Energy and electricity price scenarios 2020-2023-2030

Input to *Power to Ammonia* value chains and business cases

CE Delft

Committed to the Environment

Energy and electricity price scenarios 2020-2023-2030

Input to *Power to Ammonia* value chains and business cases

Delft, CE Delft, January 2017

This report is written by:
Maarten Afman
Sebastiaan Hers
Thijs Scholten

Publication code: 17.3H58.03

This report is commissioned by the Power to Ammonia project.
The Power to Ammonia project is a partnership between ISPT (project leader), Stedin Infrastructure Services, Nuon, ECN, Delft University of Technology, University of Twente, Proton Ventures, OCI Nitrogen, CE Delft and AkzoNobel, and made possible by a grant from the Dutch Energy Top Sector, System Integration programme.

Further information on this report and the material therein can be obtained from the contact person, Maarten Afman, e-mail: afman@ce.nl

Contents

1 Introduction

The more we proceed with the energy transition towards renewable and sustainable energy, the greater the need to innovate on a system level: we have to find and implement options that make the energy system more flexible. This must be done in a way that fits variable renewable energy sources - ample supply at some time, and shortages at other times. Technologies like Power to Ammonia, that convert electrical energy to a chemical form, store the energy for a length of time, allowing for conversion back to electricity if necessary, are just the options that are important to investigate.

As an important part of the mission of CE Delft is to contribute to structural change towards a sustainable energy system, we gladly participated in the joint Power to Ammonia project of 2016 and contributed to the development of this option.

In the project, our main contribution was two-fold:

1. Knowledge transfer within the consortium on the electricity market. For this we organised two workshops with the goal of raising the knowledge on the electricity market, the current institutional arrangements in the electricity markets, and what will change given projected developments.
2. Develop energy and price scenarios for the time scale to be used in the P2A value chains (2020-2023-2030). The scenarios were developed based on input from the consortium partners and tailored to the sensitivities surrounding the Power to Ammonia value chain. Electricity prices were simulated with the PowerFlex market simulation model.

This report describes both contributions, with emphasis on the energy and price scenarios.

2 Electricity market

Because the Power to Ammonia project brings together a number of topics and sectors, a shared knowledge level is needed on the energy system, and future challenges thereof. Two workshops were held for this purpose.

Workshop 1: electricity market

For electrochemical conversions, the electricity system is of obvious importance. Electricity is an energy carrier of a special nature. Because it cannot be stored without any form of conversion, maintaining the momentary balance between consumption and supply of electricity is a challenge that is reflected in a rather complex market design.
The main topics covered were:

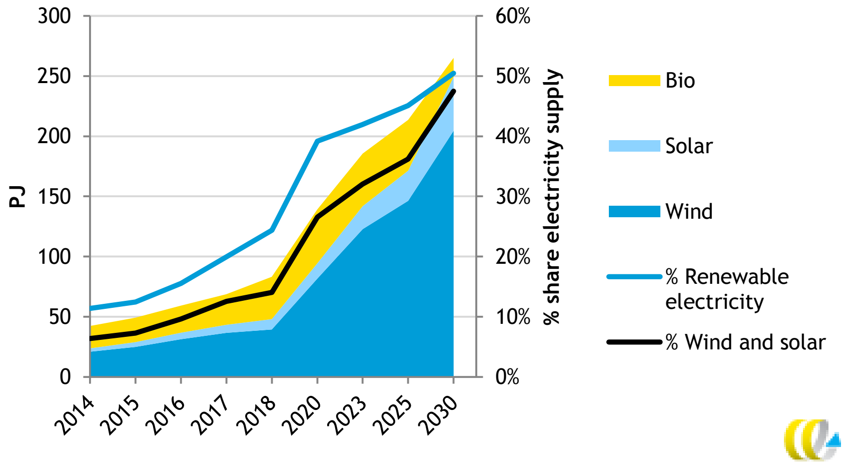
1. Wholesale market: OTC long term, bilateral, day ahead spot, intraday.
2. Balancing mechanism and markets.
3. Transport market.
4. Price formation in the Energy Only Market model, regulation.
5. Flexibility requirements and flexibility provision.

Workshop 2: transitions in the energy system and scenarios

The second work shop recapped the main results of the first workshop and continued with wider trends in the Dutch (see figure) and European energy systems and the decarbonisation challenge. Given these perspectives, the outlines and scenario design were discussed for the electricity market scenarios to be developed. Due to the large volumes of electricity required for producing ammonia via electro-synthesis in large quantities, spot market pricing is the relevant market to assess. The next chapter of the report fully details the scenarios developed.

Figure 1 Development of the supply of renewable electricity in the Netherlands

As an illustration, the figure shows the expected development in renewable electricity in the Netherlands. In 2030, wind and solar will contribute to 250 PJ towards the Dutch energy supply, a share of about 50% in the electricity demand and 13% of total (current) energy demand.



3 Energy and electricity price scenarios

3.1 Energy scenarios for Power to Ammonia

For Power to Ammonia business cases, future electricity prices and its dynamics on different timescales are important ingredients. Price scenarios are input to:

1. Selecting a suitable operation of the P2A plant: the operational dynamics, when to operate, when not, starts, stops, etc.
2. A suitable dimensioning of the P2A plant as well as of buffer tanks, etc.
3. Ultimately the expected profitability of the 'value cases', either direct from the volatility in prices simulated, or through the arbitrage between power and ammonia markets, and so on.

Therefore, one of the CE Delft work packages in the Power to Ammonia project was to develop a number of suitable energy price scenarios to be used in the three business cases. This chapter details the scenarios, the modelling approach with the PowerFlex energy market simulation model and the results.

3.2 Scenario selection

The first goal of scenarios is to do baseline projections for the future. The second goal is to be able to investigate the key sensitivities in the P2A business cases that are caused by power prices. This combined goal means two things for the scenario design. First of all, price scenarios should mimic a plausible future path given our best knowledge at this point; secondly scenarios should capture some of the profound uncertainties that relate to the business case. Therefore the scenario design should capture the relevant uncertainties.

If we look at uncertainties surrounding power prices in the time frame 2017-2030, a number of important aspects are uncertain to a larger or lesser extent. These uncertainties relate to:

- fuel prices, especially coal and gas;
- CO_2 prices;
- generating technologies and installed capacities;
- renewable energy, installed capacity;
- demand; dynamics thereof (how it fluctuates over time); elasticity of demand and demand response;
- regulatory, i.e. market design, capacity payments, RES remuneration scheme affecting power market bidding behaviour, etc.;
- technology: adoption and learning rates of innovative demand and supply technologies (such as EV, solar PV, heat pumps, P2H, P2G, etc.).

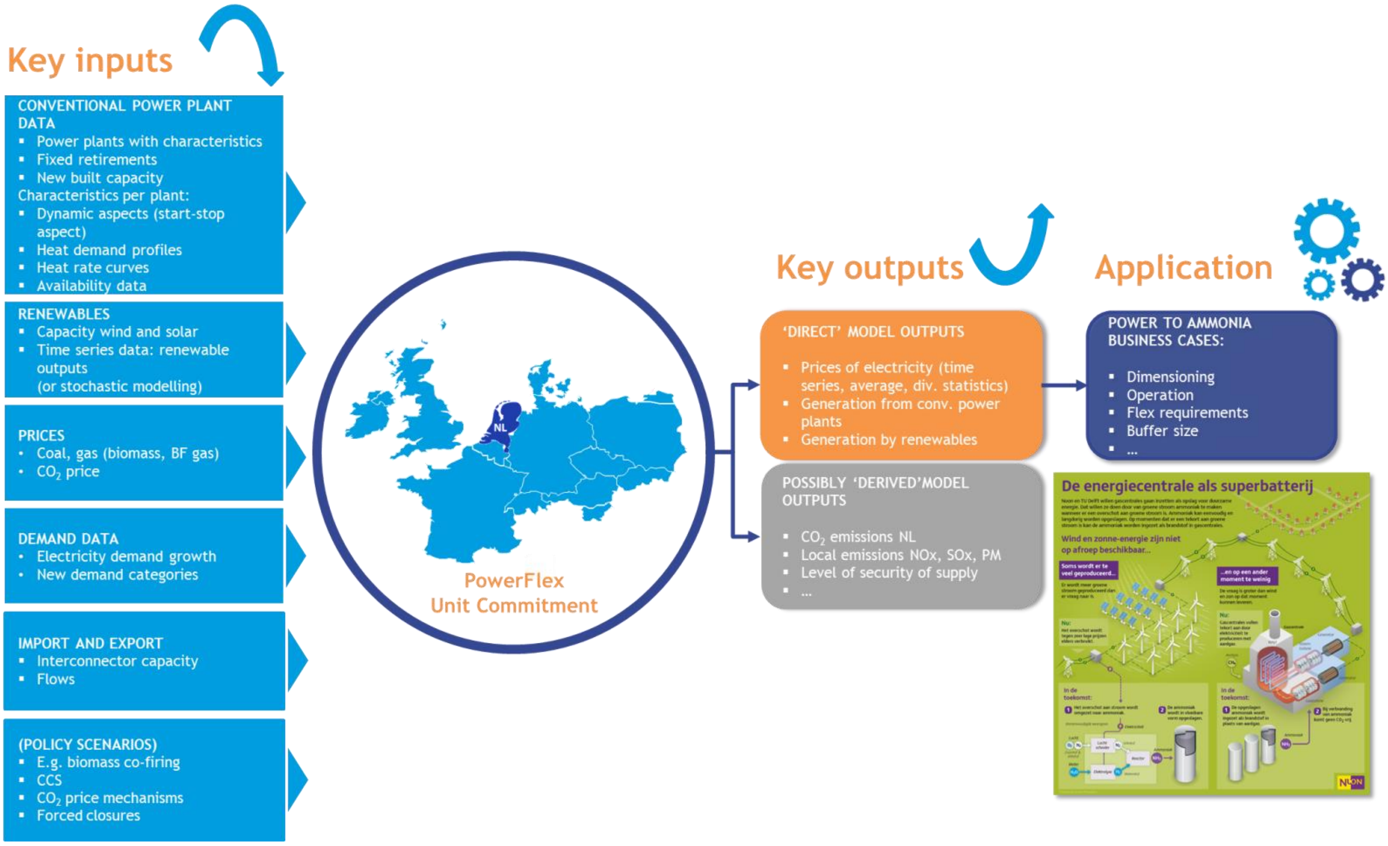
Then, the further we go in the future, there are some fundamental unknowns, the 'unknown unknowns': new demand categories of technologies, not yet existent that influence the power price; sudden events and catastrophes.

Working with scenarios aims to capture a number of these uncertainties. With a good scenario design, one is able to elucidate the key sensitivities in the business cases with a limited number of scenarios or years to simulate. With a smart scenario design, one is able to deal with the uncertainties without making the analysis itself overly complex.

3.3 The PowerFlex model

First of all, it is good to know what parameters are important for the power price simulation by describing what is needed to do a simulation with a fundamental market simulation model like PowerFlex. The key input data of impact to power price formation as calculated by the PowerFlex unit commitment and dynamic dispatch model is illustrated in Figure 2. Some more information on the model is in the Box 1. The model is further described in CE Delft (2016).

Figure 2 Inputs and outputs to the PowerFlex model



Box 1 PowerFlex - commitment model with dynamic dispatch

The PowerFlex unit commitment model is focussed on accurately simulating dispatch decisions of power generating assets on the individual unit level and from this obtain very realistic estimates of spot market bidding behaviour and thus spot market price formation. The PowerFlex model captures the full dynamics of the operation of the power generation sector and is rich in the sense that peculiar characteristics of the Dutch system are accurately represented. One unique characteristic is the Dutch market's large CHP fleet. The model includes dynamic economic dispatch, quadratic heat rate curves, must run, CHP, heat demand, minimum up/down times and start costs, and for balancing/short term dispatch: ramping capabilities. The model is mathematically unique in that it contains an advanced solver that is able to converge on price formation in relatively few computations steps saving several orders of magnitude computational time compared to models that rely on numerical solving of the full computing space. Due to this short computational time and the ability to model short term markets, the model aims to be one of the more advanced electricity market dispatch models.

3.4 Scenario design

A good approach is to start from one already established/developed scenario and take that as a baseline if we deem it sufficiently plausible. Then we decide what years to further detail the scenarios for, and then we focus on the parameters to vary and the way this is done, reflecting on the profound uncertainties that are highly relevant for the business cases we want to assess.

Baseline

One recent and well-established scenario for 2030 is the one published by ECN & PBL in the National Energy Outlook (NEO), 2015 version (ECN; PBL; CBS; RVO.nl, 2015). The NEO contains two pathways to 2030:

- *Fixed policy (F)*: this pathway incorporates the currently (as of 2015) 'fixed' policies (baseline).
- *Fixed and intended policy (F&I)*: this pathway incorporates the same policies as the other one, but now also the 'intended' policies on a national and EU level. This pathway achieves a higher share of decarbonisation in 2030.

We will use the NEO F&I as the most likely baseline trajectory for the scenarios to simulate, the other one being overly conservative. This baseline scenario will then yield the primary data for the time horizon under study - 2020, 2023 and 2030 - such as demand projections, installed capacities of wind, solar, etc.

Time horizon

The scenarios should capture a for Power to Ammonia relevant time span. For the P2A project three years were selected (2020, 2023, 2030) according to the envisioned phase of deployment of different Power to Ammonia technology options and value cases[1].

Level of renewable energy supply

This is a key aspect of Power to Ammonia applications. The NEO expects a development of installed capacities for wind and solar in the Netherlands, going from 7 GW wind and 6 GW solar PV in 2020 to 11 GW wind and 17 GW solar PV in 2030.

For the year 2030, we will compute an additional scenario with a more progressive vision on the renewable energy supply capacities, with a larger share of, primarily, offshore wind generation. Whilst the NEO F&I sees continued growth of solar PV between 2023 and 2030, a very modest growth of onshore wind, offshore wind is actually declining from 2023 due some oldest wind parks being at end of life. Therefore, we decided to simulate an additional **2030 'high-RES' scenario** with more progressive renewable energy supply capacities: 20 GW wind offshore, 8 GW wind onshore, 20 GW solar PV. For Germany, we use the prognosis from (Netzentwicklungsplan, 2016) for all years.

Coal, gas and CO_2 prices

Supposedly, for business cases where an electric ammonia production plant cycles on a daily basis (as driven by power prices), the price volatility on a daily/weekly basis is the main value driver. As electricity prices in peak and off peak are typically set by gas- and coal-fired facilities respectively, the diurnal electricity price cycle is heavily driven by the underlying fuel and emission costs. Hence, the spread between coal- and gas prices, price of CO_2 emission allowances and the installed capacities coal/gas are important

---

[1] The Goeree-Overflackee case plans to be operational around 2020 and the Eemshaven/Delfzijl case envisions to be operational around 2025/2030.

drivers for the diurnal cycle. In addition, the level of RES supply is an important daily and weekly volatility driver, since RES supply can show high volatility in these timeframes.
As these prices are a very direct impact factor for the power prices in most if not all of the hours of the year, we will include two alternative sets of coal, gas and CO_2 prices in the scenarios: high and low prices.

Coal and gas prices from the ECN NEO are substantially higher than current projections by specialised pricing data providers such as IHS, ICIS/Platts, and others. Therefore it is relevant to investigate the impact of coal and gas prices.

A note on consistency between fuel and CO_2 prices is useful for clarification. Over a longer timeframe (equilibrium), low prices for coal and gas could be viewed to be consistent with an ambitious and world-wide effective climate policy, as a result of limited demand for fossil energy sources (see e.g. (PBL and CPB, 2015)). On the other hand, high prices could be viewed to be consistent with a not so effective climate policy and hence arguably lower CO_2 prices. We will not use this aspect in the scenario design, we will use a combination of high CO_2 prices with high fuel prices, to show the maximum sensitivities for these prices.

Also a note on ammonia prices is relevant. Ammonia prices depend largely on gas and more limitedly on coal prices. In the business cases it is essential that ammonia prices are used that are consistent with the coal, gas and CO_2 prices used for the power market simulations.

Flexibility provision

The PowerFlex model is able to simulate demand side flexibility in a number of ways (e.g. power to heat boilers for heat coupled power plants).
It would be interesting to have a look at what would happen in the 'cheap hours', i.e. the 100-1,000 hours where a number of technologies compete with electric ammonia synthesis. However, it was chosen not to simulate this type of competing demand response, in order to show the 'raw effects' the scenarios have on the volatility of the power market.
The 'flexibility' in the simulation model is therefore largely on the supply side: thermal power plants of varying flexibility capabilities. An additional source of flexibility is German pumped hydro storage. This is modelled for its current capacity and known capacity expansion plans.

RES curtailment

RES curtailment is also a flexibility source, but in the model setup it is not incorporated. If RES infeed in the scenarios is too high for the model's solver to match (i.e. demand cannot be increased anymore), it will show as a price that drops below zero. Depending on the amount of oversupply, the model will show *highly negative* prices. These highly negative price excursions result from a modelling artefact and do not represent realistic pricing behaviour, so in post-processing these negative prices were put at zero.

3.5 Scenario details

Simulations were executed for three future years, with for the year 2030 two variants (NER and high-RES). Furthermore, all scenario-years were simulated under two sets of fuel/carbon price paths. Demand was taken from the NER for the Netherlands and from (Netzentwicklungsplan, 2016) for Germany.

Details on capacities used are in Table 1, on the low fuel and CO_2 prices in Table 2 and higher prices in Table 3.

Table 1 **Capacities in the simulated scenarios**

			2020	2023	2030-NER	2030-high-RES	2020	2023	2030
			The Netherlands				Germany		
RES cap	Wind on land	GW	5.1	6.1	6.7	8.0	51.3	58.8	76.3
	Wind off-shore	GW	2.3	4.5	4.3	12.0	6.3	8.8	14.5
	Solar PV	GW	5.9	9.4	17.3	20.0	47.2	51.8	57.4
Conventional generation	Nuclear	GW	0.5	0.5	-		8.1	0.0	0.0
	Lignite	GW	-	-	-		16.7	15.8	10.3
	Coal	GW	3.4	3.4	3.4		24.9	23.5	16.4
	Gas	GW	18.5	18.5	18.5		31.2	35.0	39.7
	Oil		-	-	-		2.0	1.9	0.8
	Biomass	GW	0.0	0.1	0.1		6.9	6.9	6.9
	Blast furnace gas	GW	0.6	0.6	0.6		1.9	1.9	1.1
	Waste	GW	0.6	0.6	0.5		1.8	1.8	1.8
	Total conventional	GW	24.0	24.0	23.5		93.6	86.8	77.2
Flex	Pumped storage	GW	-	-	-		6.7	8.9	12.8
	Batteries	GW	-	-	-				
	Power to heat	GW	-	-	-				

For all scenario-years we have plant capacity and technical capabilities from our proprietary data set. This includes the expected plant closures and new built capacity. In addition, we have modelled premature closure of the two coal fired power plants from the 1990's: Hemweg unit 8 in Amsterdam as well as Amercentrale unit 9 in Geertruidenberg. We modelled this capacity to be offline in all scenario-years (so also 2020). With regards to new investments, we have modelled only new capacity going online as a replacement for units that are closed, but not more than that. The model doesn't automatically add capacity if prices from the simulation would be too high (though this could be done manually).

Table 2 **Lower prices scenarios (€$_{2015}$)**

			2020	2023	2030
Fuel and carbon prices	Coal price	€/ton ARA	44.9	55.0	55.1
	Gas price	€/MWh HHV	13.4	20.2	20.8
	CO_2 price	€/ton	11.1	13.1	20.1

In the 'lower prices' scenario, the source of coal and gas prices is an established commercial provider of forecast data for these commodities, estimates dated March 2016, and for CO_2 the prices of the ECN NEO are used.

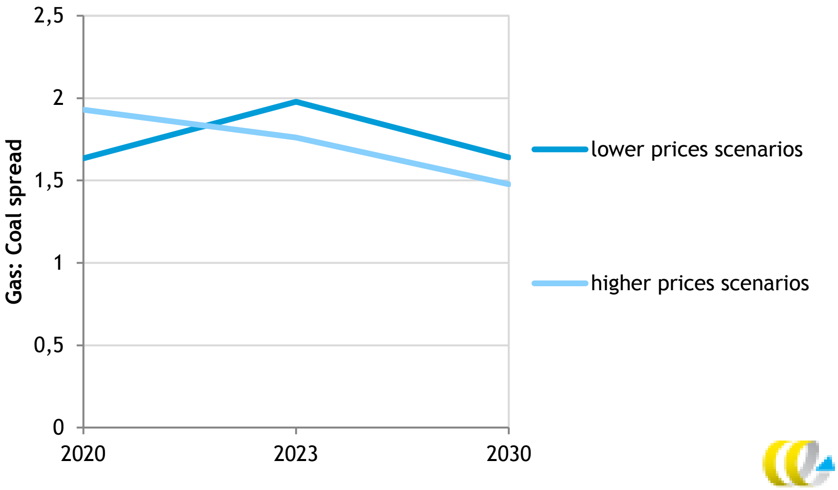
Table 3 **Higher prices scenarios (€$_{2015}$)**

			2020	2023	2030
Fuel and carbon prices	Coal price	€/ton ARA	81.5	83.5	88.5
	Gas price	€/MWh HHV	28.8	30.9	34.0
	CO_2 price	€/ton	19.1	25.6	40.6

In the ‘higher prices’ scenario, the prices for coal, gas are all from ECN NEO. For CO_2 prices we have used the WLO-scenario ‘High’ (published December, 2015) (PBL and CPB, 2015).

The following picture in Figure 3 shows the development of the Gas: Coal spread including the cost of CO_2 in the high and lower price scenarios.

Figure 3 **Gas: Coal spread**



Imports/exports

For import/export the model has two ways of running it: a single country version and a multi-country version.
In the first case the model works with scaled historic imports. This is useful to study effects in the Dutch system in the absence of what we would call ‘regime changes’. This would entail an assumption that e.g. RES infeed in the Netherlands would be much correlated with neighbouring countries, requiring balancing within the Netherlands, which is a simplification.
In the multi-country option the model also incorporates surrounding countries and this enables capturing relevant dynamics in these markets as well, for example the German nuclear phase-out. During the workshop session we had discussions on Belgian developments, but there is no clarity on closure dates, so it was decided not to model this market.
For the model results presented in this report, the multi-country version was used, in which the Dutch and the German market were modelled.

3.6 Results

The modelling results in time series of hourly electricity prices and the precise dispatch of the different generating units, large sets of data. This section details the price scenarios, depicted in a number of figures.

3.6.1 Statistics - boxplots, frequency distribution

Looking at Figure 4, we can observe that prices are expected to increase modestly from 2020 to 2030 scenario years. This is arguably driven by rising fuel and CO_2 prices. The 2030 high-RES scenario is the exception; in this scenario the majority of prices tend to be lower but there are also some higher prices or price extremes.
Furthermore, the boxes become wider over time, indicating that volatility in prices is increasing (50% of the simulated prices fall in the box). This is also seen in the widening whiskers, especially in the high-RES scenario.

Observing the frequency distribution plots of Figure 5, we note that the histograms get wider with more VRES and through time – also clearly indicating that volatility tend to increases, the ‘bell shape’ widens (flattens).
The 2030 high-RES scenario stands out with lower prices and much stronger price extremes.
In the histograms a spike in the 0-10 €/MWh category is visible. This spike is an artefact of post-processing, where al negative values have been set to zero (see Section 3.4 for more on this).

Figure 4 Boxplots of simulation results: median, first and third quartiles and extreme values

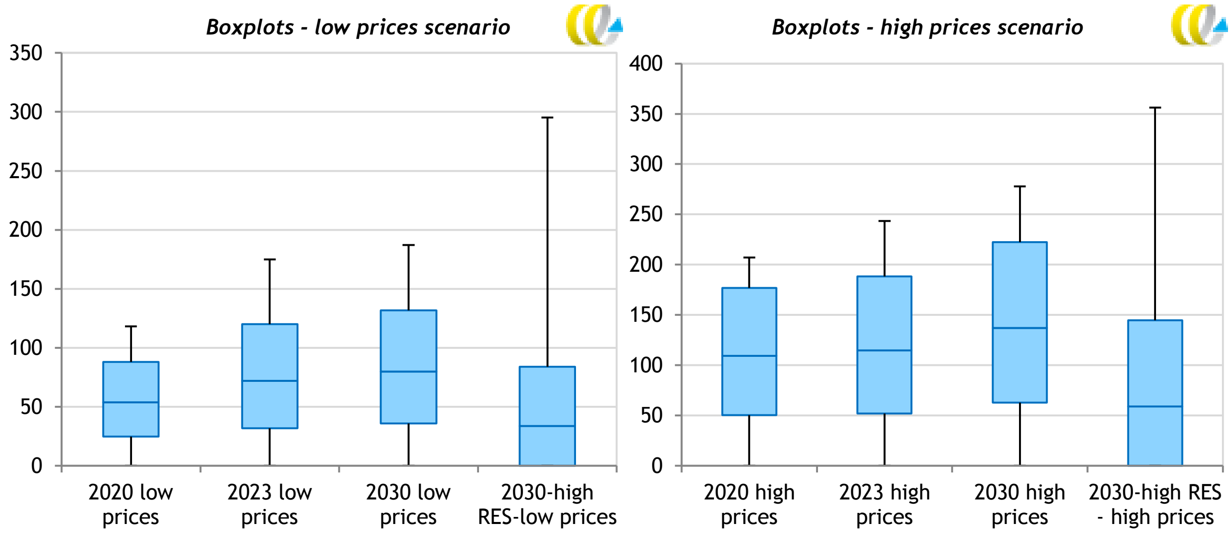
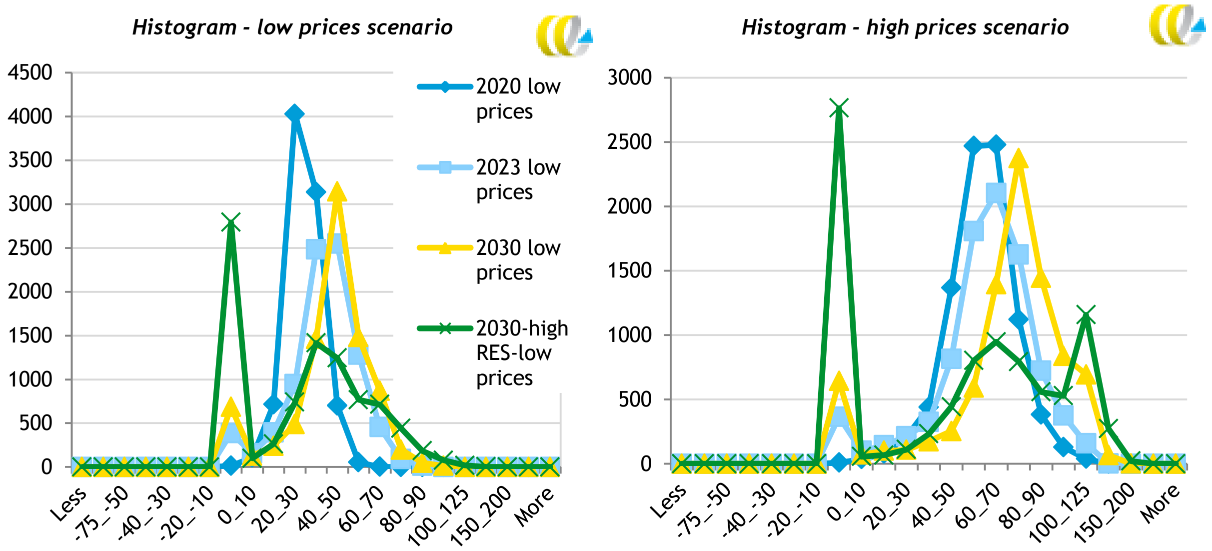


Figure 5 Frequency distribution of simulation results - counts of hourly values



3.6.2 Statistics - average prices

Figure 6 shows the year-average price of electricity, where only the 10, 20, 30, 40 or 50% cheapest hours of the year have been included in the average. Two things stand out. First of all, especially the 10-20% cheapest hours (900-1,800 hours of the year) show a declining trend over time. We expect that progression in renewables infeed is the primary reason for this.

The second thing that stands out is that the ‘high-RES’ scenario (28 GW wind and 20 GW solar) is really low during even 50% of the hours of the year – this reflects that in this scenario, the demand is way too little to accommodate excesses of RES.

Figure 6 Average price during the X% cheapest hours of the year

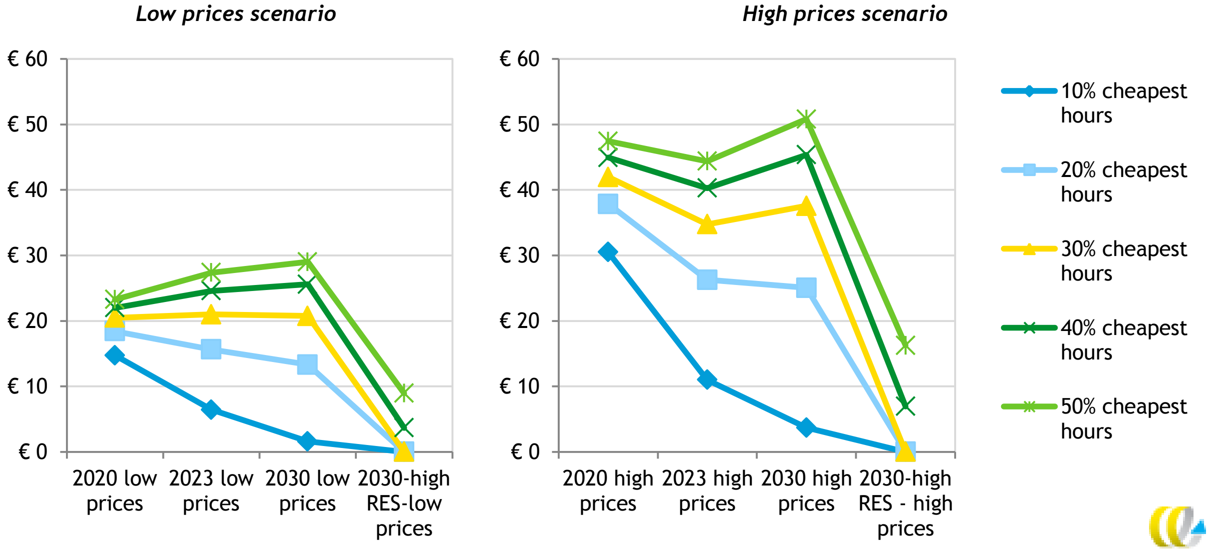
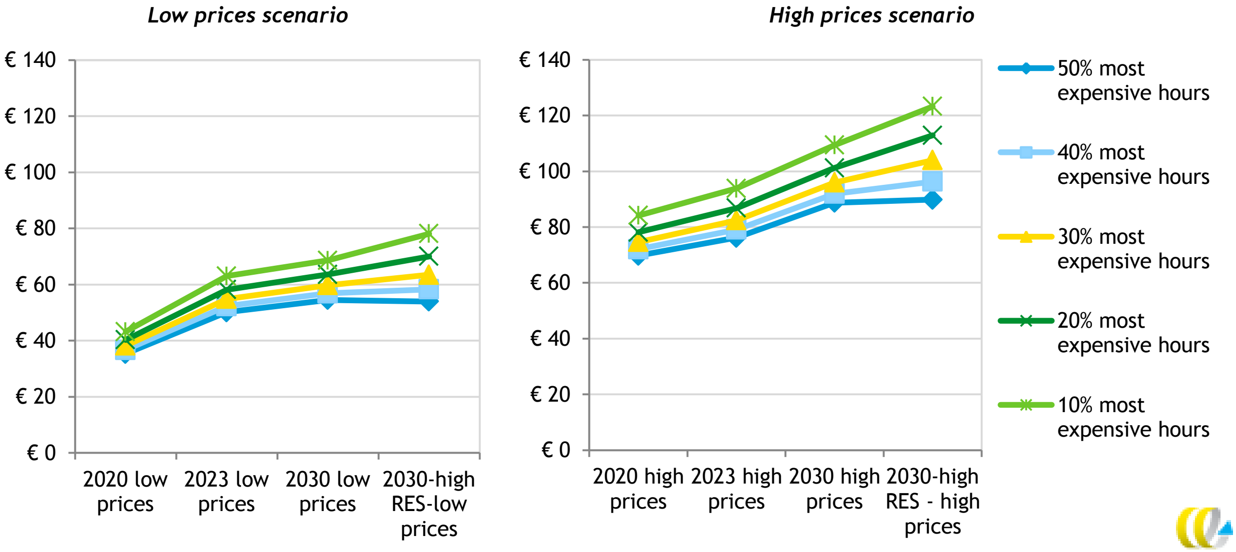


Figure 7 is similar to Figure 6, but instead of low prices, this figure reflects the most expensive hours of the year. In this figure, we see all lines rising as time progresses, so the prices rise, essentially driven by scenario fuel and CO_2 prices.

One thing is interesting to note, and that is that the prices in the 2030 'high-RES' scenario are higher than the prices in the 2030 regular scenario. This cannot be due to fuel or CO_2 prices, which are unchanged compared to the regular 2030 scenario. Therefore, we conclude that this is purely driven by *flexibility constraints* of the generating park, requiring the use of more expensive generating units. This leads to more price volatility. An insight such as this can only be generated from market simulation with a market model that captures flexibility constraints of thermal units.

Figure 7 **Average price during the X% most expensive hours of the year**



Some more statistics for the simulation results are included in Table 4.

Table 4 **Simulation results for the scenarios**

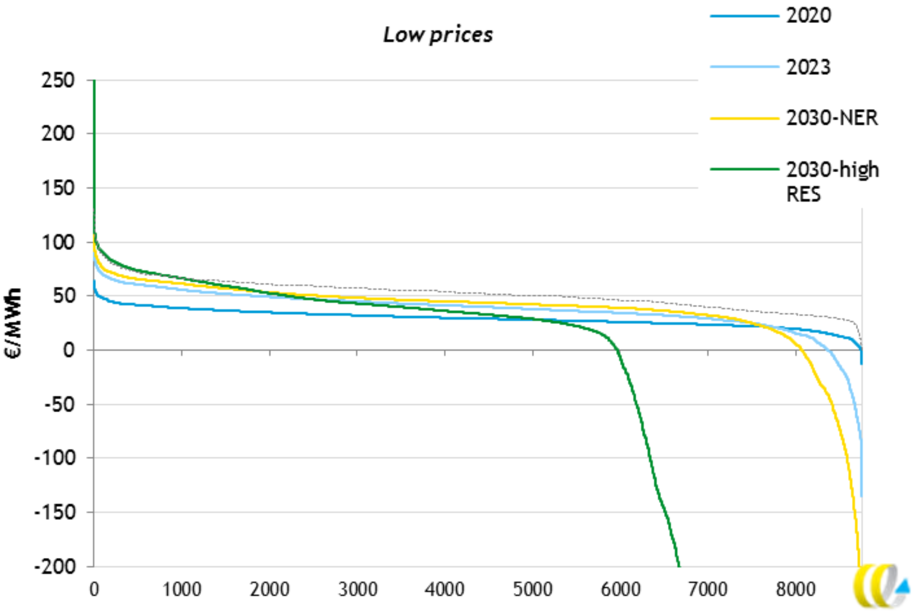
		Low prices scenario				High prices scenario			
		2020 low prices	2023 low prices	2030 low prices	2030 high RES-low prices	2020 high prices	2023 high prices	2030 high prices	2030 high RES - high prices
Avg. price	€/MWh	29.3	38.8	41.8	31.4	58.6	60.3	69.8	53.0
Std. dev	€/MWh	7.9	15.3	17.9	26.7	14.8	22.1	27.8	43.2
Maximum	€/MWh	64.3	103.0	107.4	261.7	123.1	150.4	167.4	396.3
Q1	€/MWh	24.6	31.8	35.8	0.0	50.2	52.0	62.9	0.0
Median	€/MWh	29.1	40.0	44.0	33.6	59.1	62.7	74.3	58.8
Q3	€/MWh	34.2	48.2	52.1	50.3	67.7	73.7	85.4	86.0
Minimum	€/MWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N° of hours with price below	<0	0	0	0	0	0	0	0	0
	<1	18	402	696	2,799	9	374	649	2,768
	<5	57	465	747	2,834	20	415	680	2,787
	<10	124	546	814	2,891	45	467	715	2,819
	<20	840	941	1,055	3,155	124	611	816	2,887
N° of hours with price of at least	>0	8,746	8,372	8,074	5,968	8,751	8,394	8,117	5,997
	>50	57	1,841	2,609	2,206	6,619	6,795	7,407	5,086
	>60	3	558	1,128	1,439	4,151	4,989	6,815	4,284
	>70	0	103	259	724	1,672	2,886	5,420	3,336
	>80	0	14	62	284	551	1,260	3,045	2,543
	>100	0	1	1	22	39	162	764	1,455
	>120	0	0	0	4	1	10	120	437

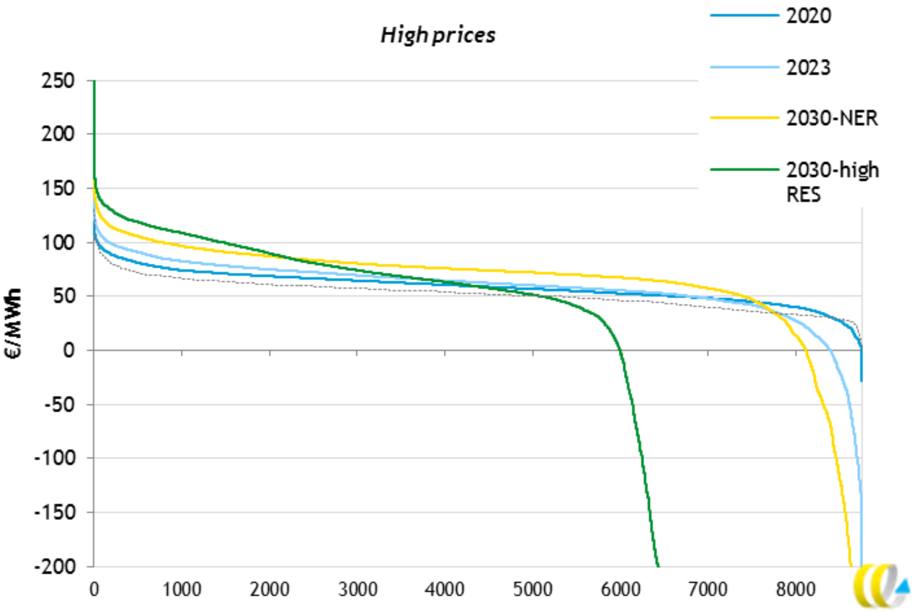
3.6.3 Price duration curves

Price duration curves show the prices of the year sorted by price from high to low. This allows for comparison of the extremes can be compared efficiently. For reference, the 2013 Dutch day ahead market results (APX DAM) are included as well.

Warning: The graphs show raw simulation results without the post-processing of the negative hours (where the model cannot solve due to RES-oversupply). In the most extreme scenarios (especially 2030 high-RES) this leads to exceedingly large negative prices. These negative values should in no case be used for quantifying a business case; RES curtailment would be a flexibility option that would take place there.

Figure 8 Price duration curves for low and high prices





4 Conclusion

For Power to Ammonia value cases, future electricity prices and its dynamics on different timescales are important ingredients.

Simulations of the power market were conducted and have resulted in a set of time series of simulated power prices for the day ahead spot market.
The time series show that:

- The average (baseload) electricity price level depends strongly on prices for coal, gas and CO_2.
- Increases in renewable electricity depresses prices, but this effect is most pronounced during the 900-1,800 hours that the price is already relatively low (the tail of the price duration curve).
- Over time, the volatility of the electricity price is expected to increase significantly. This is most extreme in the high-RES scenario for 2030.

The high-RES scenario for 2030 shows that in this scenario, with 28 GW wind and 20 GW solar PV, there is a clear need for demand response that can absorb oversupply of wind and solar. We also see that the high share of renewable infeed makes balancing the system more expensive during the hours with lower RES infeed, leading to higher prices. This will ask for flexible power production, preferably from renewable or CO_2 neutral fuels, to accommodate the times without much wind and solar.

References

CE Delft en KYOS Energy Consulting, 2016. *Het PowerFlex model*. [Online] Available at: www.ce.nl/publicatie/het_powerflex-model/1881

ECN; PBL; CBS; RVO.nl, 2015. *Nationale Energieverkenning 2015*, Petten: Energieonderzoek Centrum Nederland (ECN).

Netzentwicklungsplan, 2016. *Szenariorahmen für die Netzentwicklungsläne Strom 2030*. [Online] Available at: www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/160108_nep_szenariorahmen_2030.pdf

PBL en CPB, 2015. *Nederland in 2030 en 2050: twee referentiescenario's - Toekomstverkenning Welvaart en Leefomgeving (WLO)*, Den Haag: PBL.