PROFITABILITY AND DISPATCH OF MPP3 POWER PLANT WITH ALTERNATIVE FUELS

A report for Uniper Benelux

October 2019

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EXECUTIVE SUMMARY

On behalf of Uniper Benelux, Frontier Economics has analysed the economic viability of different fuel switch options of the MPP3 power plant from 2030 onwards. In a short study conducted in September 2019, we concluded that converting MPP3 into a biomass power plant was not a profitable investment. The September calculations are based on the market framework of Frontier's 2018 analysis undertaken on behalf of the Ministry of Economic Affairs and Climate Policy.[1] This new study represents an update to our study published in September 2019. The update consists of:

- an update of the market framework to reflect recent commodity price changes, recent information on power plant and transmission capacities in the Netherlands and neighbouring countries as well as recently introduced policy measures like the German coal phase-out and the Klimaatakkoord;
- an update of the analysis of the commercial viability of converting MPP3 into a biomass plant in 2030; and
- the analysis of the commercial viability of converting MPP3 into a combined biomass and hydrogen plant in 2030.

Also based on this updated market framework, we conclude that the conversion of MPP3 into a biomass power plant is not a profitable investment. Similarly, converting MPP3 into a combined biomass and hydrogen plant in 2030 does not yield sufficient returns to make this a profitable investment. The main results of the calculations can be summarised as follows:

Financial indicators

	Biomass	Biomass-Hydrogen
NPV (2030)	-200 mn. EUR	-246 mn. EUR

Electricity generation

	Biomass	Biomass-Hydrogen
2035	0.18 TWh	0.41 TWh
2040	0.43 TWh	1.50 TWh
2045	2.39 TWh	2.35 TWh
2050	2.60 TWh	3.23 TWh

Operating hours

	Biomass	Biomass-Hydrogen
2035	189 h	326 h
2040	454 h	1,184 h
2045	2,571 h	1,976 h
2050	3,016 h	2,768 h

Note: Throughout the report all monetary figures are expressed in real terms for 2017.

[1] Frontier Economics (2018): "Research on the effects of the minimum CO_2 price".

1 BACKGROUND AND AIM OF THIS STUDY

Background of this study

The Netherlands have committed itself to reaching the ambitious climate goals and to implement the agreements made at the 2015 climate conference in Paris. Within this framework, the Dutch Climate Agreement represents an irreversible step towards achieving a low carbon energy system in 2050.

The coalition agreement of the Rutte III government[2] sets out a medium-term emission target for 2030 and includes additional policy measures for this transformation. In this context, the Dutch parliament has passed a bill that prohibits the use of coal for power generation from 2030 onwards. This would also affect Uniper's MPP3 power plant. The bill does not foresee any general compensation to owners of the plants. The Minister argues that these plants have plenty of alternative fuel sources to which they can convert. Although this may be possible from a technical perspective, such a conversion to alternative fuels requires additional investments in the respective power stations and the economic viability as well as the commercial viability of using alternative fuels (with different variable costs and conversion efficiencies) must be assessed. The bill is currently being discussed in the Senate.

Aim of this study

In context of the discussed coal prohibition in the Netherlands, Uniper Benelux has asked Frontier Economics to conduct a study analysing the future dispatch, revenues and costs of using alternative fuels in the MPP3 power plant.

In a first study published in September 2019[3], we have analysed the profitability and dispatch of MPP3 based on the market simulations from our 2018 analysis on behalf of the Ministry of Economic Affairs and Climate Policy.[4] We concluded in that study that converting MPP3 into a biomass power plant in 2030 is not a profitable investment.

The aim of this new study is to update the market simulations underlying the evaluation of the power plant conversion. The update reflects the recent commodity price changes, recent information on generation and transmission capacity and new policy targets and measures. This allows to assess the commercial viability of converting MPP3 to alternative fuels based on the latest expectations of future market conditions. In addition to this, we widen the scope of the analysis in this study, not only reassessing the conversion of MPP3 into a biomass plant, but also analysing the option to convert MPP3 into a combined biomass and hydrogen plant. As the bill prohibits the use of coal for electricity generation from 2030 onwards, we analyse the effects of the different conversion options in 2030 and its commercial and dispatch effects in the years thereafter.

2 2017–2021 Coalition Agreement, VVD, CDA, D66, CU: "Confidence in the Future"

3 Frontier Economics (2019): "Profitability and dispatch of MPP3 power plant in case of biomass conversion"

4 Frontier Economics (2018): "Research on the effects of the minimum CO_2 price".

Structure of this report

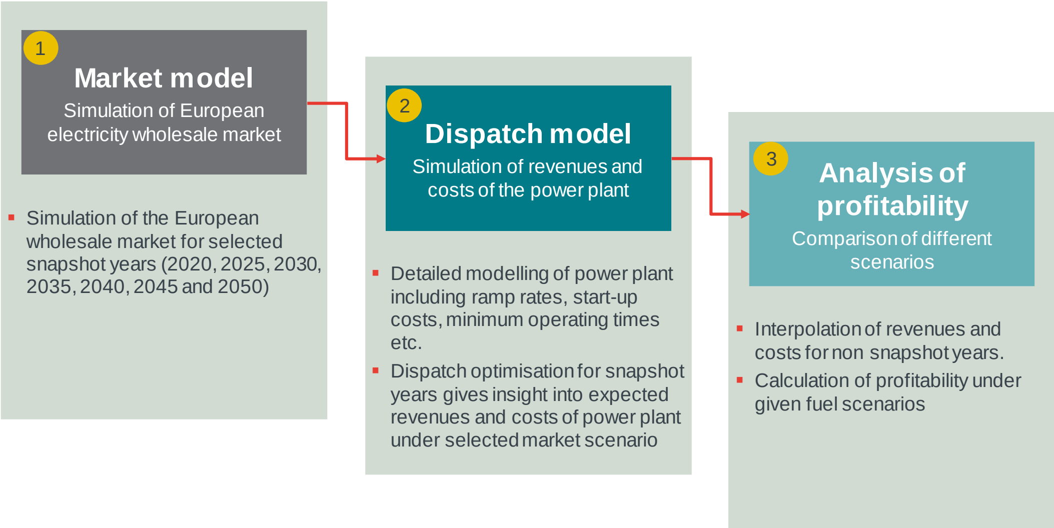
This report is structured as follows:

- in section 2, we briefly describe the approach used for the analysis;
- in section 3, we summarise the results from the updated market simulation;
- in section 4, we assess the commercial viability of converting MPP3 into a biomass plant in 2030; and
- in section 5, we analyse the commercial viability of converting MPP3 into a combined hydrogen and biomass plant.

2 APPROACH USED FOR EVALUATION

We use a three-step approach to analyse the alternative fuel options of MPP3 in 2030. The three steps consist of market modelling, dispatch modelling and profitability analysis. The approach is illustrated in Figure 1. We explain each step in more detail below.

Figure 1 Three step approach of the analysis



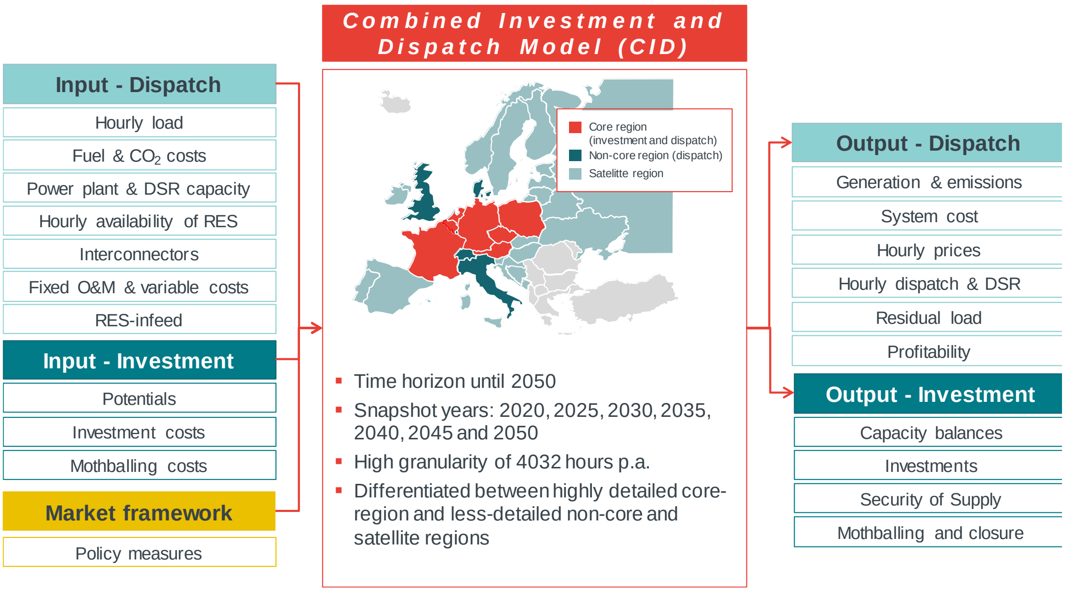
Source: Frontier Economics

2.1 Market model

As first step, we project future electricity wholesale prices for The Netherlands. We use our European power market simulation model, which we also applied in previous studies undertaken on behalf of the Ministry of Economic Affairs and Climate Policy (2015, 2016, 2018) and Energie-Nederland (2018). The market model is an integrated investment and dispatch model for the European power sector (Figure 2). In the model, the hourly dispatch of the power plants as well as the development of installed power plant capacity is optimised based on representative hours of the year and selected snapshot years (investments, divestments, mothballing and reactivation). Output of the model are for example wholesale electricity prices for The Netherlands and other European countries, the dispatch, investments, divestments and mothballing of power plants and cross-border electricity flows between countries.[5]

[5] See annex A.1 for a detailed description of the market model.

Figure 2 Frontier power market model



Source: Frontier Economics

The market model for this new study reflects the most recent energy policies in The Netherlands as well as in the other European countries covered. It incorporates most recent expectations regarding the development of central assumptions, such as future power demand, commodity prices and the EU ETS price for carbon emissions. The model focusses on Central-Western Europe as a core-region, including The Netherlands and all its neighbouring countries. These countries are modelled in high granularity, i.e. on per plant / unit basis. Other countries are included as non-core regions or satellite regions and are modelled with less granularity. This differentiated approach allows for a very detailed (unit based) representation of the power plant portfolio in the core-region.

Compared to last year's study on behalf of the Ministry of Economic Affairs and Climate Policy (2018) and our initial assessment of converting MPP3 into a biomass power plant[6], we updated the market model to reflect the latest market conditions and most recent policy changes. We describe these changes in more detail in section 3.1.

2.2 Dispatch model

In the second stage of the analysis, we model the power plant in more detail. This allows us to reflect the technical characteristics of MPP3 with alternative fuel options more accurately than through the market model.[7] We simulate the future dispatch of the MPP3 plant, based on a detailed mathematical model of the power plant and projected electricity prices for each snapshot year obtained in step one. The model maximises profits subject to the technical and marginal costs characteristics of the plant. We then estimate the revenues and costs which are associated with the operation of the power plant with biomass and biomass /

[6] See Frontier Economics (2019)

[7] For computational reasons, the market model requires the use of a simplified representation of the power plants.

hydrogen. Table 1 summarises the technical characteristics considered in the optimisation. We elaborate on these characteristics in more detail in sections 4 and 5.

Table 1 Summary of key parameters used to model MPP3 with different fuel options

	Biomass option	Biomass and Hydrogen option	unit
Net generation capacity	952	1259	MW
Efficiency at maximum capacity*	44% - 45%	52%	%
Fix operating & maintenance cost	37.5	45.75	mn. EUR (2017)
Cost of conversion	200	292	mn. EUR (2017)
Availability	84%	84%	%
Year of decommissioning**	2056	2056	Year

Source: Frontier Economics based on data provided by Uniper Benelux

*Note: Additional plant parameters used include, min. generation capacity, ramp rate, efficiency at min. load, operational restrictions such as min. operating times and min. down times, energy required for starts, wear and tear costs of starts and other variable costs associated with the use of ammonia and limestone. *Note that efficiency rate is rounded for confidentiality. **Year of decommissioning based on 40-year lifetime. No residual value or decommissioning costs considered.*

2.3 Analysis of profitability

The profitability of the investment options is assessed based on the net present value (NPV) of the revenues and fuel and fixed costs of the plant between 2030 and 2056, the end of the technical lifetime of MPP3. The NPV is calculated by discounting the revenues and fuel and fixed costs, including capital expenditures, of the power plant to the year 2030. The discount rate applied is 5.2% (real).[8] The investment required for the conversion of the power plant is profitable if the NPV is positive.

We model the years 2030, 2035, 2040, 2045 and 2050 as representative snapshot years. For the years which are not modelled as snapshot years, we derive the annual dispatch and financial parameters through linear interpolation between the snapshot years. As 2050 is the last modelled year, we derive annual figures for the profitability post 2050 and until 2056 by continuing the trend between 2045 and 2050 until 2056. However, as it is unclear how margins and operating hours will change, we refrain to estimate dispatch figures for the time after 2050.

[8] The cost of capital is expressed as a vanilla WACC and has been derived by ignoring the effects of the tax shield on the 4.8% post-tax WACC used by ECN (2017) in the calculation of base tariffs for the 2017 SDE+ scheme for “Bestaande capaciteit voor meestook” and “Bestaande capaciteit voor bijstook”.

3 RESULTS OF MARKET SIMULATION

Since our studies for the Ministry of Economic Affairs and Climate Policy (2018) market conditions and the framework of the electricity market have changed – both in The Netherlands as well as in other European countries. In this study, we update the assumptions on the market framework to derive wholesale prices reflecting the latest market conditions and expectations.

3.1 Relevant market scenario

We updated the market model's underlying assumptions especially regarding the following topics:

- **Klimaatakkoord** – The Klimaatakkoord as presented to the Parliament in June 2019 stipulates measures to achieve the climate goals in all parts of the Dutch economy. Overall, national greenhouse gas emissions should until 2030 be reduced by 49% compared to 1990 levels. The measures related to the power market include a prohibition of coal-firing from 2030 onwards. Further, the Klimaatakkoord aims at decarbonising other sectors of the economy through electrification and the use of hydrogen in industrial processes. This will most likely lead to an increase in domestic power demand, such as in PBL's analysis of the Klimaatakkoord. We assume that domestic electricity consumption will increase from ca. 115 TWh today to more than 125 TWh in 2030.

- **German coal phase-out** – The German government announced it would follow recommendations of the "Commission on Growth, Structural Change and Employment" ("Coal Commission") published in February 2019 to decommission all coal and lignite power plant capacities in Germany by the end of 2038.[9] In this report, we assume that coal-firing power plant capacity in Germany decreases according to the timeline proposed by the Coal Commission. This means that the German coal and lignite capacities fall from ca. 37 GW in 2020 to ca. 17 GW in 2030 and to 0 GW by the end of 2038.

  Change in fuel and CO_2 prices – The fuel and CO_2 prices we assume in this study reflect current future prices as well as latest long-term forecasts from the World Energy Outlook 2018 (New Policies Scenario)[10] and the EU Reference Scenario 2050[11]. Until 2050 the prices increase steadily to ca. 32 EUR/MWh_{th} for gas and to ca. 11 EUR/MWh_{th} for coal. The CO_2 price increases to 36 EUR/tCO_2 by 2040 and to 80 EUR/tCO_2 by 2050. Furthermore, we take the minimum CO_2 price into account as discussed by Dutch Parliament.[12] The future development of CO_2 prices is associated with a high degree of uncertainty. As sensitivity, we analyse a second price path, based on the alternative CO_2 prices used in the Klimaatakkoord by PBL (2019). This price path is significantly higher than current future ETS prices and the IEA's long-

9 BMWi (2019): Kommission „Wachstum, Strukturwandel und Beschäftigung“, Abschlussbericht.

10 IEA (2019): World Energy Outlook 2018.

11 European Commission (2016): EU Reference Scenario 2016.

12 Tweede Kamer der Staten-Generaal (2019)

term projection of CO_2-prices[13]. The price for biomass remains constant (in real terms) at ca. 33 EUR/MWh_{th}.[14]

Detailed information about the assumptions used in this study is provided in Annex A.

3.2 Results of the market simulation

In this section, we summarise the main results of the electricity market simulation, which reflects a prohibition of coal-firing in power stations in The Netherlands by 2030. In the following, we focus on the development of the wholesale power prices, which serve as an input to the more detailed analyses of the MPP3 power plant and for the decision to convert the power plant to be fuelled by one of the alternative fuels.

Additional results of the power market simulations, such as the development of generation capacities and electricity exports, can be found in Annex A.3.

Increasing electricity prices until 2040

In our simulation, wholesale electricity prices increase considerably compared to today's levels (Figure 3). While, according to the model results, the electricity wholesale price in 2020 is around 50 EUR/MWh[15] in 2020, it increases to 66 EUR/MWh by 2040. This change in electricity prices is driven by several factors, such as:

- a decline in conventional power generation capacities in The Netherlands. This decline in capacity is largely caused by the prohibition of coal for electricity generation by 2030;
- closure of the only nuclear power plant in The Netherlands, Borssele, by 2034;
- similar transitions from conventional and nuclear generation capacities to renewable generation capacities outside of The Netherlands (e.g. in Germany, Belgium and France); and
- an increase in natural gas, coal and CO_2 prices in line with the current market expectations.

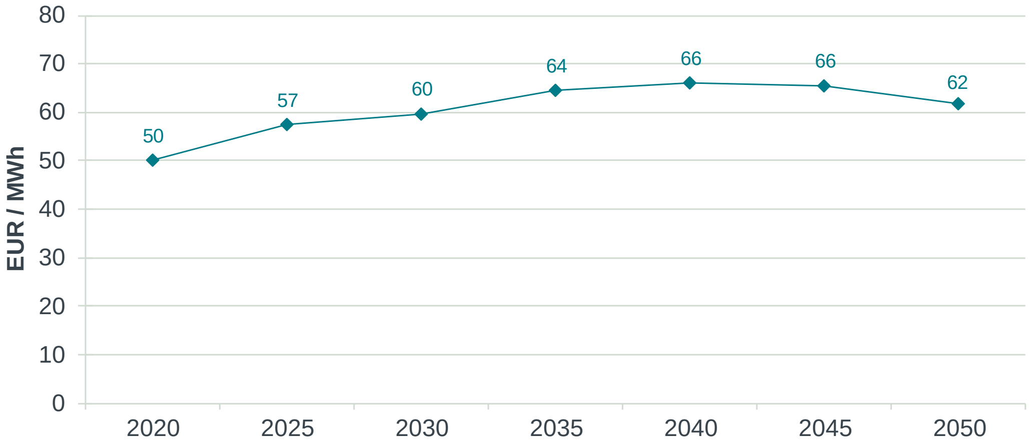
In 2050, the simulated wholesale electricity price in The Netherlands decreases slightly (in real terms). At that time, the European energy system is characterized by high penetration of renewable power generation capacities with low marginal costs of power production and higher interconnection capacities between the countries.

[13] Details on the results of the CO_2 price sensitivity are included in Annex C

[14] This is equal to 188 USD(2019) / t. The price does not include costs for transport and handling and reflects the average monthly future prices from August 2019 to July 2022 as published by EEX on the 22 August 2019: https://www.eex.com/en/market-data/energiewende-products/wood-pellets-futures.

[15] All electricity prices expressed in real terms (base year 2017).

Figure 3 Power price development in The Netherlands



Source: Frontier Economics

Note: The base price is shown. Prices are expressed in real terms (base year 2017).

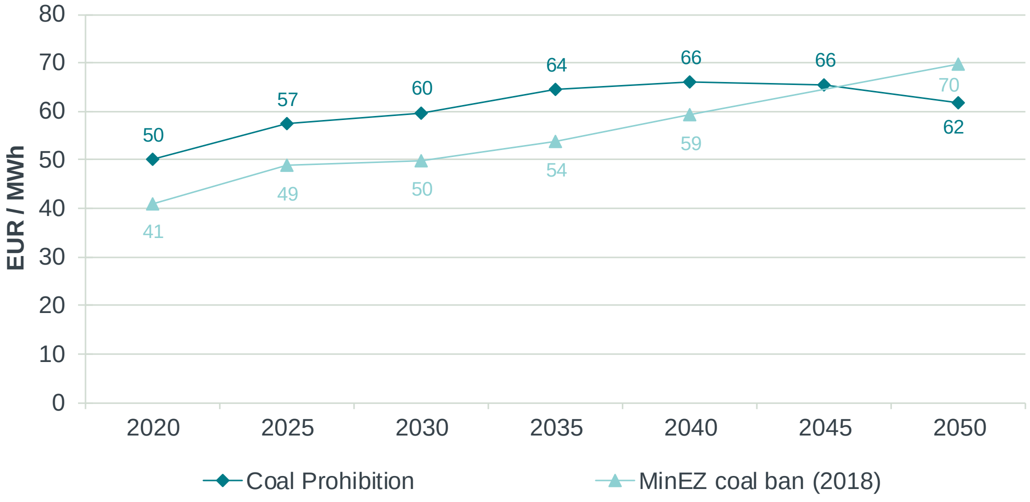
Higher electricity price level compared to study for Ministry of Economic Affairs and Climate Policy (2018)

A comparison with the “coal ban” scenario from the study for the Ministry of Economic Affairs and Climate Policy (2018) shows that the updated market simulation yields consistently higher power prices until 2040 (Figure 4).[16] While the change in the near future is driven by an increase in commodity prices, the price increase in the medium to long-term future is largely driven by changes in the energy policies in Central Western Europe, most notably the coal phase-out in Germany. These changes in energy policies lead to a substantial reduction in the region’s conventional power plant generation capacities, causing higher power prices compared to our previous study from 2018 for the Ministry.

In the long-run, the power prices of the updated market simulation develop to a similar range as in the study from 2018. In 2050, the updated power price is slightly below the forecast from 2018. This difference is caused by new fuel price forecasts for natural gas in the very long-term. The new commodity price forecast from IEA (2019) expects prices to increase at a lower rate than in the previous study, resulting in overall lower fuel price levels in the long-run.

[16] The power prices from both studies are in line with the prices of the respective futures traded at the time of conducting the market simulations.

Figure 4 Power price development in The Netherlands: Comparison with results for study for Ministry of Economic Affairs and Climate Policy (2018)



Source: Frontier Economics

Note: The base price is shown. Prices expressed in real terms (base year 2017).

4 ECONOMIC VIABILITY OF CONVERTING MPP3 TO A BIOMASS POWER PLANT

As an alternative to coal, MPP3 could be fuelled by biomass from 2030 onwards. While Uniper plans the co-firing of biomass in MPP3 within the SDE+ regime until 2028, using only biomass as fuel from 2030 onwards would require additional investments into the power plant. In the following paragraphs, we describe the modelling of MPP3 as a 100% biomass plant and summarise the results of the analysis.

4.1 Modelling of the MPP3 biomass plant

The key assumptions for modelling MPP3 as a biomass plant were provided by Uniper Benelux and are shown in Table 1. It is worth noting that biomass has a lower heating value than coal. Hence, converting MPP3 into a 100% biomass plant will result in a reduced net generation capacity of 952 MW (instead of 1070 MW) and a slightly reduced efficiency rate because of decreased capacity (44%-45% instead of 45%-46%). Furthermore, additional maintenance work is required as a result of burning biomass instead of coal, leading to higher fixed operating and maintenance costs and reduced availability of the plant. For this analysis, we assume that the plant is not in operation in the year of conversion (2030).

In addition to the power plant parameters stated in Table 1, the dispatch optimisation is based on the hourly wholesale electricity prices which were derived from the updated market simulation, assuming the prohibition of coal from 2030 onwards. In line with the update of commodity prices for the market simulation, we have updated the price of biomass (wood pellets) to reflect the latest future prices. The price for biomass used in this study is 32.6 EUR/MWh$_{th}$.[17] We assume this price to be constant for all modelled years which is a conservative assumption given that it is widely expected that the global demand for biomass will increase in future. To address the uncertainty of the biomass price, we have also analysed the profitability of the biomass plant based on a lower biomass price as a sensitivity. This biomass price sensitivity assumes the price for biomass to be 30.4 EUR/MWh$_{th}$, which is equal to the price used in the short study from September 2019.

4.2 Analysis of the MPP3 biomass plant

The annual time series of revenues and costs of MPP3 allow us to draw conclusions on the commercial viability of converting MPP3 into a biomass plant in 2030. The results from the dispatch modelling of MPP3 as a biomass power plant are summarised in Table 2. The key results are:

- Conversion of MPP3 in 2030 into a biomass plant will have a negative return on investment (NPV of -200 mn. EUR). From a commercial perspective, the

[17] This is equal to 188 USD(2019) / t. The price does not include costs for transport and handling and reflects the average monthly future prices from August 2019 to July 2022 as published by EEX on the 22 August 2019: https://www.eex.com/en/market-data/energiewende-products/wood-pellets-futures

power plant would rather be closed than converted into a biomass plant in 2030. Assuming a lower price for biomass (sensitivity) increases EBITDA of the plant. Nonetheless, the NPV remains negative and converting the plant to 100% biomass does not represent a viable option, even under these more favourable conditions.

- The operational gross margins following the investment indicate that following the conversion, the power plant will not generate a positive EBITDA during the first 11 years. In this scenario, the biomass plant is expected to generate sufficient revenues to generate a positive EBITDA from 2042 onwards.

Table 2 Key indicators of the investment required for the conversion to a 100% biomass plant (2030-2056)

Indicator	Value	
NPV (2030, 5.2%)	-200	mn. EUR (real 2017)
NPV Sensitivity (“low biomass price”) (2030, 5.2%)	-98	mn. EUR (real 2017)
Average el. generation (2031-2050)	1.16	TWh per year
Average operating hours (2031-2050)	1,274	hours per year

Source: Frontier Economics

Note: Sensitivity was calculated using the lower biomass price from our previous study in September 2019.

Overall, since both NPV’s are significantly negative, we conclude that converting MPP3 into a biomass plant in 2030 is not a viable investment case. In addition, the investment is associated with additional risks, which are caused by:

- the volatile biomass price, which would need to be secured over 20+ years at additional costs that are currently not considered in the analysis; and
- the negative EBITDA in the first 11 years after the conversion which requires extremely favourable market conditions in the long run to yield a positive return on the investment.

The results from the dispatch modelling of MPP3 as a biomass power plant are illustrated in Figure 5 and Figure 6 below. In the following, we discuss the background and implications of the results in more detail.

Conversion of MPP3 into a biomass plant expected to have a negative return on investment in the scenario analysed

Figure 5 illustrates Capex and EBITDA associated with converting MPP3 into a biomass plant. We assume the plant to be unavailable in 2030 for the conversion. The development of the EBITDA after the coal prohibition can be described as follows:

- **2030-2039:** In the years following the coal prohibition, revenues and operating margins are low, resulting in a negative EBITDA. The development between 2030 and 2039 can be explained by:

- the relatively high fuel costs of biomass in comparison to natural gas, of about 34.7 EUR/MWh$_{th}$ (delivered at plant and including cost of handling); and
- the moderate average electricity wholesale prices of 60 EUR/MWh in 2030 to 66 EUR/MWh in 2040.

The combination of both factors results in a limited number of operating hours, i.e. a very low utilisation and therefore low operating margins[18]. At the same time, the power plant still incurs (fixed) costs for staff and maintenance.

- **2040-2050:** From 2040 onwards, utilisation and revenues continue to increase. The average wholesale electricity prices remain at 66 EUR/MWh in model years 2040 and 2045. At the same time, the wholesale electricity prices become more volatile. This allows the power plant to capture prices above its marginal costs more frequently. Based on this, we expect the EBITDA to turn positive in 2042.
- **Post 2050:** For the time after 2050, we assume that the operating EBITDA will gradually increase in line with the trend between 2045 and 2050.

The analysis reveals that converting MPP3 into a biomass plant will have a negative return on investment in the scenario analysed. The NPV (2030, 5.2%) indicates a **negative return of -200 mn. EUR.** The calculation of the NPV is based on a Weighted Average Cost of Capital (WACC)[19] of 5.2%.

In a **sensitivity** scenario, we have analysed the profitability of the biomass plant using the lower biomass price from our study in September 2019 of 30.2 EUR/MWh$_{th}$.[20] This sensitivity shows a **negative return of -98 mn. EUR** and thereby confirms our finding that such an investment is not viable.

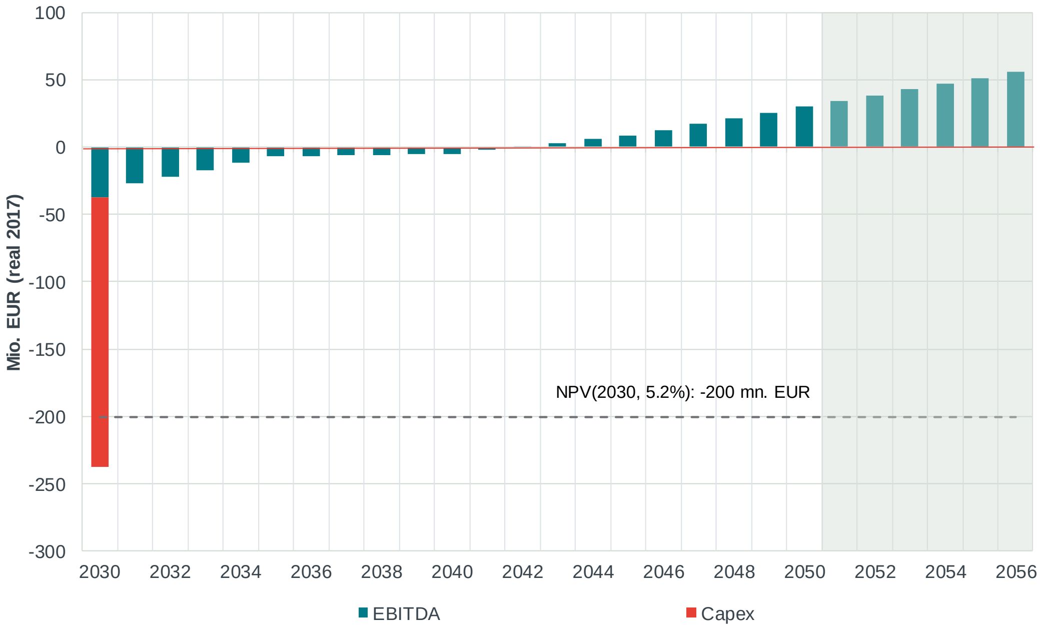
[18] Average marginal costs of electricity generation amount to c. 80 EUR/MWh$_{el}$ between 2030 and 2040.

[19] The Weighted Cost of Capital (WACC), here called vanilla WACC, is the weighted average of cost of debt and the cost of equity. A vanilla WACC is the weighted average of the pre-tax cost of debt and the post-tax cost of equity.

The WACC is derived on the basis of a typical WACC for biomass cofiring under the SDE+ scheme which is due to the subsidies less risky than the investment in the fuel conversion of a power plant which is not subject to subsidies. As the figure used by ECN is a post-tax WACC, but our analysis is calculating pre-tax margins, the WACC needs to be adjusted to a pre-tax or vanilla WACC.

[20] Excl. transportation and handling cost of ca. 2.1 €/MWh$_{th}$

Figure 5 EBITDA and Capex of the 100% biomass plant



Source: Frontier Economics

Converted power plant will not exceed 2,000 operating hours

Figure 6 shows the annual electricity generation and the operating hours of the converted power plant after 2030. The annual development of the electricity generation and the operating hours are in line with the development of the EBITDA described earlier and is described as follows:

- **2030-2039:** After the coal prohibition, electricity generation and operating hours of the plant are low until 2040. After conversion in 2030, until 2039 the average electricity generation is expected to be 0.23 TWh per year. The electricity generation of the converted power plant corresponds with operating hours between ca. 183 hours in 2031 and ca. 454 hours in 2040.
- **2040-2050:** Between 2040 and 2050, we expect average electricity prices to remain constant or decline slightly while price volatility increases. Therefore, electricity generation and utilisation of MPP3 increase over time. In 2050, we expect the power plant to generate about 2.60 TWh of electricity and have around 3,016 operating hours per year.

Overall, converting the power plant to biomass in 2030 will result in low electricity generation volumes and operating hours between 2030 and 2050. In total, we expect the plant to generate about 23 TWh over the 20 years after the coal prohibition becomes effective.

Figure 6 Electricity generation and operating hours of the 100% biomass plant

Source: Frontier Economics

5 ECONOMIC VIABILITY OF CONVERTING MPP3 TO A COMBINED BIOMASS AND HYDROGEN POWER PLANT

In the following paragraph, we assess the conversion of MPP3 into a combined biomass and hydrogen power plant as another conversion option. In this configuration, the plant still uses biomass as primary fuel source and hydrogen as a secondary fuel.

First, we describe the modelling of MPP3 as a combined biomass and hydrogen plant in more detail. Thereafter, we summarise the results of the analysis for this conversion option.

5.1 Modelling of the MPP3 combined biomass and hydrogen plant

The key assumptions of modelling MPP3 as a combined hydrogen and biomass plant were provided by Uniper Benelux and are based on the scenario “reference scope” of the recent Rotterdam H-Vision feasibility study.[21]

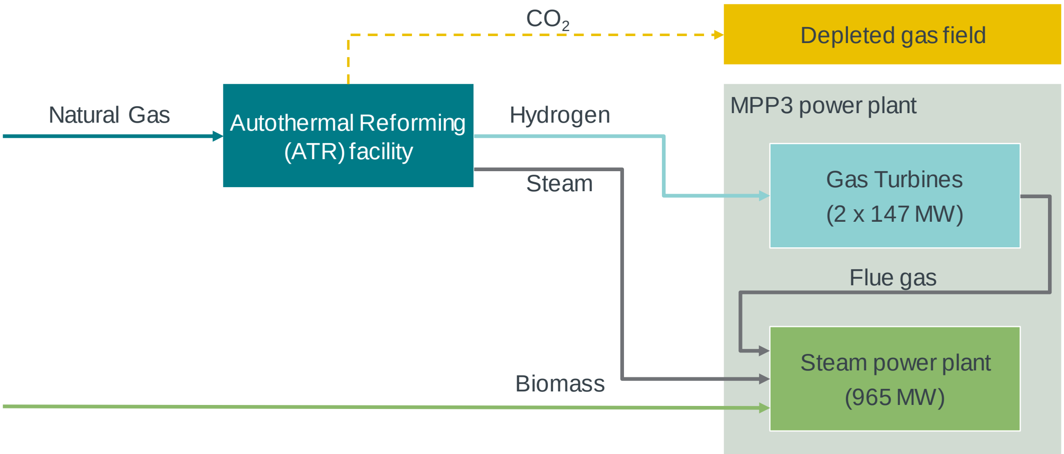
Conversion of MPP3 into a combined biomass and hydrogen plant

For this case, we assume that the MPP3 power plant will be converted into a biomass plant and that hydrogen will be used as an additional fuel source (Figure 7). To compensate for the lower heating value and heat input from biomass, two 147 MW gas turbines are added and integrated into the existing plant. The gas turbines are fired with hydrogen provided by a local (blue) hydrogen production facility[22]. The hot flue gases of the gas turbines are integrated in the steam cycle of the power plant allowing the MPP3 plant to work in a more efficient state than with biomass alone. In addition to the two gas turbines, excess steam from the nearby hydrogen production facility is also integrated in the steam cycle of MPP3. Overall, this results in an increase of MPP3’s net generation capacity to 1259 MW (instead of 1070 MW today or 952 MW for the biomass option) and an overall efficiency of 52% (instead of 45%-46% today or 44%-45% for the biomass option).

[21] H-Vision (2019)

[22] Blue hydrogen is produced in an autothermal reforming facility (ATR) from natural gas; CO_2 from the steam reforming process is captured and stored in a depleted gas field.

Figure 7 Illustration of different fuel sources of MPP3 as combined biomass and hydrogen plant



Source: Frontier Economics

As burning of biomass instead of coal requires additional maintenance work, fixed operating and maintenance costs of the plant are higher while availability is lower. Compared to the 100% biomass plant, operating and maintenance costs in this option increase because of the increased size and complexity of the power plant. Additional operating and maintenance costs from the two gas turbines and their connections into the wider MPP3 power plant are expected to amount to 8.25 mn. EUR.[23]

The total investment cost required to convert MPP3 into a combined biomass and hydrogen power plant are estimated to be 291.5 mn. EUR and include:

- 165 mn. EUR for the two gas turbines and their integration into the existing power plant; and
- 126.5 mn. EUR for the conversion of the power plant into a biomass plant.[24]

Refurbishing the power plant will take place in 2030 and causes MPP3MPP3 to be unavailable in that year.

The price of biomass and hydrogen

Further assumptions required for the dispatch optimisation of the power plant include the prices for biomass, hydrogen and steam:

- The price for biomass is equal to the price used in the analysis of the biomass only power plant (32.6 EUR/MWh) and is assumed to be constant over time.
- The price of hydrogen is derived from the economics of the Autothermal Reforming ("ATR") facility described by the scenario "reference scope" in the H-Vision feasibility study and illustrated in the figure below. To derive the price of hydrogen from the H-Vision study, we have made the following assumptions:

23 8.25 mn. EUR are equivalent to 5% of the investment costs of 165 mn. EUR required for the two gas turbines and the cost of integrating them into the MPP3 steam power plant

24 In this scenario less biomass will be used as fuel in the plant. The investment cost required to convert the power plant into a biomass plant are therefore proportionally lower than in the scenario in which biomass is the sole fuel source.

  - Cost of capital: The ATR facility has a 20 year lifetime, cost of capital of 6% and around 7000 full load hours per year. Additional margin from the sale of steam have been taken into account.
  - Operating and maintenance cost of the ATR facility are assumed to be 2.5% of the investment costs.
  - Costs for carbon capture, transport and storage are assumed to be equal to the lower bound tariff described in the H-Vision study.
  - Commodity prices: Gas, CO_2 and power prices are taken from the same assumptions as applied in the power market modelling.

  Overall, the assumptions are at the very low end of potential hydrogen production cost with steam reforming and carbon capture and storage. As a result, the costs for hydrogen applied in this analysis are well below (around 30% on average) other forecasts such as IEA (2019).

- The local ATR facility produces excess steam, which it can sell to nearby customers. In this option, we assume that MPP3 will source steam from the ATR facility to produce electricity. The price of steam sourced from the local ATR facility is set to be determined by the price of CO_2 compensated natural gas.

Figure 8 Price of hydrogen derived from H-Vision feasibility study and hydrogen price based on IEA – Future of Hydrogen study

Source: Frontier Economics

5.2 Analysis of the MPP3 biomass-hydrogen plant

The annual time series of revenues and costs of MPP3 allow us to draw conclusions on the commercial viability of converting MPP3 into a combined biomass-hydrogen plant in 2030. The results from the dispatch modelling are summarised in Table 3. The key results are:

- Conversion of MPP3 in 2030 into a combined biomass and hydrogen plant will have a negative return on investment (NPV of -246 mn. EUR). From a commercial perspective, the power plant would rather be closed than converted into a biomass plant in 2030.

- The gross margins following the investment indicate that following the conversion, the power plant will not generate positive EBITDA for the first 10 years. In this scenario, the combined biomass and hydrogen plant is expected to generate sufficient revenues to generate positive EBITDA from 2041 onwards, however at a low level.

Table 3 Key indicators of the investment for conversion into a biomass-hydrogen plant (2030-2056)

Indicator	Value	
NPV (2030, 5.2%)	-246	mn. EUR (real 2017)
Average el. generation (2031-2050)	1.56	TWh per year
Average operating hours (2031-2050)	1,307	hours per year

Source: Frontier Economics

Overall, we conclude that converting MPP3 into a combined biomass and hydrogen plant in 2030 is not a viable investment. In addition, the investment is associated with additional risks, which are caused by a volatile biomass price and the negative EBITDA in the first years after the conversion.

The results from the dispatch modelling of MPP3 as a combined biomass and hydrogen power plant are illustrated in Figure 9 and Figure 10 below. In the following, we discuss the background and implications of the results in more detail.

Conversion of MPP3 into a combined biomass and hydrogen plant expected to have a negative return on investment in the scenario analysed

Figure 9 illustrates Capex and EBITDA associated with converting MPP3 into a combined biomass and hydrogen plant. We assume that the investment will take place in year 2030 and requires the plant to be unavailable for one year. The development of the EBITDA over time can be described as follows:

- **2030-2039:** In the years following the coal prohibition, revenues are low, resulting in a negative EBITDA. The development between 2030 and 2039 can be explained by:
  - the relatively high fuel costs of both biomass and hydrogen of about 32.6 EUR/MWh_{th} for biomass and 44.5 EUR/MWh_{th} to 48.4 EUR/MWh_{th} for hydrogen; and
  - the moderate average electricity wholesale prices of 60 EUR/MWh in 2030 to 66 EUR/MWh in 2040.

  The combination of both factors results in a limited number of running hours, i.e. a low utilisation and low operating gross margins, while at the same time the power plant still incurs (fixed) costs for staff and maintenance work[25].
- **2040-2050:** After 2040, utilisation and revenues continue to increase as power prices become more volatile. This allows the plant to capture power prices above the marginal fuel costs more frequently. The increase in revenues is

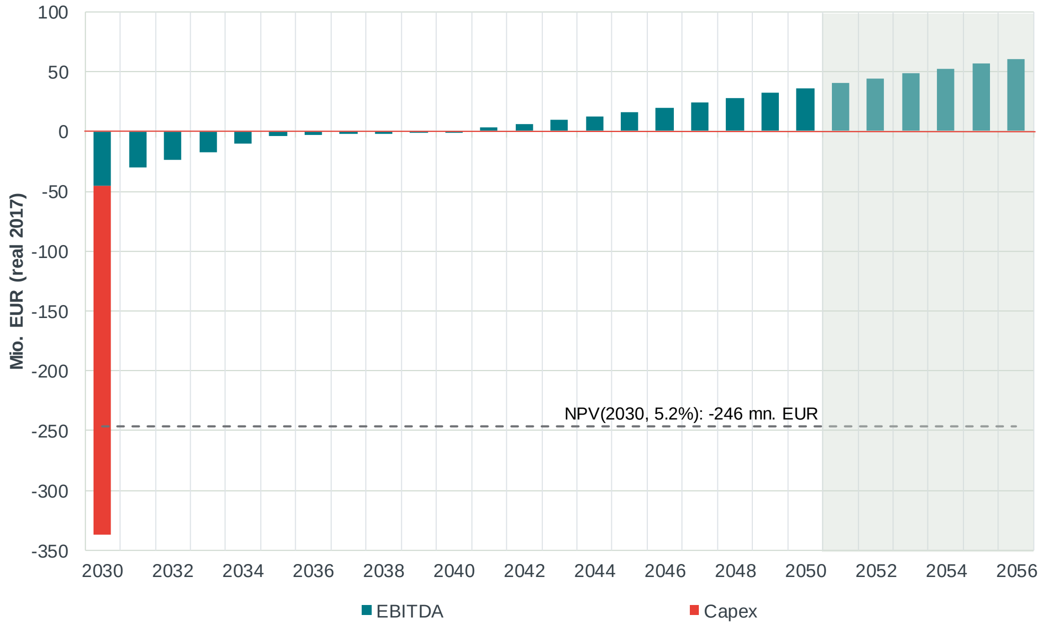
[25] Short-run marginal costs of the combined biomass hydrogen depend on the split of biomass / hydrogen. In this configuration ca. 1/3 of the required steam is produced from hydrogen, 2/3 from biomass. Average marginal costs between 2030 and 2040 amount to ca. 77 EUR/MWh_{el}.

however dampened as prices for hydrogen also increase from 48.4 EUR/MWh$_{th}$ to 52.3 EUR/MWh$_{th}$ in this time period.

- **Post 2050:** For the time after 2050, we assume that the operating EBITDA will gradually increase in line with the trend between 2045 and 2050.

The analysis reveals that converting MPP3 into a combined biomass and hydrogen plant will have a negative return on investment in the scenario analysed. The NPV (2030, 5.2%) indicates a **negative return of -246 mn. EUR**. The calculation of the NPV is based on a Weighted Average Cost of Capital (WACC)[26] of 5.2%.

Figure 9 EBITDA and Capex of the combined biomass and hydrogen plant



Source: Frontier Economics

Converted power plant will not exceed ca. 2,800 operating hours per year

Figure 10 shows the annual electricity generation and the operating hours of the converted biomass / hydrogen power plant after 2030. The annual development of the electricity generation and the operating hours are in line with the development of the EBITDA described earlier. The development of the electricity generation and the operating hours is described as follows:

- **2030-2039:** After the conversion, electricity generation and operating hours of the plant are low until 2040. Between 2031 and 2039 the average electricity generation is expected to be 0.61 TWh per year. The electricity generation of

[26] The Weighted Cost of Capital (WACC), here called vanilla WACC, is the weighted average of cost of debt and the cost of equity. A vanilla WACC is the weighted average of the pre-tax cost of debt and the post-tax cost of equity.

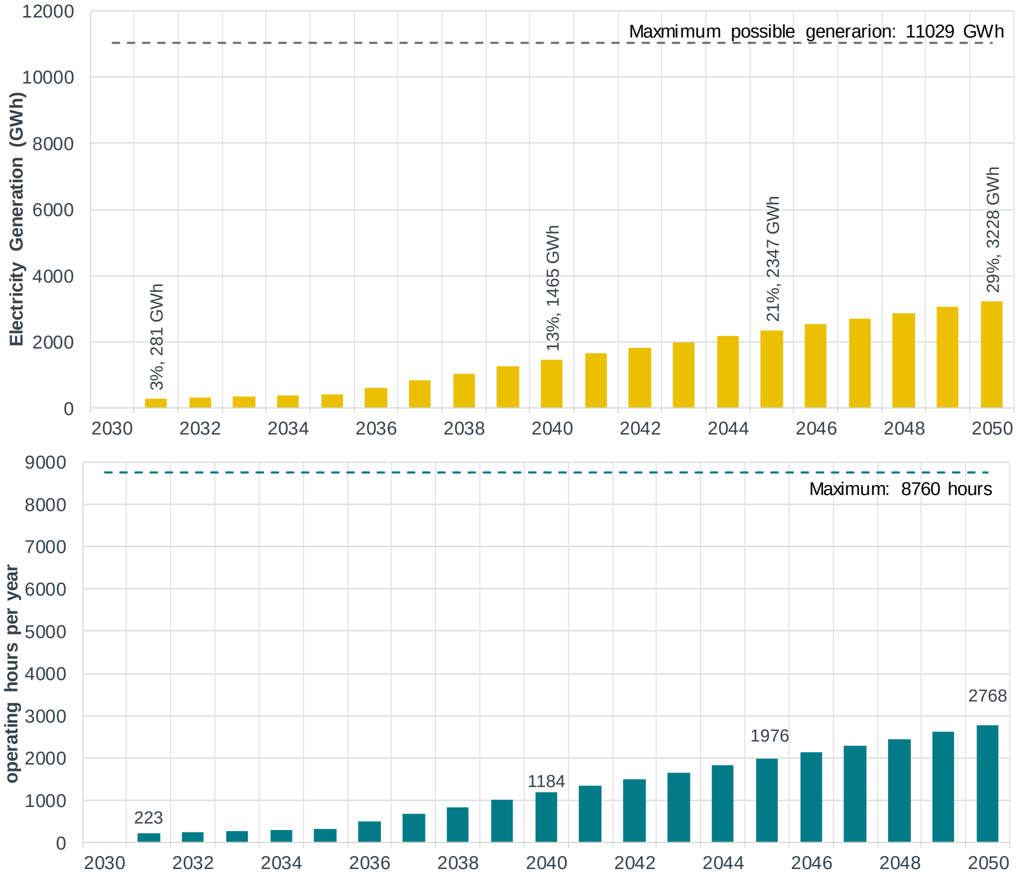
The WACC is derived on the basis of a typical WACC for biomass cofiring under the SDE+ scheme which is due to the subsidies less risky than the investment in the fuel conversion of a power plant which is not subject to subsidies. As the figure used by ECN is a post-tax WACC, but our analysis is calculating pre-tax margins, the WACC needs to be adjusted to a pre-tax or vanilla WACC.

the converted power plant corresponds with operating hours between ca. 223 hours in 2031 and ca. 1,184 hours in 2040.

- **2040-2050:** Between 2040 and 2050, we expect an increase in the electricity wholesale price relative to the price of biomass. Therefore, electricity generation and utilisation of MPP3 increases over time. In 2050, we expect the power plant to generate about 3.23 TWh of electricity and have around 2,768 operating hours per year.

Overall, converting the power plant to biomass and hydrogen in 2030 will result in a low electricity generation and operating hours between 2030 and 2050. In total, we expect the plant to generate about 31.30 TWh over the 20 years after the coal prohibition becomes effective.

Figure 10 Electricity generation and operating hours of the combined biomass and hydrogen plant



Source: Frontier Economics

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ANNEX A MARKET MODEL ASSUMPTIONS AND RESULTS

A.1 The market model

In this assignment, we employ our power market model already applied in the previous studies undertaken on behalf of the Ministry of Economic Affairs and Climate Policy and Energie-Nederland. The main characteristics of the model can be summarised as follows:

- **Cost optimisation model:** The model is an integrated investment and dispatch model for the European power sector. The model is set up as an optimisation problem, minimising the system costs for serving power demand across the modelled regions. The model optimises the hourly dispatch of the power plants as well as the development of installed capacity based on representative hours and selected snapshot-years (investments, divestments, mothballing and reactivation).
- **Geographical scope:** Our model focusses on Central-Western Europe as core-region, including the Netherlands. Other neighbouring countries are included as non-core regions or satellite regions. This differentiation allows for modelling of the power plant park in the core-region on a very detailed (unit-based) basis. Power exchange with regions modelled with lower granularity and level of detail are at the same time included:
  - **Core-regions:** The Netherlands, Belgium, Germany, Austria, France, Poland and Czech Republic. The power plant park is modelled on a very detailed (unit-based) level, the dispatch of power plants and demand-side response (DSR), as well as investment or divestment, are model outcomes.
  - **Other model regions:** Great Britain, Denmark, Switzerland and Italy. The power plant park is modelled as aggregated blocks. Capacity is set exogenously, i.e. investment and divestment decisions are not optimised.
  - **Satellite regions:** Other adjacent regions – for example South-Eastern Europe, the Nord Pool region and Spain – are modelled as satellite regions. Power can be traded with those regions based on typical prices representing the marginal costs of generation in those countries / regions.
- **Temporal resolution:** The timeframe for optimisation follows the technical lifetime of power plants. The time horizon for our analysis is from 2020 until 2050 with an hourly resolution of 4032 representative hours per snap-shot year, the model optimises until the time period 2059. We have modelled the representative snapshot years of 2020, 2025, 2030, 2035, 2040, 2045 and 2050.

A.2 Market model assumptions

In the following, we describe the key assumptions for the electricity market used in the market model.

Fuel and CO_2 prices

The **fuel price** projections are based on current future prices as well as projected price developments from the World Energy Outlook 2018 (New Policies scenario) (see Table 4).

- **Coal and gas**: The short-term price projection for coal and gas prices is derived from current forward prices (until 2022). The long-term trend (after 2025) is based on the price development of the World Energy Outlook 2018. Prices until 2050 are extrapolated based on 2040 prices using the average price growth rate between 2025 and 2040.
- **Biomass**: We assume that the price of biomass will remain constant in real terms at the level of today's forward prices (32.6 EUR/MWh). Transportation and handling costs of 2.12 EUR/MWh are added to the biomass price.
- To project **CO_2 prices,** we use current future prices for EU ETS certificates until 2025**.** Afterwards, we interpolate to the WEO's price projection in 2040 (35.83 EUR/tCO_2) and the EU Reference Scenario in 2050 (80 EUR/tCO_2). At any point in time, we use the minimum CO_2 price as discussed by the Dutch Parliament as a lower bound (see Table 4).[27]

Table 4 Fuel and CO_2 prices

		2020	2025	2030	2035	2040	2045	2050
Coal	EUR/MWhth	7.20	9.07	9.91	10.03	10.15	10.36	10.58
Gas	EUR/MWhth	18.67	23.18	26.19	27.45	28.71	30.20	31.77
Biomass	EUR/MWhth	34.72	34.72	34.72	34.72	34.72	34.72	34.72
Biomass (Sensitivity)	EUR/MWhth	32.3	32.3	32.3	32.3	32.3	32.3	32.3
CO2 price	EUR/tCO2	24.78	24.53	31.90	32.07	35.83	58.03	80.22

Source: Frontier Economics based on IEA (2018), PBL (2019b), EEX (2019) and European Commission (2016).

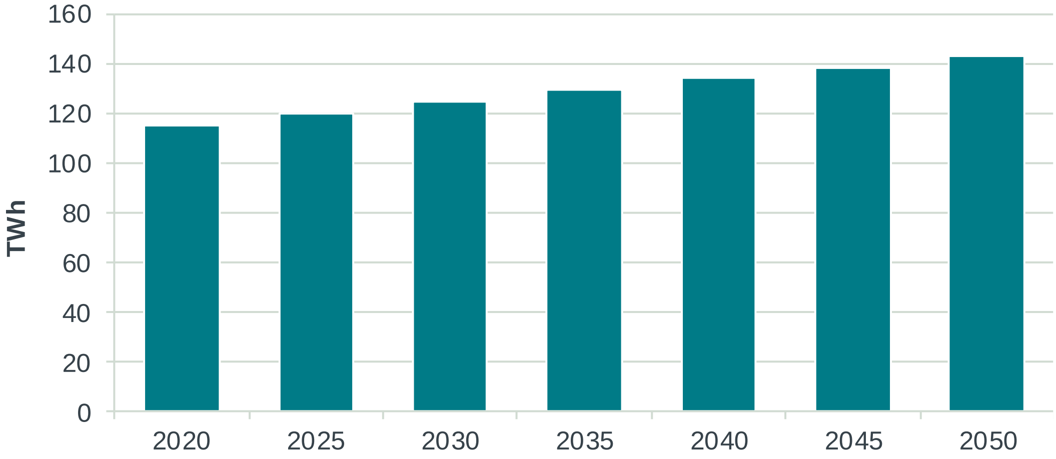
Note: Biomass price includes transport costs. All other fuel prices exclude transport costs. Prices expressed in real terms (base year 2017). Prices for futures were taken on 22/08/2019. The biomass price (sensitivity) is used as input into the dispatch optimisation of MPP3, not as input for the market model.

Power demand and renewable growth in the Netherlands

The **power demand** is in line with PBL's latest analysis of the Klimaatakkoord. The assumption for 2030 is based on the upper bound in PBL (2019b) to reflect the increasing amount of sector coupling. The power demand between 2020 and 2030 is based on a linear interpolation between 2020 and 2030; after 2030 linear growth until 2050 is assumed.

[27] Tweede Kamer der Staten-Generaal (2019).

Figure 11 Power demand in The Netherlands



Source: Frontier Economics based on PBL (2019a)
Note: The chart shows net power demand.

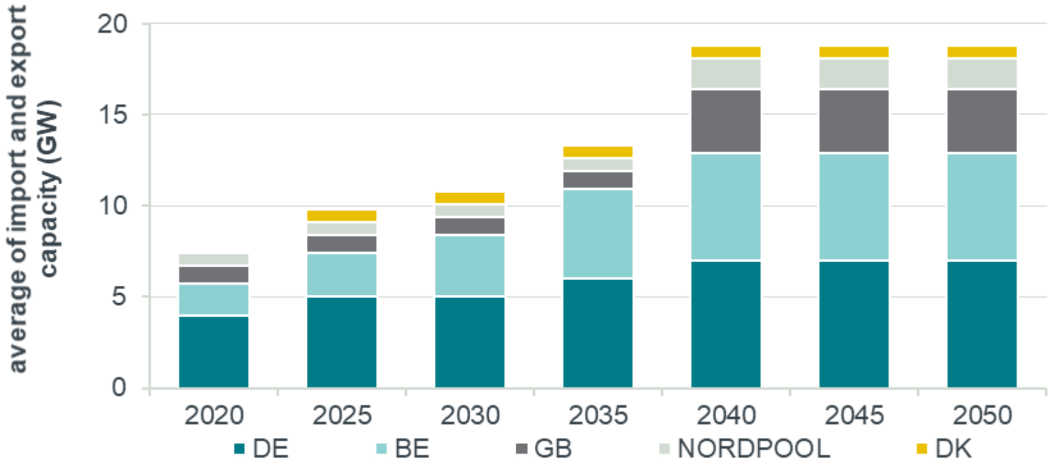
The development of renewable energy in electricity supply is in the short- and medium-run driven by renewable support policies, which is reflected as an exogenous path of renewable capacity development in the market model. The assumptions on renewable power generation in the Netherlands until 2035 are based on PBL (2019b). After 2035, we assume a continuation of exogenous renewable growth but with a lower growth rate. However, if economically viable, the model can endogenously invest in additional renewable energy sources in electricity supply. The electricity generation from wind and solar in The Netherlands is shown in Annex A.3 in Figure 16.

Interconnection capacity

The Netherlands have high interconnection capacities to its neighbouring countries, notably Germany and Belgium. Additional interconnections are in place to Great Britain (BritNed) and Norway (NorNed). In 2018, total cross-border capacity from / to the Netherlands amount to almost 6 GW, approximately one third of peak load.

Based on our assumptions, cross-border capacity will increase further in the next years. Our assumptions regarding the development of interconnection capacity in the model region are based on ENTSO-E's Ten Year Network Development Plan (2017). The development of Dutch interconnection capacity is based on TenneT's monitoring report (2018) and the German Network Development Plan (2019). Figure 12 shows the average of import and export capacity to / from the Netherlands.

Figure 12 Average of Dutch import and export interconnector capacity



Source: Frontier Economics based on TenneT (2018), BNetzA (2019) and ENTSO-E (2018).

Prohibition to use coal as fuel in The Netherlands

Our assumptions in the market model reflect the latest expectations with regards to the prohibition to use coal as a fuel in power plants in The Netherlands. The resulting coal prohibition dates for the respective power plants in The Netherlands are shown in Table 5.

Table 5 Coal plants in The Netherlands

Plant name	Operating / Owner company	Online date	Coal prohibition
Amercentrale 9	RWE	1993	31.12.2024
Hemweg	Nuon NV (Vattenfall)	1994	31.12.2019
Engie Maasvlakte	Engie	2014	31.12.2029
Eemshaven A / B	RWE	2015	31.12.2029
MPP3	Uniper	2016	31.12.2029

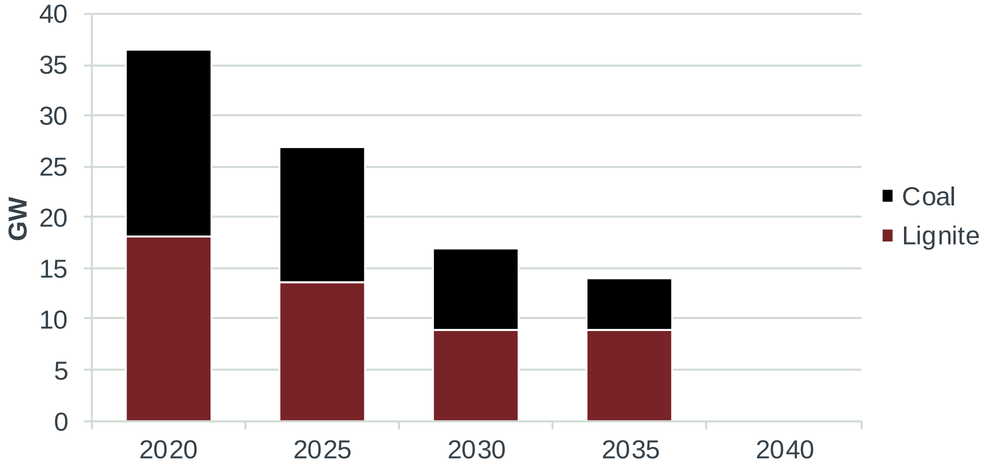
Source: Frontier Economics based on public sources.

Coal phase-out in Germany

The German government announced it would follow recommendations made by the Commission on Growth, Structural Change and Employment ("Coal Commission") to shut down all coal and lignite capacities by the end of 2038.[28] In this report, we assume that coal-firing capacity decreases according to the official timeline published by the Coal Commission.

[28] BMWi (2019): Kommission „Wachstum, Strukturwandel und Beschäftigung", Abschlussbericht.

Figure 13 Generation capacities from coal and lignite in Germany

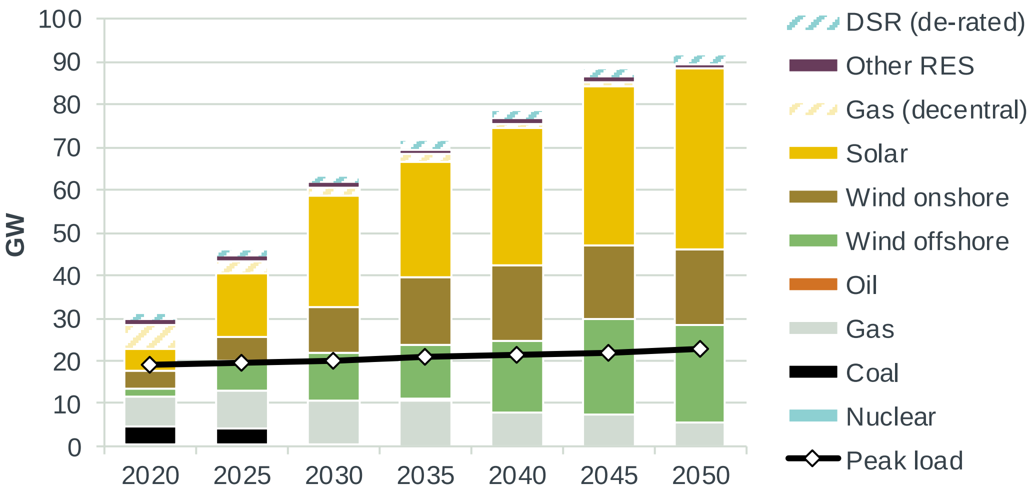


Source: Frontier Economics based on recommendations by the Commission on Growth, Structural Change and Employment (BMWi 2019)

A.3 Market model results

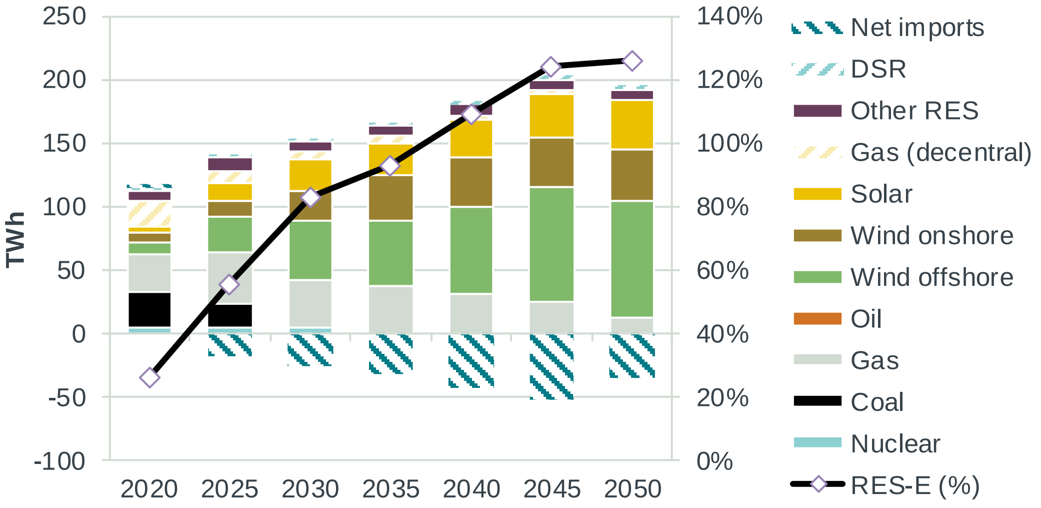
In this annex, we provide further model results, showing the operational capacities, the electricity generation in as well as imports and exports of The Netherlands.

Figure 14 Operational capacities in The Netherlands



Source: Frontier Economics

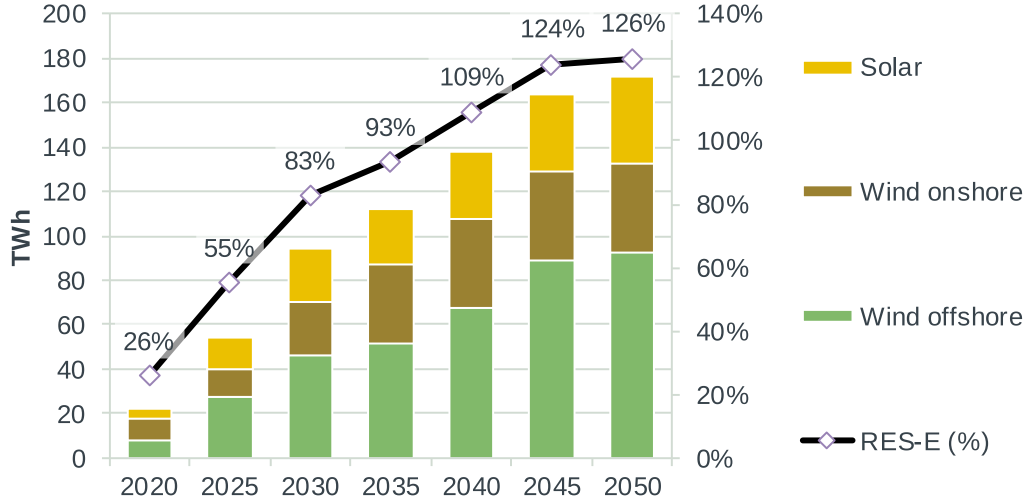
Figure 15 Electricity generation in The Netherlands



Source: Frontier Economics

Note: The black line (right axis) shows the share of renewable electricity generation of demand.

Figure 16 Electricity generation from wind and solar in The Netherlands



Source: Frontier Economics

Note: The black line (right axis) shows the share of renewable electricity generation of demand.

Figure 17 Imports to and exports from The Netherlands

Source: Frontier Economics

ANNEX B DISPATCH MODEL RESULTS

This annex provides additional information on the dispatch model results of both conversion options (Table 6 and Table 7).

The sensitivity “low biomass price” is based on a biomass price of 32,3 EUR/MWh_{th} (incl. transport and handling cost) compared to 34,7 EUR/MWh_{th} in the base case.

Table 6 MPP3 dispatch model results for biomass option

		2030	2031	2035	2040	2045	2050
Base Case							
Electricity Generation	GWh	0	169	179	431	2,390	2,604
Operating hours	h/a	0	183	189	454	2,571	3,016
EBITDA	mn. EUR (2017)	-37.5	-26.9	-6.7	-5.0	8.6	30.0
Sensitivity (“low biomass price”)							
Electricity Generation	GWh	0	340	349	1,505	3,584	2,888
Operating hours	h/a	0	373	369	1,616	3,918	3,401
EBITDA	mn. EUR (2017)	-37.5	-26.4	-5.4	0.5	25.1	44.4

Source: Frontier Economics

Table 7 MPP3 dispatch model results for combined biomass and hydrogen option

		2030	2031	2035	2040	2045	2050
Electricity Generation	GWh	0	281	409	1,465	2,347	3,228
Operating hours	h/a	0	223	326	1,184	1,976	2,768
EBITDA	mn. EUR (2017)	-45.8	-30.3	-3.8	-0.1	16.3	36.6

Source: Frontier Economics

ANNEX C SENSITIVITY OF CO_2 PRICES

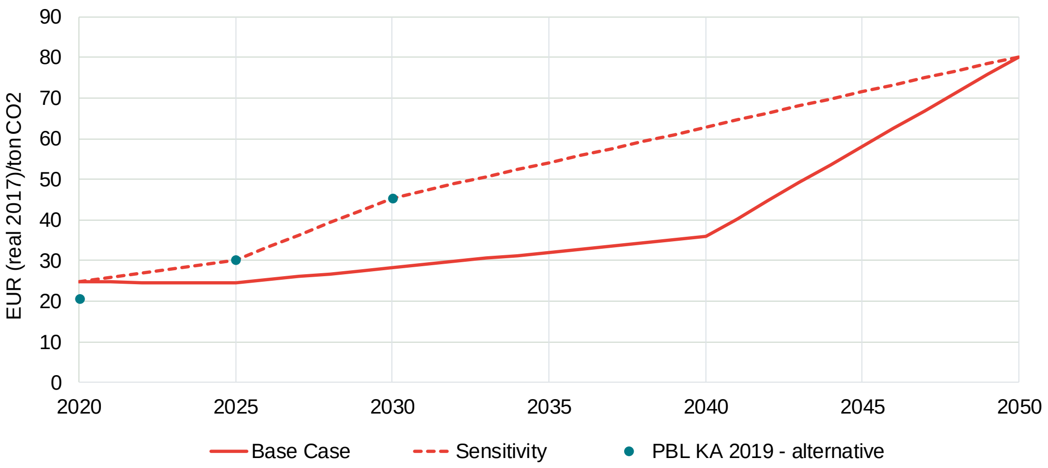
In this annex, we analyse the sensitivity of the results with respect to a variation in CO_2 prices. We derive a new wholesale electricity price forecast based on a higher CO_2 price path. The wholesale prices reflecting the higher CO_2 price path are then used to analyse the profitability and dispatch in the dispatch model.

C.1 Market Simulation of CO_2 Price Sensitivity

In this sensitivity, we base our CO_2 price assumption on the alternative CO_2 prices used in the Klimaatakkoord by PBL (2019). This price path is significantly higher than current future ETS prices and the IEA's long-term projection of CO_2 prices. All other assumptions for the market model are held equal compared to the base case of this study presented in detail in Annex A.

In this sensitivity, the CO_2 price increases to 30 EUR/tCO_2 in 2025 and to 45 EUR/tCO_2 in 2030. As PBL does not provide price projections for the period after 2030, we assume that prices increase on a linear path to the EU Reference price of 80 EUR/tCO_2 in 2050 (Figure 18).

Figure 18 CO_2 price and CO_2 price used for sensitivity



Source: Frontier Economics

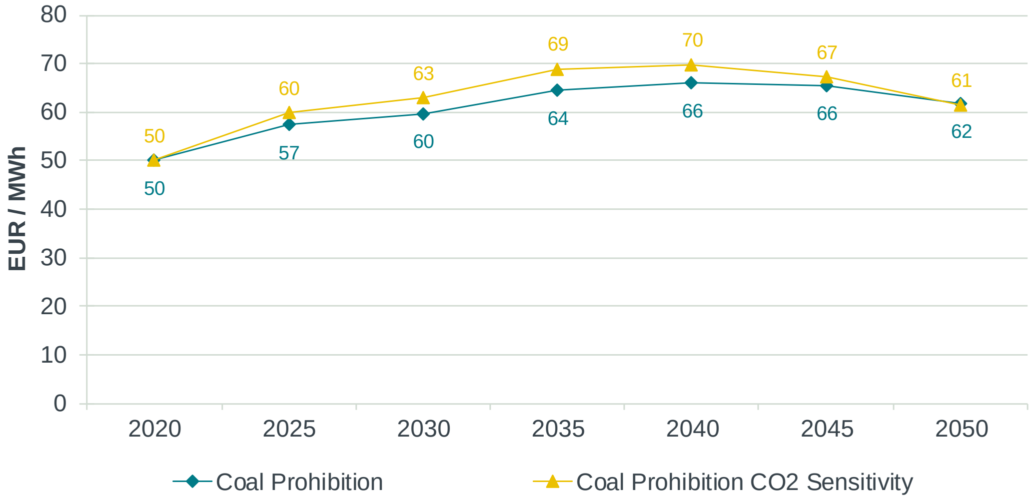
Table 8 CO_2 price and CO_2 price used for sensitivity (EUR/tCO2)

	2020	2025	2030	2035	2040	2045	2050
Base Case	24.78	24.53	31.90	32.07	35.83	58.03	80.22
Sensitivity	24.78	30.20	45.39	54.10	62.81	71.51	80.22

Source: Frontier Economics based on IEA (2018), PBL (2019b) and European Commission (2016).

The electricity wholesale prices of the sensitivity are illustrated in Figure 19. Electricity prices are higher than in the base case (section 3.2): From 2020 onwards, prices are 4-5 EUR/MWh higher and increase to 70 EUR/MWh in 2040. After 2040, increased renewable generation with low marginal cost causes a decline in average wholesale electricity prices to 61 EUR/MWh in 2050.

Figure 19 Power price development in The Netherlands in the CO_2 price sensitivity



Source: Frontier Economics

C.2 Dispatch Model results of CO_2 price sensitivity

Based on the wholesale prices derived in Annex C.1, we analyse in the following the profitability and dispatch of MPP3 as a 100% biomass plant (as presented in section 4) and a combined biomass and hydrogen plant (as presented in section 5). In both configurations, the EBITDA increases compared to the base case CO_2 price assumption.

Based on the higher CO_2 prices assumed in this sensitivity, the combined biomass hydrogen plant is able to generate higher revenues from electricity production than the 100% biomass plant. The higher earnings, however, are offset by higher fuel costs and investment costs for conversion, leading to similar NPV.

Analysis of the MPP3 as 100% biomass plant in the sensitivity

In line with the higher electricity wholesale prices, operating hours and electricity generation of the MPP3 as a 100% biomass plant increase. This corresponds to higher revenues and EBITDA. The NPV (2030, 5.2%) amounts to -143 mn. EUR (period 2039 to 2056).

Detailed results of the dispatch modelling are shown in Table 9.

Table 9 MPP3 dispatch model results for biomass option in CO_2 price sensitivity

		2030	2031	2035	2040	2045	2050
Electricity Generation	GWh	0	309	776	2,862	3,227	2,553
Operating hours	h/a	0	331	847	3,057	3,513	2,947
EBITDA	mn. EUR (2017)	-37.5	-26	-4.4	8.1	20.6	28.6

Source: Frontier Economics

Analysis of the MPP3 combined biomass and hydrogen plant in the sensitivity

In line with the higher electricity wholesale prices, operating hours and electricity generation of the combined biomass and hydrogen plant increase. This corresponds to higher revenues and EBITDA. The NPV (2030, 5.2%) amounts to -143 mn. EUR (period 2030 to 2056).

Detailed results of the dispatch modelling are shown in Table 10.

Table 10 MPP3 dispatch model results for combined biomass and hydrogen option in CO_2 price sensitivity

		2030	2031	2035	2040	2045	2050
Electricity Generation	GWh	0	1,284	2,236	4,337	3,707	3,078
Operating hours	h/a	0	1,037	1,900	3,503	3,072	2,641
EBITDA	mn. EUR (2017)	-45.8	-27.6	3.2	20.6	30.1	35.4

Source: Frontier Economics

www.frontier-economics.com