom). In case a new grid connection is required for the project, the costs clearly outstrip the benefits. The overall benefit of some
87 k€/MW on natural gas savings is largely offset by some 59 k€/MW for additional electricity costs and 23 k€/MW for the transmission tariff.
In case a grid connection is in place already, the project roughly breaks even and shows marginally positive returns for the lower end of the range of today's transmission tariffs of 19 k€/MW. Alternatively, the business case will result positively if electricity prices decline an additional 10% or more below the average price levels simulated. However, instalment of Power-to-Heat will also affect the electricity prices, as found in Section 4.2.

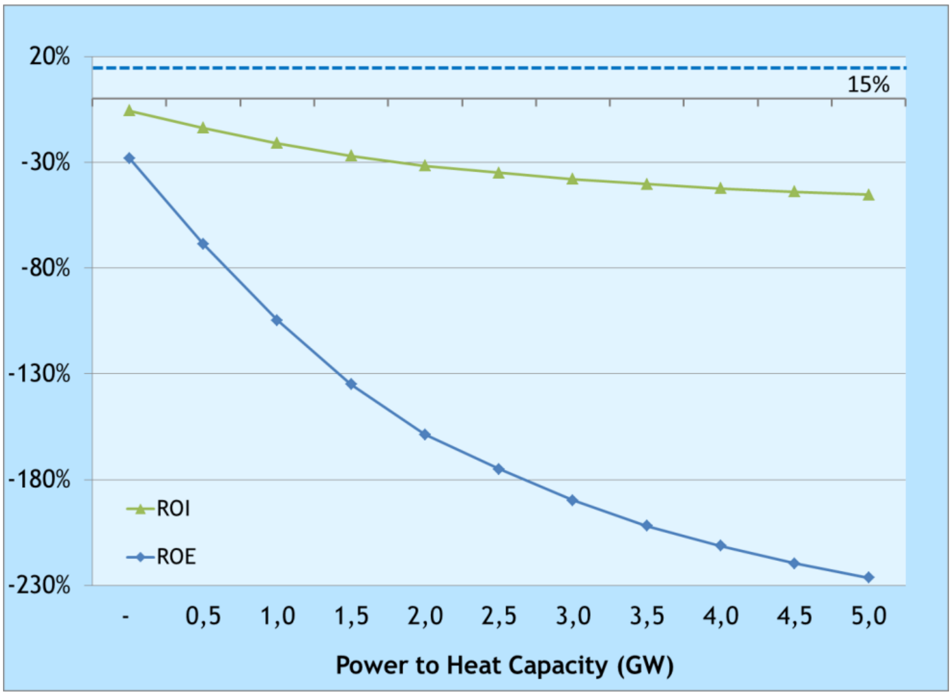
Higher levels of installed capacity of Power-to-Heat may therefore deteriorate the business case substantially. In order to establish this impact, the ROI and ROE for a Power-to-Heat project on the basis of the previously presented simulations of the electricity market in 2023 is presented in Figure 17.
As before, the evaluation distinguishes between the case that a new grid connection is required for the project (Figure 17, top), and the case that an adequate grid connection is already available reflecting the situation that a Combined-heat-and-power installation is already on-site (Figure 17, bottom).
In both instances ROI and ROE are evaluated for increasing levels of Power-to-Heat instalment in the Netherlands, ranging from absence to 5 GW installed capacity.

Both in case of a Power-to-Heat project in the situation where a new grid connection is required, the project ROE fails the 15% requirement for low levels of installed capacity already.

In case of the evaluation of a Power-to-Heat project where an adequate grid connection is available, the project breaks even for low levels of installed capacity of Power-to-Heat. This suggests a limited economic potential for Power-to-Heat in industrial context in the Netherlands even in case grid connection costs can be avoided.

Figure 17 **Return on investment (ROI) and return on equity (ROE) for a Power-to-Heat project for electricity price simulations for 2023 for increasing levels of installed electric boiler capacity, assuming a new grid connection is required (top) and assuming a grid connection is in place due to presence of a Combined-heat-and-power installation (bottom)**





4.4 Conclusions

In this chapter a high-level assessment of system costs and benefits of Power-to-Heat deployment for heat generation in the Netherlands is presented. Power-to-Heat offers opportunities to reduce heating costs by replacing conventional heat generation at times that electricity prices fall below 35 €/MWh, while applying the existing means of heat generation for the reminder.

Here, two situations should be distinguished:
1. Existing heat generation is primarily from gas-fired boilers.
2. Existing heat generation is primarily from Combined-heat-and-power installations.

In the first case, Power-to-Heat investments will require a new grid connection, which increases investment costs significantly. In the second case, an adequate grid connection will be on-site and grid connection costs are no longer required. In this case only investment costs for the high voltage electrode boiler remains.

The evaluation of projects the first type of project, where a new grid connection is required to accommodate Power-to-Heat, for actual APX prices of 2010-2013 shows that these projects failed to meet the 15% ROE requirement. In the longer run, up to 2023, declining price levels on the Dutch electricity market may improve the ROE significantly. The assessment on the basis of electricity price simulations in this Chapter however shows negative returns and suggests that the ROE requirement is unlikely to be met by 2023.

The second type of projects, with adequate grid connections in place already due to existing Combined-heat-and-power installations, lower investment costs result. For the APX prices observed in 2010-2013, the year-on-year the returns differ substantially, but the 15% ROE requirement are however not met in any of the years. In the longer run, up to 2023, declining price levels on the Dutch electricity market due to the introduction of wind and solar PV may add to a substantial investment potential for Power-to-Heat applications. In case of the assessment presented in this Chapter, Power-to-Heat projects in presence of adequate grid connections may just break even so that the 15% ROE requirement is not met. Additional evaluation of the business case for Increasing levels of installed Power-to-Heat capacity shows that the case quickly deteriorates further.

These results suggest a highly constrained investment potential for Power-to-Heat applications in the current Dutch context and market outlook. Only if stronger electricity price depreciations occur or if transmission tariffs are restructured.

5 Conclusions

This report aims to evaluate the potential for Power-to-Heat applications in the context of the Dutch market.

The assessment sets off with a closer look at the fundamental changes in the current and future Northwest European electricity market resulting from the large-scale deployment of renewables. Current electricity system and price dynamics in countries with large-scale deployment of renewables offer an outlook of declining electricity prices in general. Two distinct patterns of extremely low electricity prices emerge: in wintertime at times of strong windy conditions combined with low demand, and second strong declines of peak prices in summertime. In the latter case even a reversal of the peak-base spread due to large contributions of solar PV is observed.

Low electricity prices offer new opportunities for number of electricity applications, provided these applications are sufficiently flexible to respond to short-term price variations. Power-to-Heat was found to be an important application that fulfils this requirement. With Power-to-Heat, industrial electric boilers, a proven technology, are installed to generate low temperature steam or hot water. Capitalizing on low electricity prices, Power-to-Heat provides for an interesting opportunity to reduce cost of heat generation. In the Dutch context, the technical potential for such applications is conservatively estimated to vary from some 3 to 5.5 GW for applications summer-on-winter in the process industry, while a technical potential of some 0.1 to 0.5 GW summer-on-winter may span the opportunities in district heating.

A more detailed evaluation of the system costs and benefits of Power-to-Heat was carried out on the basis of both electricity prices of the recent years as well as an outlook for future electricity prices given the current agenda for the penetration of renewable energy sources. This evaluation indicates that by 2023 some 500 MW of Power-to-Heat capacity may be deployed profitably in combination with gas-fired boilers.

Much higher levels of profitable deployment should be expected if Power-to-Heat is employed at sites where grid connection is sufficient, e.g. combined with existing Combined-heat-and-power installations, in which case investment costs for Power-to-Heat are reduced substantially since a grid connection is already present. For these instances, profitable deployment may be expected for capacities up to some 2.5 GW of installed Power-to-Heat capacity matching the existing base of installed Combined-heat-and-power capacity of 2.8 GW_e.

Table 12 Technical and economic potential for Power-to-Heat application by 2023 in the Netherlands by market segment and season

Sector	Technical Potential Summer	Technical Potential Winter
District Heating	0.1	0.5
Industry	3.0	5.5
Horticulture	n/a	n/a
Total Technical Potential	3.1	6.0

Table 12 summarizes the technical potential in the Netherlands. Though a substantial technical potential is found, the investment outlook for Power-to-Heat application in the Netherlands is highly limited however. In all cases, potential savings are outstripped by investment costs, operating and maintenance cost, and costs of transmission for infrequent high capacity offtake. The evaluation presented in this report indicates that the costs saving based on the electricity price simulations applied will not suffice to overcome this barrier, or at best allow the project to break-even.

References

Agora Energiewende, 2013. *12 insights on Germany's Energiewende,* Berlin: Agora Energiewende.

Agora Energiewende, 2014. *Power-to Heat zur Integration von ansonstenabgeregeltem Strom aus Eneubaren Energien,* Berlin: Agora Energiewende.

Brandt, I., Zuhmann, M. & Skriver (ed.), G., 2013. Best Practice in District Heating: Stadtwerke Flensburg has for more than 40 years been an icon of energy efficiency in Germany. *Hot/Cool,* Issue 2, pp. 10-13.

Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag, 2012. *Regenerative Energieträger zur Sicherung der Grundlast in der Stromversorgung, Endbericht zum Monitoring,* Berlin: Karlsruher Institut für Technologie (KIT).

CE Delft ; DNV GL, 2014. *Toekomst WKK en warmtevoorziening industrie en glastuinbouw,* Delft: CE Delft.

CE Delft, 2009. *Warmtenetten in Nederland : overzicht van grootschalige en kleinschalige warmtenetten in Nederland,* Delft: CE Delft.

CE Delft, 2014a. *Dreigende mismatch van vraag en aanbod,* Delft: CE Delft.

CE Delft, 2014b. *Kansen voor warmte,* Delft: CE Delft.

Davidse Consultancy, 2012. *Wamte-energie, de motor van de industrie,* Bennekom: Davidse Consultancy.

ECN, 2010. *Benutting restwarmte : notitie aan Werkgroep Heroverweging Energie en Klimaat,* Petten: ECN.

Energie-Nederland, 2012. *Rapport Tariefadvies voor de levering van warmte aan kleinverbruikers 2013,* Den haag: Energie-Nederland.

EPIA, 2013. *Global Market Outlook for Photovoltaics 2013-2017,* Brussels: European Photovoltaic Industry Association (EPIA).

Fraunhofer ISE, 2014. *Electricity Spot-Prices and Production Data in Germany 2013,* Freiburg: Fraunhofer Institute for Solar Energy Systems ISE.

GWEC, 2013. *Global Wind Report 2013 - Annual market update,* Brussels: Global Wind Energy Council.

Stadtwerke Flensburg, 2012. *Stadtwerke Flensburg Pressemeldung 09.03 Halle für Flensburgs Stromheizung" termingerecht fertig – Stadtwerke Flensburg feiern Richtfest.*. [Online]
Available at: http://www.stadtwerke-flensburg.de/
[Accessed 2 September 2014].

Annex A Power-to-Heat projects

A.1 Germany[13]

Versorger	Ort	Kesselart	el. Leistung [MW]	Inbetriebnahme
Alte Bestandsanlagen*				
EnBW			ca. 160	
Vattenfall	Hamburg		?	
E.ON			?	
RWE			?	
Neue PtH-Projekte**				
Stadtwerke Tübingen	Tübingen	Elektrokessel	5	geplant
EEW Energy from Waste	Premnitz	EHK	20	ca. August 2014
Stadtwerke Nürnberg	Nürnberg	EHK	50	ca. August 2014
Infraserv Höchst	Frankfurt (Höchst)	EHK	40	April 2014
VV Saarbrücken	Saarbrücken	EHK	10	in Betrieb
Stadtwerke Schwerin	Schwerin	Elektrokessel	15	in Betrieb
E.ON Ruhrenergie (Sham-rock)	Herne (NRW)	EHK	60	in Betrieb
Stadtwerke München	München (HKW Süd)	Elektrokessel	10	in Betrieb
Stadtwerke Lemgo	Lemgo	Elektrokessel	5	in Betrieb
Stadtwerke Flensburg	Flensburg	EHK	30	in Betrieb
SUMME - Anzahl 9			**225**	

Source: (Agora Energiewende, 2014).

13 Before liberalization in Germany Power-to-Heat plants already existed in nuclear plants, operated by the four major utilities. Nevertheless, the figures for installed capacity are not public available. The information for new Power-to-Heat systems, which have emerged in recent years, were based on industry data.

A.2 Denmark

Versorger	el. Leistung [MW]	Spannungsebene [kV]	Inbetriebnahme
AffaldVarme Århus	*80*	*150*	*2015*
Brønderslev Forsyning	20	10	2012
Ribe Fjernvarme	10	15	2012
Brøndum A/S	0,1	0,4	2012
Karstensens Skibsværft	0,1	0,7	2012
Jerslev Kraftvarme	2,4	0,4	2012
Bravida Danmark A/S Tilst	0,1	0,4	2012
Christiansfeld Fjernvarme	3,0	0,4	2012
Nr. Broby Varmeværk	1,5	0,4	2012
Brørup	10,0	10,5	2012
Egtved Varmeværk	4,0	0,7	2012
Hjallerup Fjernvarme	6,0	10,5	2012
Smørum Kraftvarmeværk	10,0	10,5	2012
Strandby Varmeværk	10,0	10,5	2012
Augustenborg Fjernvarme	8,0	10,5	2011
Bredsten-Balle Kraftvarmeværk	2,9	0,7	2011
Brædstrup Fjernvarme	10,0	10,5	2011
E.ON Danmark, Præstø	4,4	0,7	2011
EON-Frederiksund	10,0	10,5	2011
Gartneriet Madsendø	10,0	10,5	2011
Hanstholm Varmeværk	10,0	10,5	2011
Nykøbing Mors	6,0	10,5	2011
Outrup Varmeværk	1,1	0,7	2011
Snedsted	6,0	10,5	2011
Videbæk Energiforsyning	10,0	10,5	2011
Vojens Fjernvarme	10,0	15	2011
Vorupør Kraftvarme	11,0	0,4	2011
Aulum Fjernvarme	10,0	10,5	2010
Brovst Fjernvarme	10,0	10,5	2010
Helsinge Fjernvarme	10,0	10,5	2010
Hvide Sande	10,0	10,5	2010
Nørre Snede	4,5	0,7	2010
Ringkøbing Fjernvarmeværk	12,0	10,5	2010
Sæby Varmeværk	12,0	10,5	2010
Vildbjerg Varmeværk	12,0	10,5	2010
Østervraa Varmeværk	3,0	0,7	2010
Hornum Fjernvarme	1,0	0,4	2009
Struer Forsyning	0,9	0,4	2009
Danfoss Redan	0,2	0,4	2008
Grindsted El & Varmeforsyning	18,0	10,5	2008
Hindsholm Kraftvarmeværk	3,0	0,4	2008
Skagen Varmeværk	10,0	10,5	2008
Energi Fyn - Assens	16,0	10,5	2007
Energi Fyn - Kratholm	16,0	10,5	2006
SUMME - Anzahl 44	**405,2**		

Source: (Agora Energiewende, 2014).

Annex B Technical specifications electric boilers

Electric boilers*. The Stadtwerke Flensburg electric boiler has a capacity of 30 MW.

ZVPI/ZVP	1600	1800	2000	2500	2800
Capacity (MW)	0-5	5-9	10-20	16-24	24-40
Height (mm)	3800	4700	5200	5300	6750
Width (mm)	2140	2600	3250	3250	
length (mm)	2700	3000	4700	4700	
Diameter pressure vessel including insulation (mm)	1800	2000	2200	2700	3000
Pipe connection	100	150	200	300	400
Shipping weight (tons)	1,5	1,8	2,8	4	8
Pressure test weight (tons)	6,5	10	13	18	30
General data					
Volage kV	6-20				
insulations thickness (mm)	100				
Material dished ends and shell	P295GH				
Control range	8-100 %				
Regulating time min/max (min)	3				
Design pressure (bar e)	16				
Operating pressure (bar e)	2 till 3				
Design temperature °C	204				
Maximum operating temperature °C	180				
Efficiency	>99 %				
Standard EN 12953					

Source: Zeta.se.

* Hot water boilers are shown in table.

High Voltage Electric boilers: hot water and steam boilers

Technical data	
Capacity (MW)	1-90
Voltage (kV)	6-36
Control range	0/10-100%
Efficiency	>99%
Operating pressure (bar)	up to 25 bar

Source: Vapec.ch.

Table 13 Technical specifications of industrial electric boilers

Technology	Electric boilers			
	2015	2020	2030	2050
Energy/technical data				
Generation capacity for one unit (MW)	1-25			
Efficiency (%)	99	99	99	99
Technical lifetime (years)	20	20	20	20
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1
Environment				
Local emissions	-			
Financial data				
Nominal investment (M€/MW); 400 V; 1-3 MW	0.13-0.16	0.13-0.16	0.13-0.16	0.13-0.16
Nominal investment (M€/MW); 10 kV; 10 MW	0.06-0.09	0.06-0.09	0.06-0.09	0.06-0.09
Nominal investment (M€/MW); 10 kV; 20 MW	0.05-0.07	0.05-0.07	0.05-0.07	0.05-0.07
Fixed O&M (€/MW per year)	1100	1100	1100	1100
Variable O&M (€/MWh)	0.5	0.5	0.5	0.5

Source: Energinet, 2012.

Annex C Electricity Market Model

C.1 Purpose

For the purpose of assessing price impacts of future market development CE Delft developed a simplified electricity market model for the Netherlands on the basis of a detailed representation of the merit order. The model is limited to marginal cost evaluations of production on the basis of fuel prices and system efficiency. On the other hand, the model is highly suitable for evaluation of the impact of renewables and associated stochastics as it requires little preparation and runtime. Results from the model should be taken to offer a reasonable outlook on price developments and price impact assessments for initial evaluation in order to justify the need for more detailed evaluations.

C.2 Model structure

The model includes detailed characterisation of the quadratic heat rates of electricity production facilities varying from min. load to max. load on a unit-by-unit basis. Other technical specifications relating to dynamic constraints like minimum up- and downtime, ramp rates, start costs and the associated unit commitment (on/off decisions) are not included in the model.
Foreign contributions have been included by form of a simplified representation of the foreign supply system in a singular system marginal cost curve reflecting the underlying system on a unit-by-unit basis.

The electricity market model uses the following input data:
- hourly demand profile;
- hourly wind energy production (wind data KNMI 2011, wind data German TSOs);
- hourly solar energy production (data German TSOs 2011);
- conventional supply 2011 and 2023 (Referentieramingen en Quality and Capacity Plan 2013 by TenneT);
- conventional foreign countries (WEPPS database 2010, BnetzA, Elia);
- net hourly import (ENTSO-E data 2011), used for calibration only;
- Energy prices IEA World Energy Outlook 2013.

C.3 Validation 2011

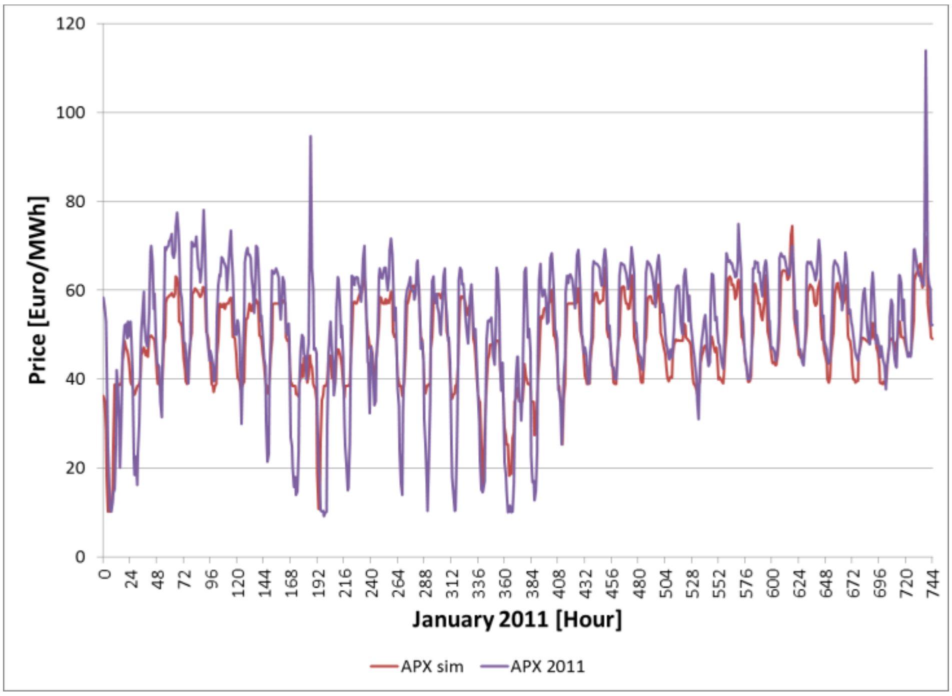
The model was validated through simulation of the Dutch market in 2011 and comparison of price results with APX spot price data 2011. Such a comparison serves for the validation of the merit order data in comparison to demand, where primarily a comparable price level given the main demand categories (peak and off-peak) is required.

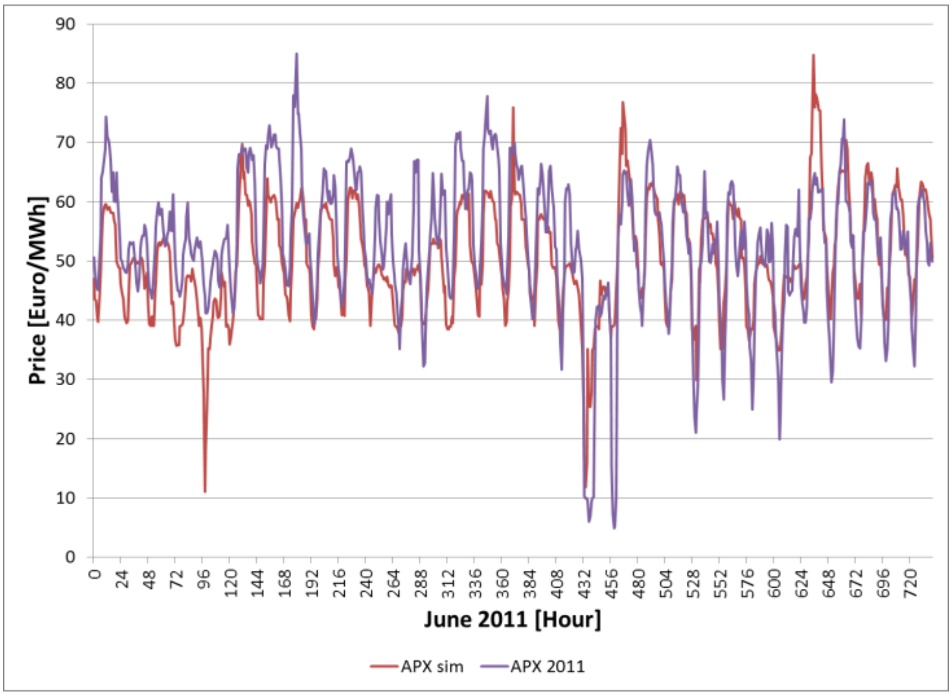
Table 14 Comparison price simulation and APX data for 2011

	Baseload €/MW	Offpeak €/MW	Peak €/MWh
APX 2011	52,03	46,76	61,57
Simulation 2011	50,51	46,05	58,58

Source: CE Delft, 2014.

Figure 18 Simulated and actual APX prices winter (January) and summer (June) 2011



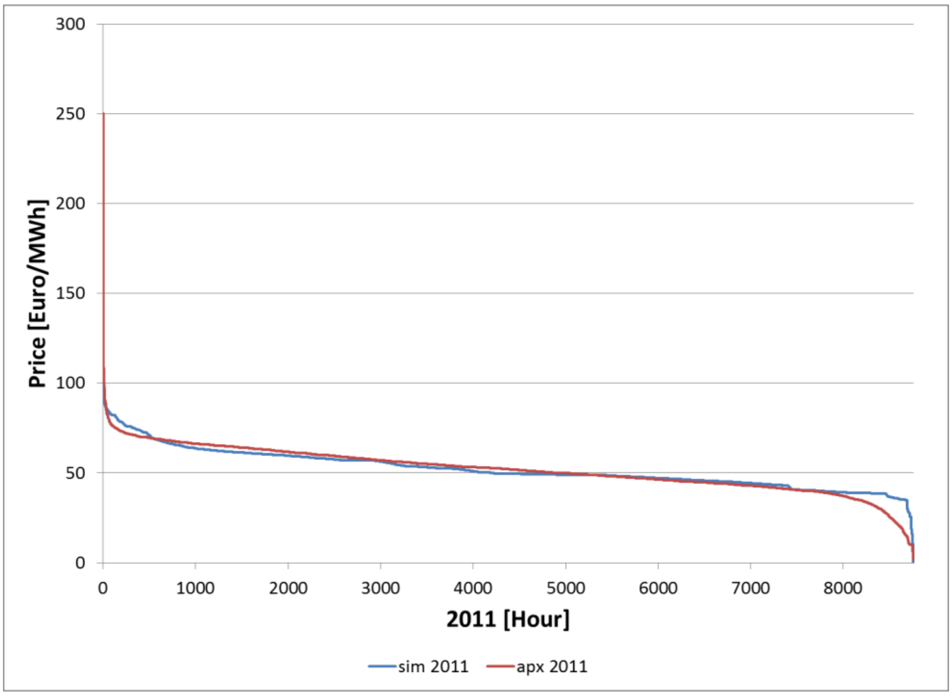


Results of this validation are presented in Table 14, Figure 18 and Figure 19.

- Table 14 shows comparable price levels for peak, off-peak and base for 2011.
- Figure 18 show simulated prices and APX prices for a month in winter and summer respectively. The figure illustrates that the simulations are reasonably well representing the actual price levels. The patters are followed nicely, though fluctuations on the APX show to be somewhat more extreme. This may be the result of limited representation of the underlying dynamic limitations of the production facilities, such as start-up time, minimum up- and downtime, ramp rates and the costs associated with start-up.

– Figure 19 presents the price duration curve for both the simulation and APX 2011. It may be observed that the simulated price duration curve follows the APX price duration curve reasonable well, though in the lower end of the curve, some divergence occurs and the simulation overestimates prices somewhat for low demand levels. This is likely to be explained by the assumptions with regard to Combined-heat-and-power. The Combined-heat-and-power assumptions for the Dutch market involve some degree of aggregation and must-run assumptions have been applied on the basis of (CE Delft ; DNV GL, 2014). Higher levels of must-run would result in lower price levels in low demand periods.

Figure 19 Simulated and actual APX Price duration curve 2011



The results confirm that a the model provides for a reasonably accurate representation of the Dutch market that captures the price dynamics involved with electricity production and demand for yearly averages quite accurately with deviations in the order of only several €/MWh. With regard to the volatility, actual price dynamics are captured nicely, though price extremes tend to be somewhat more dampened that in case of the actual market prices in 2011. For lower price levels the model shows to be overestimation prices somewhat, likely to be caused by limitations in the representation (must-run or flexible dispatch) and parameterisation (heat rate) of Combined-heat-and-powers.