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RESEARCH ON THE EFFECTS OF THE MINIMUM CO_2 PRICE

A report for the Ministry of Economic Affairs and Climate Policy

09 July 2018

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EXECUTIVE SUMMARY

The coalition agreement of the Rutte III government sets out a new medium-term emission target and includes additional policy measures for this transformation: The Netherlands aim at a 49%-reduction of national CO_2 emissions compared to 1990 and are planning to introduce a national carbon price floor (CPF), in addition to the EU ETS price. Furthermore, the government plans to proceed with a ban of coal in power supply before 2030.

Frontier Economics has been commissioned by the Ministry of Economic Affairs and Climate Policy of the Netherlands to analyse the potential effects of the coal ban and the introduction of the carbon price floor, as envisaged in the coalition agreement. In this report, we explain the approach of the study and present the findings of our analysis:

- **Approach** – We follow a model based approach using Frontier’s European Power Market Model. The same model has been applied in our 2016-study “Research of scenarios for coal-fired power plants in the Netherlands“.
- **Main Scenarios** – We analyse different policy scenarios compared to the counterfactual “Reference Case” based on current policies in the Netherlands and Central-Western-Europe. The central policy scenarios are:
  - “Coal ban”: Prohibition to use coal in electricity supply from 2025/2030 onwards; and
  - “CPF & coal ban”: Introduction of a national carbon price floor from 2020 and a coal ban from 2025/ 2030 onwards.

  Additional sensitivities around policies in the neighbouring countries are also subject of the analysis.

The main results can be summarised as following:

Electricity supply

- Banning the use of coal in power supply increases electricity imports from abroad and increases in the long-run the use of biomass, however, to a lesser extent.
- If a CPF is introduced, both coal-fired power generation as well as gas-fired power generation decrease compared to the Reference Case; hence, imports increase further (largely based on German gas, coal and lignite).

Emission of CO_2

- The coal ban reduces emissions in the Netherlands by up to 18 mn. tCO2 (in 2030); if combined with the CPF, the reduction compared to the Reference Case increases to 26 mn. tCO2.
- However, the majority of the power is imported from other countries with a higher emission intensity than the Netherlands.
- Therefore, the net-effect of the CPF & coal ban (-4 mn. tCO_2 in 2030) is smaller than the net-reduction of a coal-ban in isolation (-8 mn. tCO_2 in 2030): Electricity supply from Dutch gas and coal plants is replaced by generation from other countries with a higher emission intensity.

Impact on Security of Supply and import reliance

- Banning the use of coal has moderate effects on Security of Supply; capacity margins (reliable generation capacity, including some imports, minus peak demand) in the Netherlands decrease slightly but remain positive.
- A CPF and coal ban in combination have significant effects on Security of Supply. The Netherlands will be more dependent on imports, especially in peak hours. Domestic capacity margins become negative in model periods 2025/2030, which means more import capacity is needed to serve peak demand than is assumed to be reliably available in the calculations.

Impact on gas-fired power plants

- Banning coal in power supply improves the profitability of gas-fired power plants slightly; the first mothballed plants are reactivated in the model period 2023.
- If a CPF is introduced, the profitability of gas-fired power generation is significantly reduced; reactivations take only place in the very long term in the model, which may be a challenge in practice.

Impact on power prices

- The impact on power prices is dampened by low-cost power generation available abroad:
  - The coal ban increases prices by up to 1.4 €/MWh in 2030;
  - If the coal ban is combined with the CPF, prices rise by up to 3 €/MWh.

The table below summarises the key figures of our analysis.

Table 1 Key indicators for the central scenarios (compared to Reference Case)

	Coal ban	CPF & coal ban
Domestic CO_2 emission reduction (NL)	▪ 2020: 0 ▪ 2025: - 4 mn. tCO2 ▪ 2030: - 18 mn. tCO2	▪ 2020: - 10 mn. tCO2 ▪ 2025: - 16 mn. tCO2 ▪ 2030: - 26 mn. tCO2
Net-reduction of CO_2 emissions (EU*)	▪ 2020: 0 ▪ 2025: - 2 mn. tCO2 ▪ 2030: - 8 mn. tCO2	▪ 2020: + 1 mn. tCO2 ▪ 2025: - 0 mn. tCO2 ▪ 2030: - 4 mn. tCO2
Impact on import/exports of power	▪ + 17 TWh net-imports in 2030	▪ + 39 TWh net-imports in 2030
Impact on ARM** and import contribution***	▪ ARM remains positive ▪ Utilisation of interconnector increases by 1/3 in peak hours[1] ▪ Import contribution in peak hours grows from 29% to 44% in 2030	▪ ARM negative in 2025/30 ▪ Utilisation of interconnector in peak hours doubles compared to Reference Case ▪ Import contribution in peak hours grows from 29% to 62% in 2030
Impact on capacity margins and CCGTs****	▪ CCGTs benefit from coal ban ▪ First reactivations of CCGTs (2.7 GW) in model period 2023	▪ CCGTs suffer from CPF ▪ First reactivations of CCGTs (5.3 GW) in model period 2035
Impact on power prices in 2023/2030	▪ 2023: + 0 € ▪ 2025: + 0.2 € ▪ 2030: + 1.4 €	▪ 2023: + 1.2 € ▪ 2025: + 2.1 € ▪ 2030: + 2.9 €

Source: Frontier Economics

Note: All values shown are differences to the Reference Case.
** Modelled: NL, DE, BE, FR, DK, CZ, PL, GB, IT;*
*** ARM = adequacy reserve margin (ARM = de-rated capacity + de-rated IC capacity - peak load);*
**** Contribution of imports to meet peak residual load (average over 10 highest residual load hours);*
***** CCGT = Combined-Cycle Gas Turbine.*

[1] Average import capacity utilisation in ten peak residual load hours.

1 INTRODUCTION

1.1 Background of the report

The Netherlands has committed itself to reaching a low-carbon energy system that is reliable, affordable and safe in 2050. Within this context, the Dutch Energy Agreement represents an irreversible step towards achieving this goal. As part of the Energy Agreement, two of seven remaining coal-fired power stations that are currently operational in the Netherlands have been closed mid-2017.

The coalition agreement of the Rutte III government sets out a new medium-term emission target and includes additional policy measures for this transformation: The Netherlands aim at a 49%-reduction of CO_2 emissions compared to 1990 and are planning to introduce a national carbon price floor, in addition to the EU ETS price. Furthermore, the government plans to proceed with the ban of coal in electricity supply before 2030.

In order to get an overview of the effect of the introduction of a CPF in accordance with the coalition agreement, the Ministry of Economic Affairs and Climate Policy has asked Frontier Economics to analyse the impact of these measures on:

- The power-related emission of CO_2 in the Netherlands and neighbouring countries;
- The relocation of electricity generation from the Netherlands to neighbouring countries;
- The security of supply in the Dutch electricity system, especially the profitability and economic position of Dutch gas-fired power plants, including those that are currently mothballed.

1.2 Structure of the report

The report is structured as follows:

- Description of our approach and definition of the scenarios to be analysed (**section 2**);
- Analysis of the key indicators and differences between the main policy scenarios (**section 3**);
- Detailed description of the results and additional sensitivity calculations in the **Annexes**.

2 APPROACH AND SCENARIO DEFINITION

The following section is structured as follows:

- Approach of the analysis (**section 2.1**);
- Description of the power market model (**section 2.2**);
- Definition of the Reference Case scenario (**section 2.3**);
- Definition of policy scenarios (**section 2.4**); and
- Definition of indicators to be analysed (**section 2.5**).

2.1 Approach

In this study, we analyse the impact of the introduction of a carbon price floor in combination with the prohibition to use coal in the Dutch coal fired power plants. In this section, we describe our approach (**Figure 1**):

- **Step 1 –** Modelling the Dutch and Central-Western-European power market is a central element of our analysis;
- **Step 2 –** Definition of a Reference Scenario that describes the current policy framework of the Dutch and neighbouring power markets;
- **Step 3 –** Definition of policy scenarios to be analysed as central scenarios (three policy scenarios);
- **Step 4 –** Definition of alternative policy frameworks in neighbouring markets in order to analyse the impact of foreign policies on the outcome of the analysis (one alternative policy scenario for foreign countries); and
- **Step 5 –** Description of a set of output indicators that will be used to evaluate the impact of the different policy options on the power market.

Figure 1 Approach of the analysis

1 Power market model

- Combined investment and dispatch model (used in 2015/16 studies on behalf of the Ministry)
- Taking into account plant specific information provided by plant operators

2 Reference Case

- Current market and policy framework in NL and CWE
- Based on NEV 2017 / Tennet monitoring report
- No carbon price floor or coal ban

3 NL Policy scenarios

- Introduction of national Carbon Price Floor
- **Prohibition to use coal in power plants after 2030**
- **National Carbon Price Floor & Coal ban**

4 CWE-Policy

- Changing policies in neighbouring countries, e.g.
  - Coal phase out DE
  - Nuclear phase out BE/FR

5 Output analysis

- Definition and assessment of quantitative and qualitative indicators that allow for comparison of different policy alternatives (scenarios and sub-scenarios):
  - Impact on Electricity Supply
  - CO_2-emissions (domestic vs. EU)
  - Security of Supply (ARM)
  - Mothballing and economics of CCGTs
  - Impact on power prices

Source: Frontier Economics

2.2 Power market modelling

In this assignment, we use our power market model already applied in the previous studies undertaken on behalf of the Ministry of Economic Affairs and Climate Policy.[2]

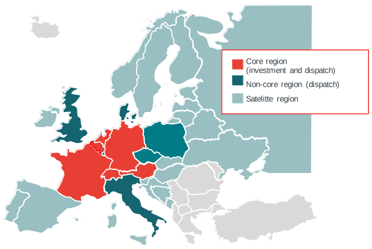
Figure 2 Frontier Power Market Model

Input - Dispatch
- Hourly load
- Fuel costs/ CO_2
- Power plant capacity and DSR
- Hourly availability of RES
- interconnectors
- Fixed O&M + variable costs
- RES-In-feed

Input - Investment
- Potentials
- Investment costs
- Mothballing costs

Market framework
- Policy measures

Combined Investment and Dispatch Model (CID)



- Time horizon until 2050
- For up to 8 snap-shot years: 2018, 2020, 2023, 2025, 2030, 2035, 2040 and 2050
- High granularity of 4032 hours p.a.
- Differentiated between highly detailed core-region and less-detailed non-core/satellite regions

Output - Dispatch
- Generation / emissions
- System cost
- Hourly prices
- Hourly dispatch / DSR
- Residual load
- Profitability

Output - Investment
- Capacity balances
- Investments
- Security of Supply
- Mothballing and closure

Source: Frontier Economics

[2] Frontier Economics (2015): Scenarios for the Dutch electricity supply system; Frontier Economics (2016): Research of scenarios for coal-fired power plants in the Netherlands.

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 and France,. 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, Poland and the Czech Republic, 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 2015 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 2018, 2020, 2023, 2025, 2030, 2035, 2040, 2050.

The model has been adapted to allow for a conversion of the Dutch coal plants from burning coal (plus co-firing of biomass) to stand-alone biomass. The conversion to biomass only would lead to a situation in which power production of the respective plants became carbon neutral. For the modelling, the plant operators of the coal-plants in question provided information on technical and economic constraints of converting the coal-fired installations to stand-alone biomass (investment costs for conversion, impact on operational efficiency).

2.3 Reference Case scenario definition

In order to analyse the impact of the policy measures of the coalition agreement, we define a counterfactual scenario ("Reference Case") against which the policy scenarios can be benchmarked. The Reference Case is based on the current and intended policy framework in the Netherlands and in North-Western Europe. It represents a scenario which is built upon a combination of current market expectations, e.g. regarding fuel prices and CO_2 prices, and political targets for example for the development of RES-E. However, we only take those policy decisions into account which are defined in an operational manner and are officially decided. Hence, it excludes a national carbon price floor in the Netherlands and the prohibition to burn coal at specific points in time.

2.3.1 Market framework

In the following, we describe the key-assumptions for the electricity market in the Reference Case. These assumptions also form the basis for the policy scenarios.

Figure 3 Summary of main assumptions

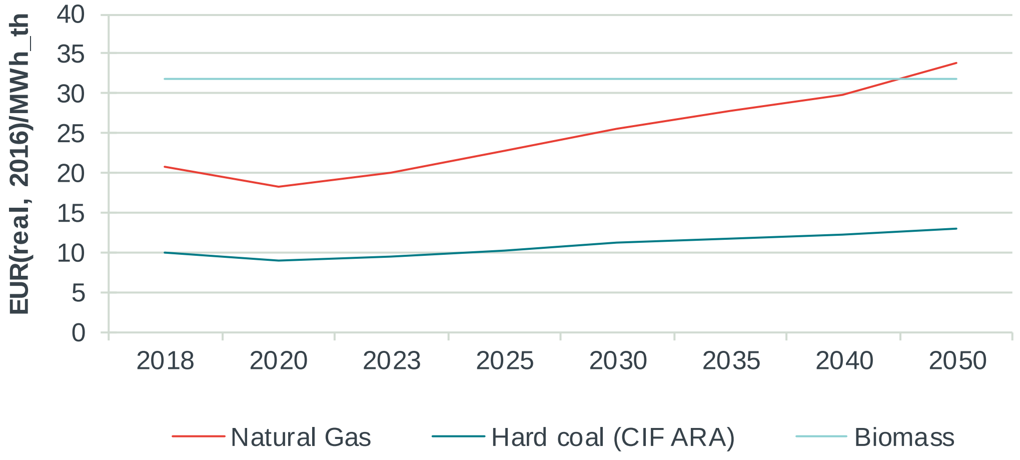
	Approach / Sources	Assumption
Fuel & CO_2 prices	▪ Coal and gas prices: Current future prices, medium- to long-term using heat-equivalence ratios and the IEA WEO NP 2017 oil-price ▪ CO_2-price: Current futures, IEA WEO NP 2017 & EU Ref Scen in 2050	▪ Moderate increase in the medium-term (coal 12 €/MWh* / gas : 28 €/MWh* in 2035) ▪ CO_2 prices increase to 40 €/tCO_2 in 2040 and 79 €/tCO_2 in 2050 (real, 2016)
Power Demand	▪ NL- power demand based on TenneT SoS Monitoring report (extrapolated into the future) ▪ EU: National statistics and grid-development plans	▪ NL: moderate increase by 0.3% p.a. to 126 TWh in 2050 ▪ DE: sector coupling increases demand after 2030 until 2050 (790 TWh)
RES-E growth	▪ NL: NEV 2017 "vastgesteld beleid" (co-firing subsidies until incl. 2027) ▪ EU: National targets for RES-E Growth / ENTSO-E TYNDP 2018 (Sustainable Transition)	▪ NL: Significant increase until 2030 (+ 65 TWh) mainly driven by offshore wind ▪ Overall increase in RES-E across all modelled countries
IC-capacities	▪ NL: TenneT SoS Monitoring Report ▪ EU: ENTSOE TYNDP / National grid development plans	▪ NL: increase to c. 10 GW (average import/export) in 2035 ▪ EU: doubling of cross-border capacities in the long-run (2050)

Source: Frontier Economics

- **Fuel prices** –The fuel price projections are based on current future prices as well as projected price developments from the World Energy Outlook 2017 (New Policies scenario) (**Figure 3**). A comparison with the assumptions used in the National Energy Outlook 2017 is provided in Annex A.
  - **Coal and gas**: The short-term price projection for coal and gas prices is derived from current forward prices (until incl. 2021). The long-term trend (after 2025) is based on the price development of the World Energy Outlook 2017. Prices in between 2021 and 2025 are interpolated linearly.
  - **Biomass**: We assume that prices of biomass will remain constant in real-terms at the level of today's forward prices (31.9 € (real, 2016) /MWh_{th}).[3]

[3] Free plant, including 10 €/t transportation cost.

Figure 4 Fuel price projection

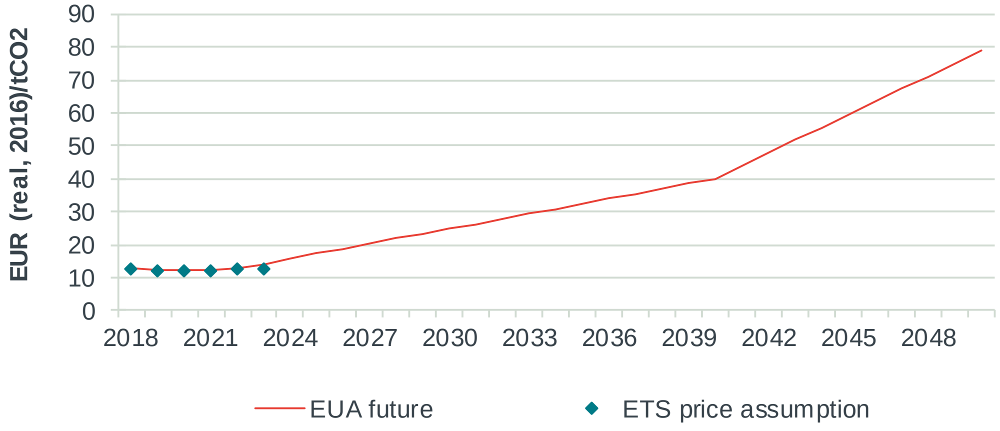


Source: Frontier Economics

Note: All values expressed in real terms (base year 2016).

- **CO_2 price (EU ETS)** – We use current future prices until 2022 (including)**.** Afterwards, we interpolate to the WEO's price projection of 40 €/tCO_2 in 2040 and the EU Reference Scenario in 2050 (ca. 80 €/t CO_2, real 2016).

Figure 5 CO_2 price projection



Source: Frontier Economics

Note: All values expressed in real terms (base year 2016), Future prices dated 03/05/2018.

- **Power demand** – Our assumption for the development of power demand is based on the demand projection in TenneT's Monitoring Report 2017. The Monitoring Report assumes a moderate growth of power consumption in the period depicted. Including network losses, net electricity consumption is assumed to increase from 116 TWh in 2018 to 118 TWh in 2030. We base our assumptions on the assumed demand growth of the Monitoring Report until 2030 and use linear extrapolation for the years after 2030. Electricity demand in other modelled countries has been derived from national statistics, network development plans or secondary sources.

Table 2 Power demand

Parameter	Unit	2018	2020	2023	2028	2030	2035	2040	2050
Net power demand (NL)	TWh	116.2	115.9	116.4	117.9	118.7	120.4	122.2	125.9
Power demand (model-region)	TWh	2,297	2,309	2,330	2,374	2,392	2,501	2,606	2,790
Peak load (NL)	GW	19.0	18.9	19.0	19.2	19.3	19.5	19.8	20.3

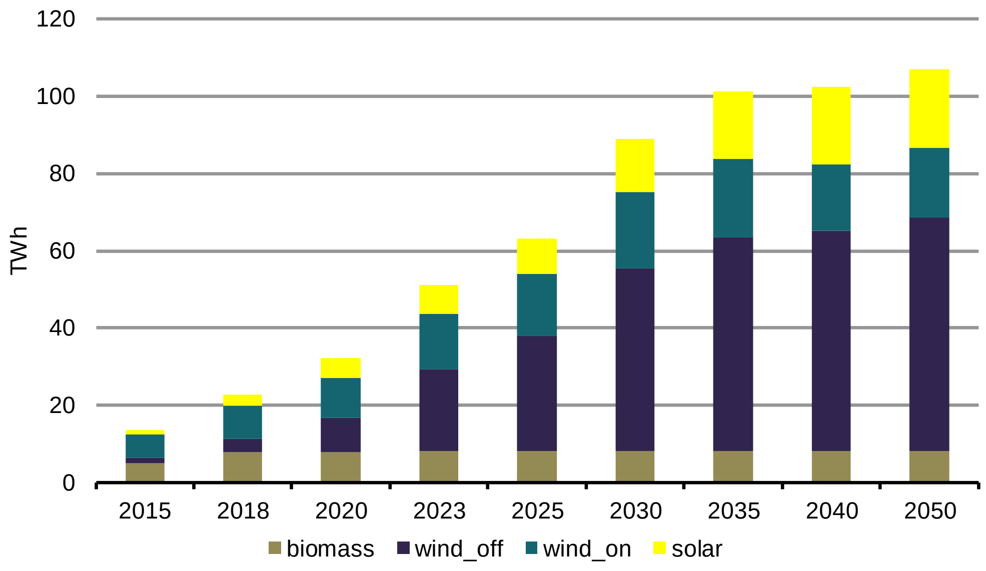
Source: Frontier Economics based on TenneT's Monitoring Report 2017

Note: Net power demand incl. Network loses, excl. own-consumption of power plants and pumping demand. The model region includes DE, FR, NL, BE, GB, IT, AT, CH, DK, CZ, PL.

- **Renewable growth –** The development of Renewable energies in electricity supply is driven by support policies. We assume support driven renewable growth as exogenously given. The assumptions on renewable power generation in the Netherlands until 2035 are based on the NEV 2017 (current policies). The NEV assumes the following generation figures for wind and solar PV for 2035:
  - Wind (offshore and onshore): 80.2 TWh
  - Solar PV: 17.4 TWh

  After 2035, we assume a continuation of exogenous renewable growth but with a much lower growth rate (Figure 6). However, if economically viable, the model can endogenously invest in additional renewable energy sources in electricity supply.

Figure 6 Assumed development of renewable energy sources in electricity Supply (NL)



Source: Frontier Economics (based on NEV 2017)

- **Thermal power plants –** The capacity development of thermal power plants in the Netherlands and neighbouring countries is an outcome of the model optimisation. Nevertheless, known investment/divestment decisions as well as mandatory phase out schemes (nuclear or coal) have to be taken into account:

- Nuclear phase-out in Belgium: We assume that the nuclear phase-out is completed as planned before 2025.
- Reduction of nuclear electricity supply in France: The initially targeted reduction of the share of nuclear power to 50% in 2025 has been postponed in the light of planned phasing out of the remaining coal plants in the same time horizon. We assume a reduction of the share of nuclear power to 50% of electricity supply until 2040.
- German coal phase out: Currently, there is no legal obligation to phase-out coal at a certain point in time. However, discussions around the future of coal in the so-called "coal-commission" have started in June. Therefore, we do not assume mandatory closure of coal fired generation in Germany. Known closures of coal plants and the technical lifetime of power plants are taken into account (see **Annex D.1**).

- **Interconnection capacity**[4]

  The Netherlands dispose of high interconnection capacity 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.[5] The development of Dutch interconnection capacity is based on TenneT's monitoring report (2017) and the German Network Development Plan (2019). Figure 7 shows the average of import and export capacity to/from the Netherlands:[6]

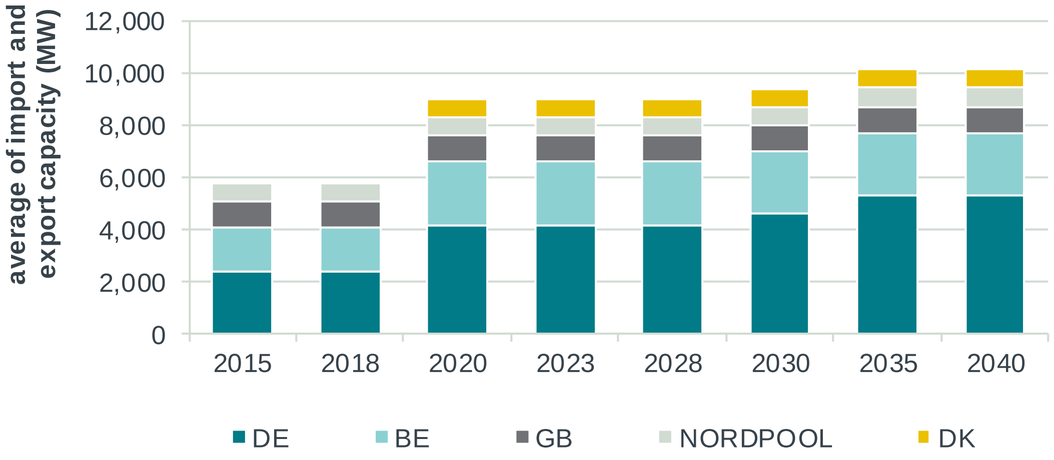
  - Interconnections to Germany increase by 1.8 GW until 2020. Additional interconnection to Germany is assumed to come online between 2028 and 2035 (+1.2 GW).
  - Interconnections to Belgium increase by 0.7 GW until 2020.
  - Interconnections to Denmark (Cobra Cable) will have a capacity of 0.7 GW by 2019.

[4] So-called "C-Function", TenneT TSO GmbH (2012): "Bestimmungen der Übertragungskapazität an auktionierten Grenzkuppelstellen der TenneT TSO GmbH". Flow-based market coupling is not incorporated in the model since the modelling of interconnections is based on Net Transfer Capacities (NTC) due to restrictions regarding computational time of the model.

[5] We assume that projects that are in the earlier planning phases will come online with a certain delay: "design and permitting" + 2 years; "planning" + 5 years; "under consideration" + 15 years.

[6] It has to be noted that the modelling of interconnectors does not take internal congestions inside the modelled countries into account. However, we assume that the availability of interconnectors from Germany to other neighbouring countries (NL, FR, CH) is influenced by loop or transit flows caused by high infeed from wind-power in Germany.

Figure 7 Assumed development of Dutch interconnection capacity



Source: *Frontier Economics based on TenneT's monitoring report (2017) and the German Network Development Plan (2019)*

2.3.2 Policy framework in the Netherlands

The policy assumptions underlying the Reference Case reflect climate and energy policy as of April 2018. This relates notably to:

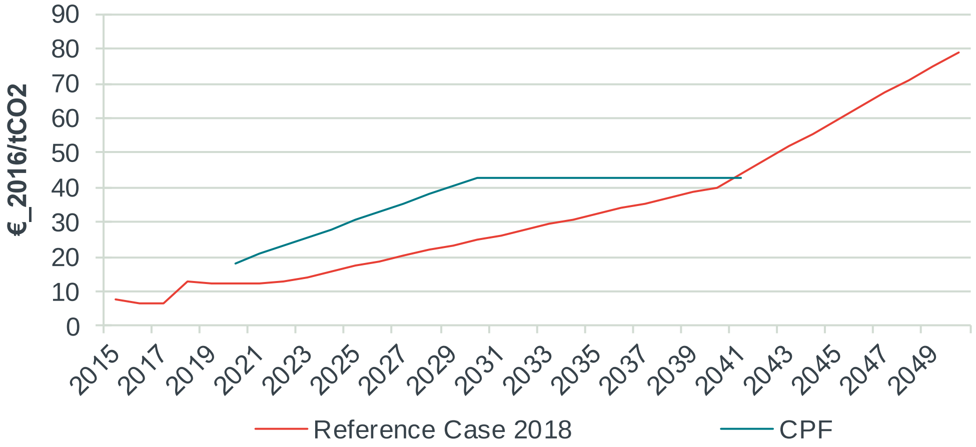
- Continued support of co-firing of biomass in coal-plants until the end of 2027;
- No mandatory closure of coal-plants or ban of coal as fuel in power supply; and
- No introduction of a Carbon Floor Price.

2.4 Policy scenarios

In the following, we describe the definition of the key policy measures subject to our analysis:

- **Introduction of a national carbon price floor (CPF)** – The coalition agreement envisages the introduction of a carbon price floor that rises gradually from 18 €/tCO_2 in 2020 to 43 €/tCO_2 in 2030. The CPF will only apply to those power plants which are located in the Netherlands. Based on the assumed CO_2 price in the European emission trading system (ETS), the CPF induces an uplift of the CO_2 price by 8.5 €/tCO_2 in 2020 and 20 €/tCO_2 in 2030 (**Figure 8**). We assume that the CPF will remain at 43€/tCO_2 until the ETS price reaches that level (after 2040).

Figure 8 National carbon price floor



Source: Frontier Economics

Note: All values expressed in real terms (base year 2016).

- **Ban of using coal until 2025 / 2030** – Currently, five coal-fired power plants are operating in the Netherlands. The coalition agreement also foresees a closure of the remaining 4.6 GW of coal-fired power plants or a ban of using coal in these plants before 2030.

  We assume two dates after which the use of coal is prohibited:

  - The two older plants (Hemweg, Amercentral 9) will be prohibited to use coal after 2024;
  - The three more modern power plants, (Eemshaven, Maasvlakte, MPP3), will be allowed to use coal as a fuel until the end of 2029.

  The plants are not forced to cease operation and be decommissioned but are allowed to convert to biomass only power plants.[7]

Table 3 Coal-fired power plants in the Netherlands

Plant name	Operating / Owner company	Online date	Net generating capacity	End of technical lifetime	Prohibition to use coal in scenarios c) & d)
Amercentrale 9	RWE / ESSENT	1993	631	31.12.2033	31.12.2024
Hemweg	Nuon NV (Vattenfall)	1994	650	31.12.2034	31.12.2024
Engie Maasvlakte	Engie	2014	735	> 2050	31.12.2029
Eemshaven A / B	RWE / ESSENT	2015	1.580	> 2050	31.12.2029
MPP3	Uniper	2016	1.069	> 2050	31.12.2029

Source: Frontier Economics

[7] The plant operating companies provided technical and financial information the conversion to biomass.

Based on these two key parameters, national CPF and coal ban, we define the following set of central policy scenarios

- **Reference Case ("current policy")**: It is assumed that none of the 5 remaining coal fired power plants in the Netherlands are prohibited to use coal and no carbon price floor is introduced.
- **Coal ban:** No carbon price floor, use of coal banned before 2025 for two older and before 2030 for three younger plants.
- **CPF & coal ban**: Scenario with national carbon price floor in line with coalition agreement for the period 2020-2030 and the ban on using coal before 2030.

2.5 Indicators

In the following, we define a set of key-indicators to describe the impact of the different policy measures.

2.5.1 Electricity supply and power exchanges

The policy measures could lead to structural changes in the Dutch power market. We describe how the policy measures impact the different elements of power supply:

- Operational capacity;
- Net-electricity generation; and
- Power exchange with neighbouring countries.

2.5.2 Impact on CO_2 emissions

Regarding CO_2 emissions, we differentiate between:

- The change in domestic emissions (NL); and
- The net-change in emission in all modelled countries (taking into account changing import/export volumes).[8]

2.5.3 Security of Supply

In order to assess the impact of the policy measures on the capacity balance and the contribution of imports in scarce hours, we analyse

- Adequacy Reserve Margins (ARM): the difference between reliable capacity and peak load;
- The utilisation of import capacity in critical hours and over the year; and
- The contribution of imports to residual load in critical (highest residual load) hours.

[8] It has to be noted that an effective reduction of emissions under the ETS is only completed if certificates up to the amount of expected emissions from the affected coal plants won't become available to the market.

2.5.4 Mothballing and economics of CCGTs

We illustrate how the different policy instrument change incentives for mothballed plants to re-enter the market or for operating plants to go into mothballing by analysing the mothballing / reactivation behaviour in the model.

In this context, it is important to note that the decision to reactivate a mothballed power plants is influenced by a number of factors and only some of them are captured in the power market mode. In the end, the decision is driven by the plant operator's expectation of future revenues and costs of reactivation:

- Reactivation costs depend on the period of time, the plant has been mothballed;
- Reactivation costs depend on the individual maintenance cycles;
- Reactivating a power plant provides an option value to realise profits that are not known/expected today.

In our analysis, we assume a uniform cost of preservation during the mothballing period of ca. 1,500 €/MWa (ca. 10% of fixed operation and maintenance costs) and a uniform cost of reactivation (in addition to annual fixed operation and maintenance costs) of 5,100 €/MW.[9]

2.5.5 Power prices

We analyse the development of wholesale power prices in the individual scenarios and how these compare to power prices in the Reference Scenario. Power prices are an outcome of the model, we analyse annual average (base) prices.

[9] Frontier based on TenneT/UMS (2017).

3 INDICATOR BASED ASSESSMENT

The section is structured as follows:

- Summary of main results (**section 3.1**);
- Results of the Reference Case (**section 3.2**);
- Impact of the policy measures on electricity supply and imports/exports (**section 3.3**);
- Impact of the policy measures on power-related CO_2 emissions (**section 3.4**);
- Impact of the policy measures on capacity margins (ARM) and import contribution (**section 3.5**);
- Impact of the policy measures on mothballing and the economics of CCTGs (**section 3.6**); and
- Impact of the policy measures on power prices (**section 3.7**).

3.1 Summary

The following table summarises the modelling results for the key indicators of our analyses.

Table 4 Key indicators for the central scenarios (compared to Reference Case)

	Coal ban	CPF & coal ban
Domestic CO_2 emission reduction (NL)	▪ 2020: 0 ▪ 2025: - 4 mn. tCO2 ▪ 2030: - 18 mn. tCO2	▪ 2020: - 10 mn. tCO2 ▪ 2025: - 16 mn. tCO2 ▪ 2030: - 26 mn. tCO2
Net-reduction of CO_2 emissions (EU*)	▪ 2020: 0 ▪ 2025: - 2 mn. tCO2 ▪ 2030: - 8 mn. tCO2	▪ 2020: + 1 mn. tCO2 ▪ 2025: - 0 mn. tCO2 ▪ 2030: - 4 mn. tCO2
Impact on import/exports of power	▪ + 17 TWh net-imports in 2030	▪ + 39 TWh net-imports in 2030
Impact on ARM** and import contribution***	▪ ARM remains positive ▪ Utilisation of interconnector increases by 1/3 in peak hours[10] ▪ Import contribution in peak hours grows from 29% to 44% in 2030	▪ ARM negative in 2025/30 ▪ Utilisation of interconnector in peak hours doubles compared to Reference Case[11] ▪ Import contribution in peak hours grows from 29% to 62% in 2030
Impact on capacity margins and CCGTs****	▪ CCGTs benefit from coal ban ▪ First reactivations of CCGTs (2.7 GW) in model period 2023	▪ CCGTs suffer from CPF ▪ First reactivations of CCGTs (5.3 GW) in model period 2035
Impact on power prices in 2023/2030	▪ 2023: + 0 € ▪ 2025: + 0.2 € ▪ 2030: + 1.4 €	▪ 2023: + 1.2 € ▪ 2025: + 2.1 € ▪ 2030: + 2.9 €

Source: *Frontier Economics*

Note: *All values shown are differences to the Reference Case.*
** Modelled: NL, DE, BE, FR, DK, CZ, PL, GB, IT;*
*** ARM = adequacy reserve margin (ARM = de-rated capacity + de-rated IC capacity - peak load);*
**** Contribution of imports to meet peak residual load (average over 10 highest residual load hours);*
***** CCGT = Combined-Cycle Gas Turbine.*

3.2 Reference Case

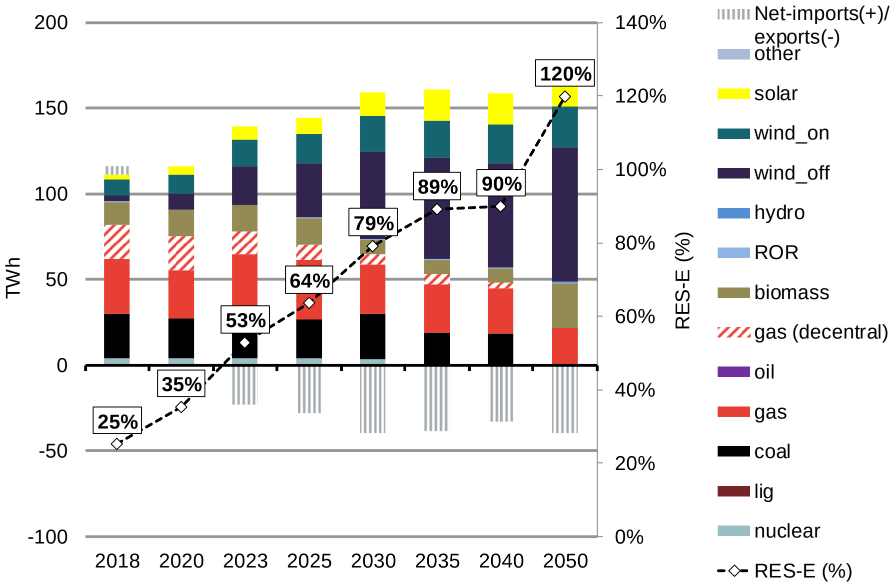
The developments in the Dutch power system in the Reference Case are driven by the transition from conventional generation capacities to largely renewable generation capacities. This transition has direct effects on the conventional generation capacities in the Netherlands and thereby on the Dutch capacity margin, on the electricity exchange with neighbouring countries and on the conversion of coal-fired plans to biomass-fired plants.

[10] Average import capacity utilisation in ten peak residual load hours.

[11] ibid.

- **Electricity supply** – The expansion of renewable generation capacities increase overall electricity generation in the Netherlands from c. 110 TWh in 2018 to 158 TWh in 2030 (Figure 5). As a result, the Netherlands become a net-exporter from 2020/2023 onwards.

Figure 9 Reference Case: Electricity generation in the Netherlands

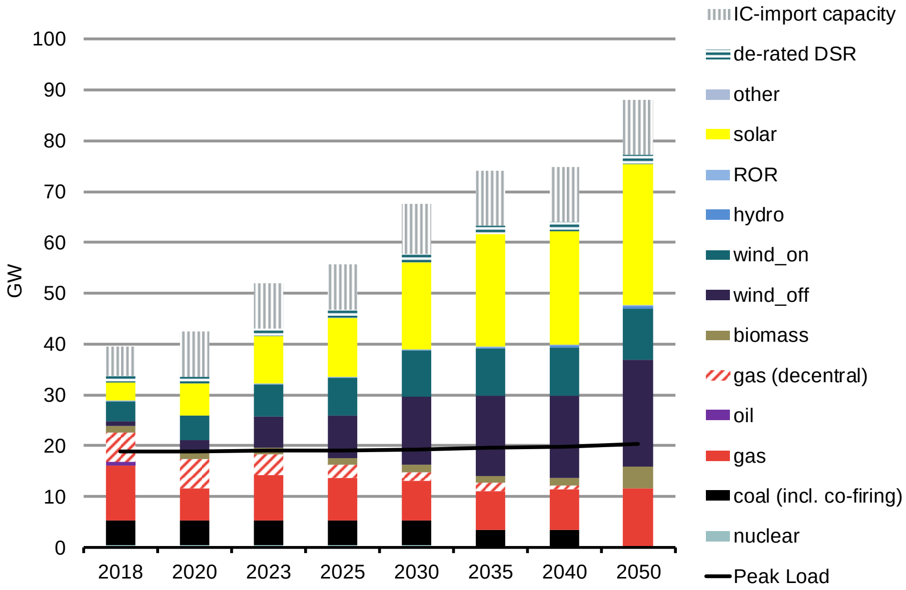


Source: Frontier Economics

- **Operational capacities** – In the short-run, additional gas-fired power plant capacities are mothballed (1.6 GW by 2020) and closed (2.5 GW by 2020). From 2023 onwards gas-fired power capacities are stepwise reactivated: power plants comprising 3 GW are reactivated between 2023 and 2025 and an additional capacities of c. 2 GW are reactivated by 2035 and by 2040. In the long-run (2050) new investments into CCGT plants are undertaken (5.9 GW).

  Conversion of coal-fired plants into biomass plants becomes economically viable only in the very long-run (2050), when a total of c. 3 GW is converted.

Figure 10 Operational capacities (Reference Case)



Source: Frontier Economics

- **Capacity margin and mothballing** – The capacity margin of the Dutch electricity system declines with increasing renewable capacities and decreasing conventional capacities. Adequacy reserve margins (ARM)[12] fall as a result, however, taking into account import capacity to a certain extent, remain positive.

3.3 Policy measures: Impact on electricity supply and import/exports

Banning the use of coal in power supply from 2025 / 2030 onwards as well as the introduction of a Carbon Floor price lead to a structural change in the Dutch power plant park.

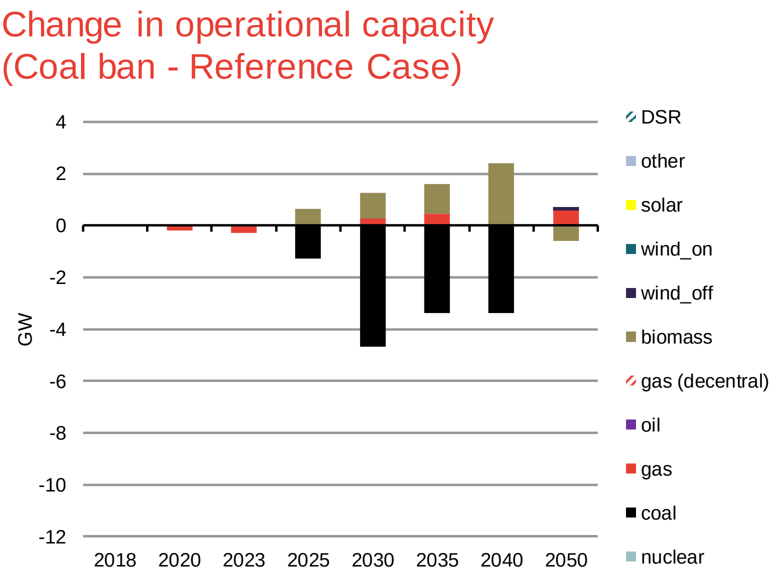
3.3.1 Coal ban – electricity supply

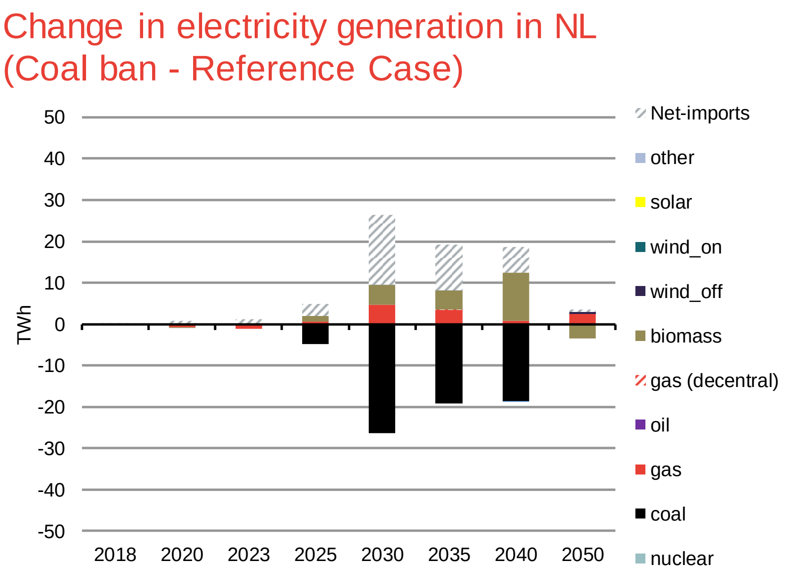
Banning the use of coal makes conversion to biomass plants attractive at an earlier point in time. Partially driven by required heat production, partially by economic rationale. Coal-plants are increasingly converted already in 2040 (instead of 2050). In addition, gas-fired power generation benefits and reactivation of mothballed gas-fired power generation takes place earlier.

[12] The adequacy reserve margin informs about the level of reliable capacity compared to peak load. It is calculated as the difference of the de-rated available capacity (incl. a share of reliable import capacity) and peak load. We de-rate import capacity with 60%, which corresponds to the lowest availability of import capacity observed in the modelled years (footnote 6 explains the availability of interconnectors in the model). Deriving an exact value for de-rating IC capacity would need extensive probabilistic analyses of availability of foreign generation capacities and the interconnectors which is not subject of this study.

Nonetheless, the majority of the power formerly produced by coal plants is imported from neighbouring countries, and net-imports increase by 17 TWh.[13]

Figure 11 Coal ban - Impact on operation capacity and electricity supply in the Netherlands





Source: Frontier Economics

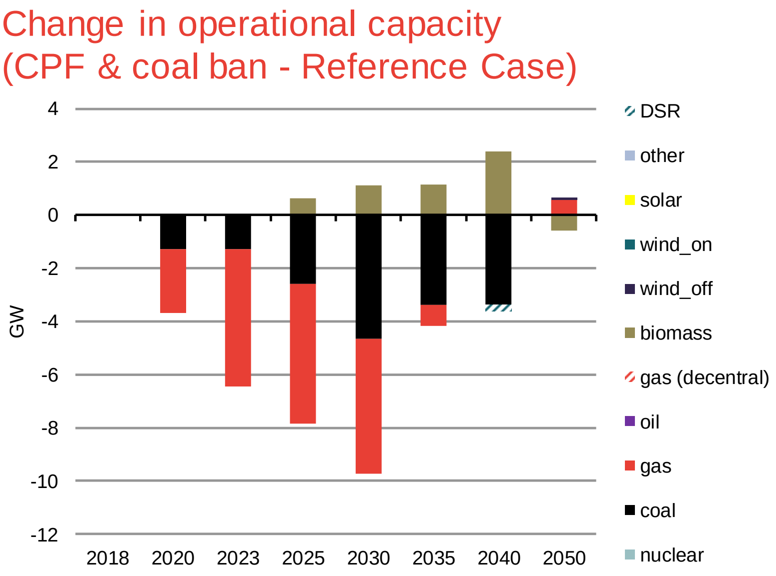
3.3.2 CPF & Coal ban – electricity supply

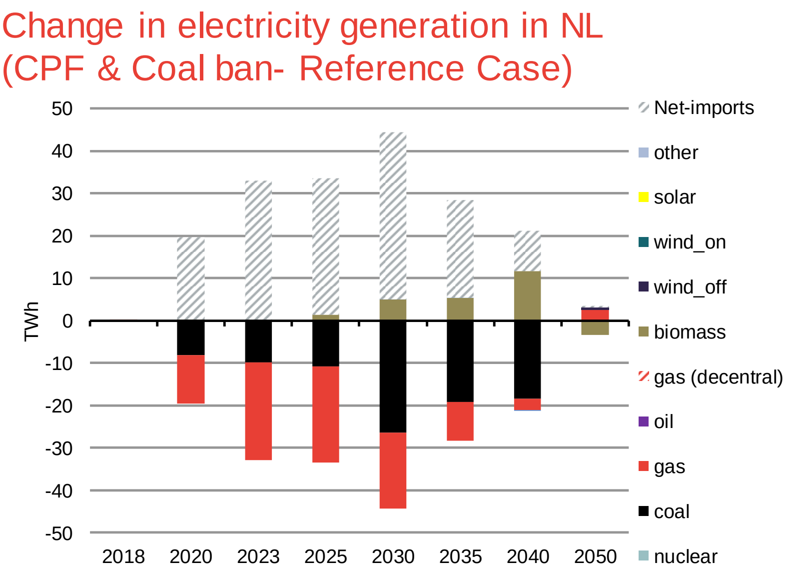
A national CPF leads to earlier closure of gas and coal plants (as of 2020). Due to the CPF, additional gas plants are mothballed (2.4 GW more than in the Reference Case in 2020) and the period of mothballing of currently non-operational

[13] In the model, there is a small dip in gas-fired power generation in the Netherlands in 2020/2023. This can be interpreted as a model result due to intertemporal optimisation and perfect foresight: For example, additional power plant capacity is made available in foreign countries in the medium and longer term, however, this can lead to less decommissioning in the short term abroad, leading to slightly lower gas-fired power generation in the Netherlands.

plants is significantly prolonged. Imports increase accordingly, especially when the coal ban is completed in 2030. The conversion of coal plants to biomass plants is similar to the coal ban scenario.

Figure 12 CPF & Coal ban - Impact on operation capacity and electricity supply in the Netherlands



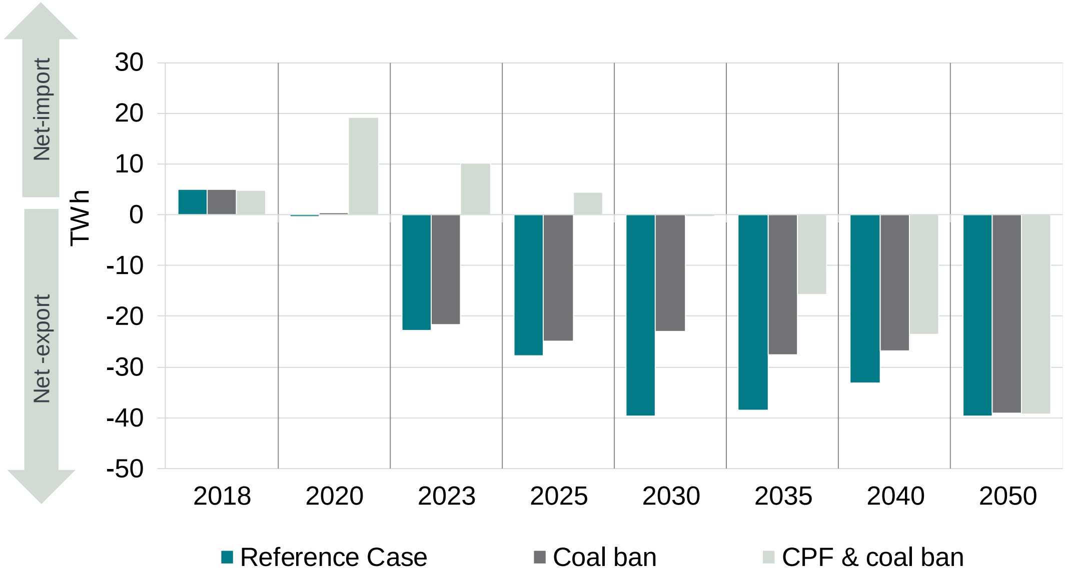


Source: Frontier Economics

3.3.3 Impact on imports and exports from/to the Netherlands

The completion of the coal ban in 2030 lowers the net-exports compared to the Reference Case. If a CPF is introduced, the Netherlands will remain net-importer of power for a longer period of time (until after 2030). As the gap between the CPF and the ETS price diminishes over time (after 2030), the position turns into a net-export position due to the high share of renewable electricity in the Netherlands.

Figure 13 Net-imports and exports to/from the Netherlands



Source: Frontier Economics

Note: Positive values represent imports into the Netherlands and vice versa.

3.4 Policy measures: Impact on power-related emission of CO_2

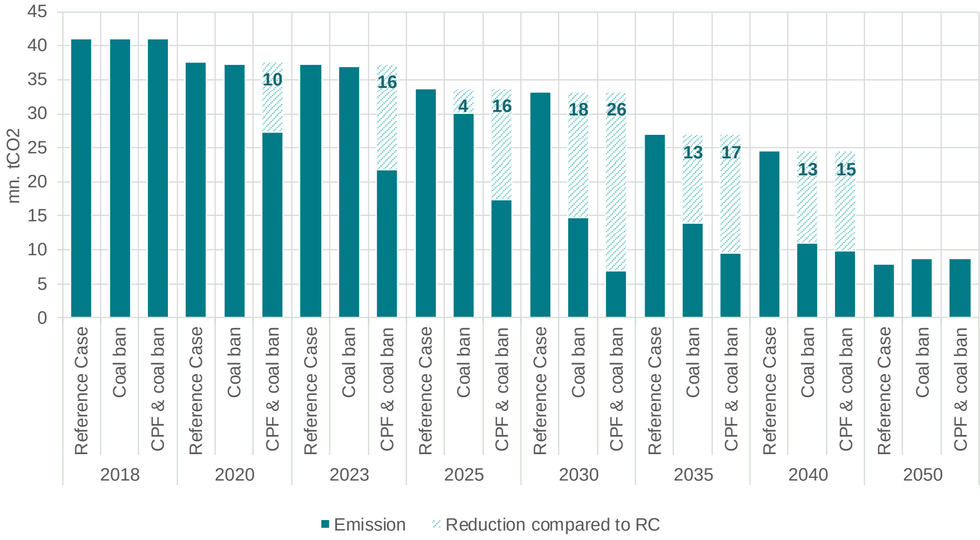
In this section, we describe the impact of the policy measures on the emission of CO_2 in the Netherlands and neighbouring countries.

3.4.1 Domestic CO_2 emissions (NL)

Banning the use of coal and the introduction of a carbon price floor have significant effects on the electricity supply in the Netherlands and associated CO_2 emissions:

- Compared to the Reference Case, the coal ban lowers emissions in the Netherlands as from 2025 onwards and by up to 18 mn. tCO_2 in 2030.
- The introduction of the CPF reduces CO_2 emissions already in year 2020 (by 10 mn. tCO_2). Since coal-fired as well as gas-fired power generation decreases, CO_2 emissions are reduced additionally by up to 26 mn. tCO_2 compared to the Reference Case in 2030 (**Figure 14**).

Figure 14 Comparison of power related CO_2 emissions



Source: Frontier Economics

Note: Dashed area represents the difference to the Reference Case.

3.4.2 Net-reduction of emissions

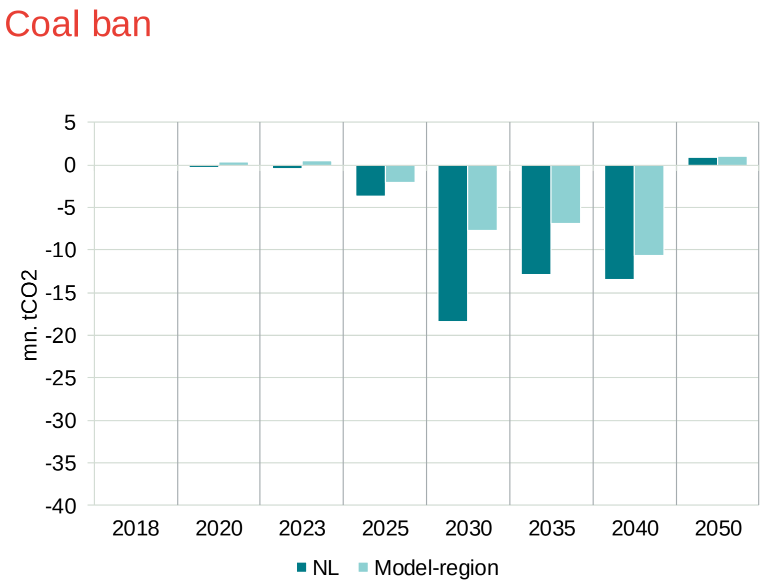
Decreasing emissions in the Netherlands have to be evaluated against a potential increase in emissions in other countries as import/export flows in Central-Western Europe are affected by the Dutch policy measures. The impact on overall CO_2-emissions in the modelled countries deviates from the domestic perspective; net-reduction in all countries is lower than the domestic reduction as the power generation from Dutch plants is compensated for by foreign plants, mostly with higher emission intensity.[14]

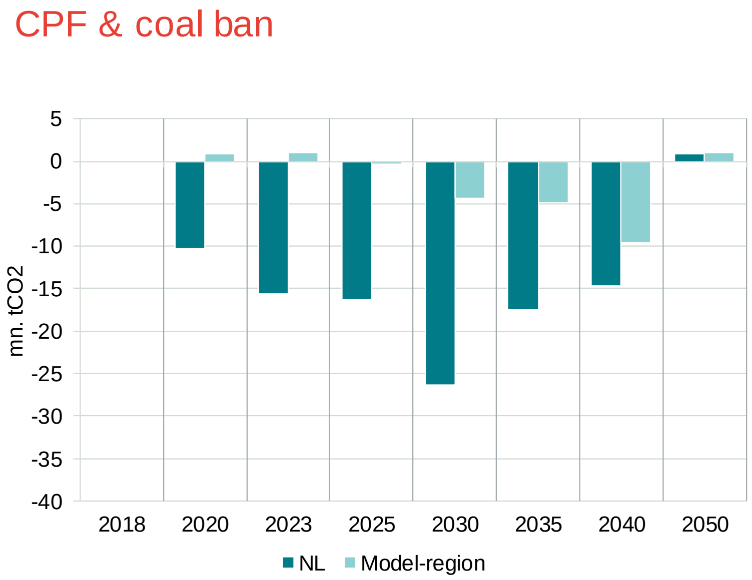
- The coal ban leads to a net-reduction of emissions in the modelled region of 8 mn. tCO_2 in 2030.
- Combining the coal ban with the CPF substitutes Dutch gas generation with foreign generation from coal and gas. Therefore, the net-reduction in the modelled countries is smaller and only amounts to 4 mn. tCO_2 in 2030 (Figure 15).[15]

[14] In addition, as a result of the emission trading system, CO_2 certificates that are "freed up" by lower Dutch emissions can now, as long as they are not taken up by the market stability reserve, be used by other entities covered by the EU ETS system. This effect is not captured by the model, so emission reductions stated above are likely to present an upper bound for the achieved reductions.

[15] The impact of the carbon price floor is crucially dependent on the difference between ETS prices and the carbon price floor in the Netherlands. A lower CPF (or higher market based ETS price) than assumed in our study would most likely reduce the impact of the CPF on Security of Supply and the economics of gas-fired plants, but at the same time lead to a lower reduction of domestic CO_2 emissions than is observed with the CPF of the coalition agreement. However, since the market based carbon price fluctuates significantly in time as well as other market parameter, the exact impact of a CPF can change significantly under relatively short notice.

Figure 15 Impact on emissions in NL and in model-region





Source: Frontier Economics

3.5 Policy measures: Impact on ARM and imports in critical hours

In order to assess the impact of the policy measures on the capacity balance and the contribution of imports in scarce hours, we analyse:

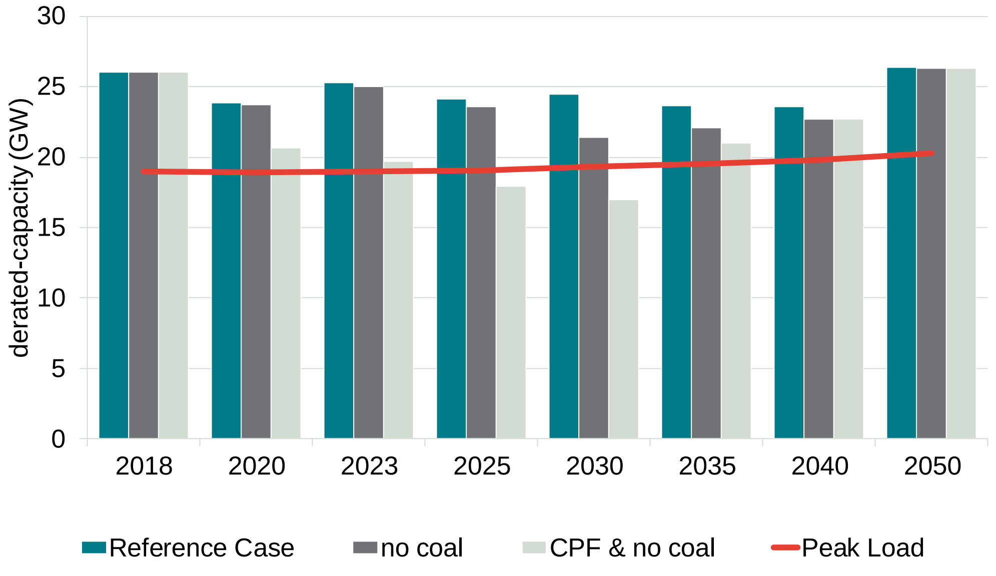
- Adequacy Reserve Margins (ARM) (reliable capacity minus peak load), and
- The utilisation of import capacity and the contribution of imports to residual load in critical (highest residual load) hours.

3.5.1 Capacity margins and generation adequacy (ARM)

The adequacy reserve margin informs about the level of reliable capacity compared to peak load. It is calculated as the difference of the de-rated available capacity (incl. a share of reliable import capacity) and peak load. A negative ARM indicates that more import capacity is used than assumed to be available in the critical periods (we assume availability of 60% of IC capacity in the calculations[16]).

- **Coal ban –** The use of coal in electricity supply could partially be substituted by a conversion from coal to biomass. This conversion becomes economically viable in the medium- to long-run in our model.[17] In addition, reactivation of gas plants becomes economically earlier than in the Reference Case, this also offsets some of the pressure on adequacy reserve margins resulting from the coal ban. Hence, the ARM remains positive for all years and ranges only slightly below those of the Reference Case (Figure 16).
- **CPF & coal ban –** Due to the impact on gas-fired plants as well as coal-plants, the effect of the CPF on operational capacity is more pronounced; the level of reliable capacities is reduced already in 2020 and lies below peak load (ARM becomes negative) in 2025 / 2030. The negative ARM does not indicate a risk for security of supply per se, but rather indicates that more import capacity is needed to serve peak demand than is assumed to be reliably available (in the calculations of the ARM, we assume an availability of foreign capacity of 60% of IC capacity).

Figure 16 Comparison of de-rated capacity and peak load per annum



Source: Frontier Economics

Note: De-rated capacity includes DSR and IC-capacity de-rated at 60%.

[16] We de-rate import capacity with 60%.

[17] It is assumed that the price of biomass is inelastic to the increase in demand from the Netherlands.

EXCURSUS – IMPACT OF ALTERNATIVE CO_2 ASSUMPTIONS

The impact of the policy measures described above on market outcomes is determined by the assumed fuel and CO_2 prices. While the underlying fundamental mechanics of the instruments remain the same, the order of magnitude of the effects can change.

The impact of the carbon price floor is crucially dependent on the difference between the ETS price and the carbon price floor in the Netherlands. A lower CPF (or higher market based ETS price) than assumed in our study would most likely:

- Reduce the impact of the CPF on security of supply and the economics of gas-fired plants, but
- at the same time lead to a lower reduction of domestic CO_2 emissions than observed with the CPF of the coalition agreement.

However, it can be expected that a moderately lower CPF than assumed in the study will only slightly improve the security of supply and the economic situation of gas-fired plants, and lead to a slightly lower reduction in CO_2 emissions within the Netherlands.

In a developing and changing market environment, it is not possible to calculate a CPF which leads in the medium and longer term to a specific CO_2-abatement or a specific security of supply level. This is because, for example, a variation in fuel prices or market based carbon prices has a direct impact on the results. Therefore, the results of our analyses have to be interpreted within the context of the set of assumptions regarding the future market framework.[18]

3.5.2 Impact on interconnector utilisation and import contribution to residual load

We analyse the impact of the policy measures on the import of electricity to the Netherlands based on:

- the utilisation of import capacity over the year and in critical hours; and
- the share of residual load in critical peak hours that is served by imports.

It is important to note that the hourly interconnector flows are an outcome of the economically optimised dispatch of power plants in the Netherlands and the neighbouring countries. Increasing imports indicate that electricity in other countries is less costly than in the Netherlands.

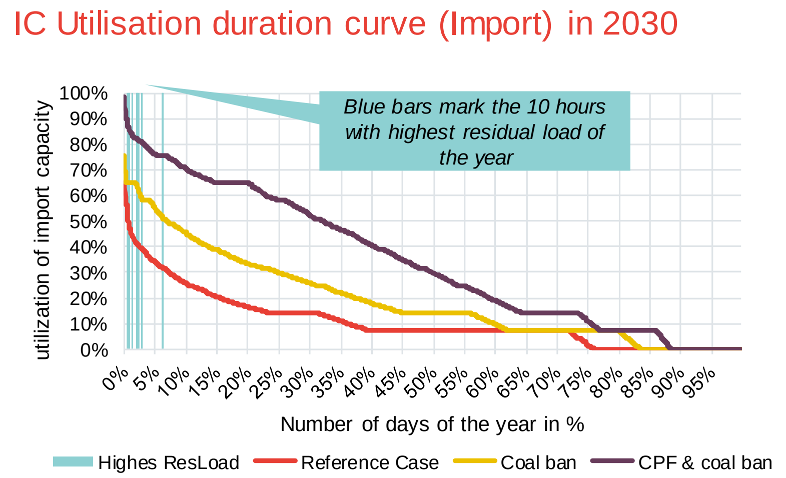
- **Coal ban –** Banning the use of coal changes the merit order of Dutch power supply, imports become to a certain extent cheaper than domestic production and increase in most hours of the year. This is illustrated by the upward shift of the yellow line compared to the red line (Reference Case) (**Figure 17,** first graph). In the 10 hours with highest residual load (second graph), the average

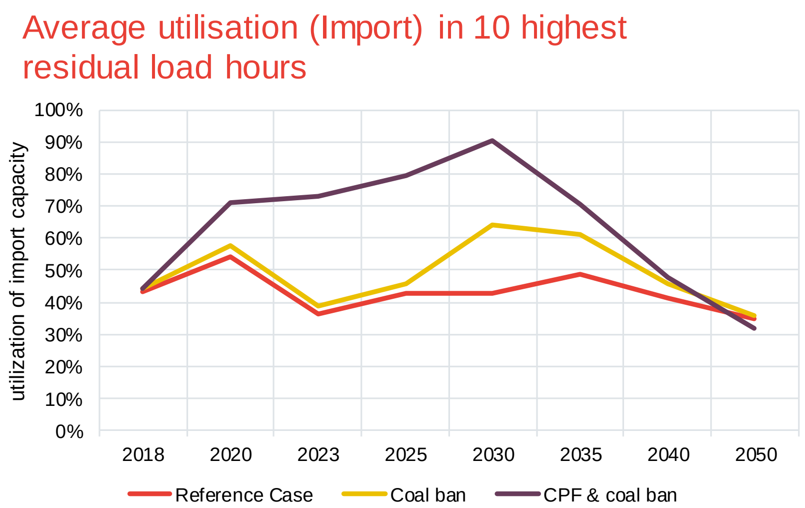
[18] See Annex A for an indicative comparison between assumptions underlying this study and the assumptions of the NEV 2017.

utilisation of import capacity increases from ca. 40% in the Reference Case to more than 60%.

- **CPF & coal ban** – The introduction of the CPF increases imports further. The utilisation of import capacity in 2030 increases on average from 11% to 34% and in more than 1/3 of the year, utilisation of import capacity is greater than 50%. Furthermore, during the 10 hours with highest residual load in 2030, more than 90% of the import capacity is utilised (**Figure 17**).

Figure 17 Utilisation of import capacity





Source: Frontier Economics

Note: Residual load = load – wind infeed – solar infeed – CHP must run.
The figure shows the utilization of the import capacity relative to the physically existing capacity.

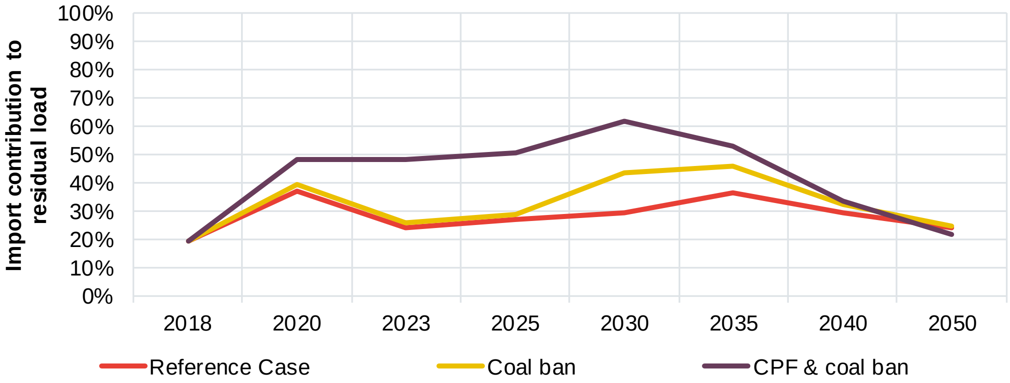
In addition to the utilisation of import capacity, we have analysed by how much imports contribute to domestic consumption when domestic demand is high but generation from intermittent renewable energy sources in the Netherlands is low (**Figure 18**).

- **Coal ban** – The sections above have shown that imports become more important when coal is banned from power supply. The share of domestic residual load that is served by imports increases from ca. 30% in the Reference Case to 40% (average of 10 peak residual load hours, 2030).

- **CPF & coal ban –** The additional introduction of the CPF increases the contribution of imports to domestic demand in peak hours from 2020 onwards and to more than 60% in 2030, the year in which the CPF reaches its highest level and the coal ban is completed.

it has to be noted that the results on power exchange presented in this section are outcome of an economic optimisation, *not* the result of physical scarcity or the requirement of filling a supply gap in the Netherlands. A higher share of imports or an increase in IC-utilisation result from cost differences between the exporting and the importing country. Therefore, high imports do not per se represent a threat to security of supply. However, the CPF increases generation costs within the Netherlands, which can lead to lower generation capacities in the Netherlands (as these are replaced by imports) and thereby to a lower adequacy reserve margin.

Figure 18 Import contribution to residual load (average, 10 peak residual load hours)



Source: Frontier Economics
Note: Residual load = load - wind infeed - solar infeed - CHP must run.

3.6 Policy measures: Mothballing and the economics of CCGTs

The economics of gas-fired power plants depend on the costs of the plant and the power prices achievable on the market. In the following we analyse:

- Possible running hours of an exemplary CCGT and contribution margins from day-ahead operation; and
- The mothballing and reactivation of gas-fired generation in the policy scenarios.

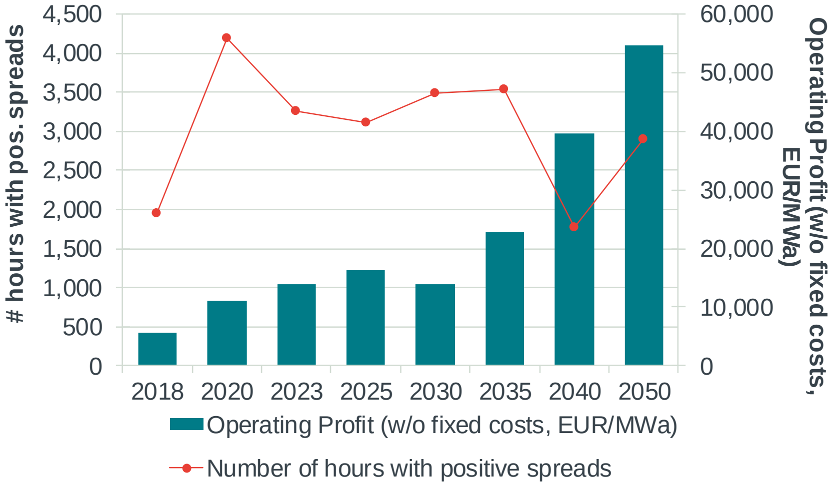
The model optimises mothballing and reactivation subject to the assumed cost savings and additional investment necessary to reactivate a plant after mothballing from a system cost perspective. The limitations listed in section 2.5.4 have to be taken into account when interpreting the results of the analysis.

3.6.1 Impact on profitability of CCGTs

The graphs below shows the contribution margin[19] of an exemplary CCGT and the number of hours, in which this plant realises a positive spread (price minus variable costs) when operating.[20]

- **Coal ban** – Banning coal from power supply has a moderately positive effect on gas-fired power generation, running hours and contribution margins would increase compared to the Reference Case. Especially in the medium-term until 2030, hours in which a modern gas-fired power plants achieves a positive spread on the market remain below 3,000-3,500 h/a and contribution margins (€/MW) are sufficiently high to cover fixed costs (**Figure 19**).

Figure 19 Running hours and operating profit – Coal ban



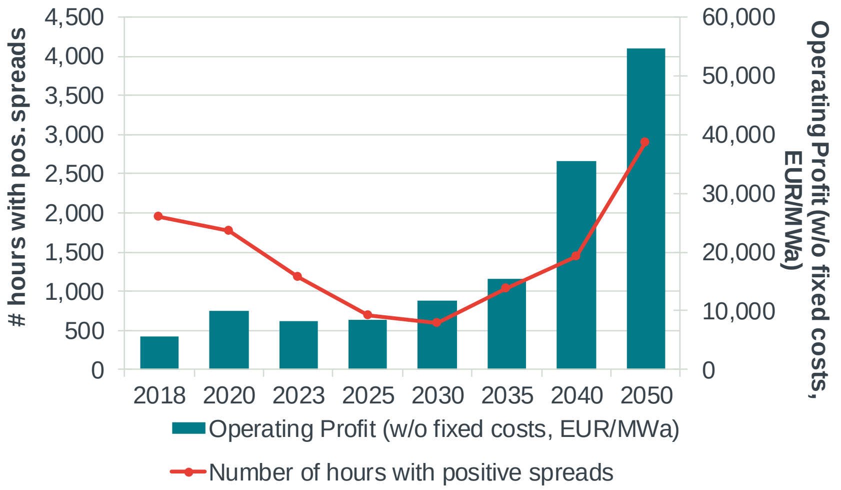
Source: Frontier Economics

- **CPF & coal ban** – The CPF increases the variable costs of the gas-fired as well as of the coal-fired generation assets considerably. The CPF therefore worsens the economic situation of gas-fired power plants significantly especially since foreign thermal power plants are not subject to the CPF: The number of hours in which a modern gas-fired power plant achieves a positive spread on the market and a contribution margin are substantially lower than in the Coal ban scenario (**Figure 20**).

[19] (Price - variable costs) * running hours.

[20] Not taking into account technical constraints like minimum load condition or ramping.

Figure 20 Running hours and operating profit – CPF & Coal ban



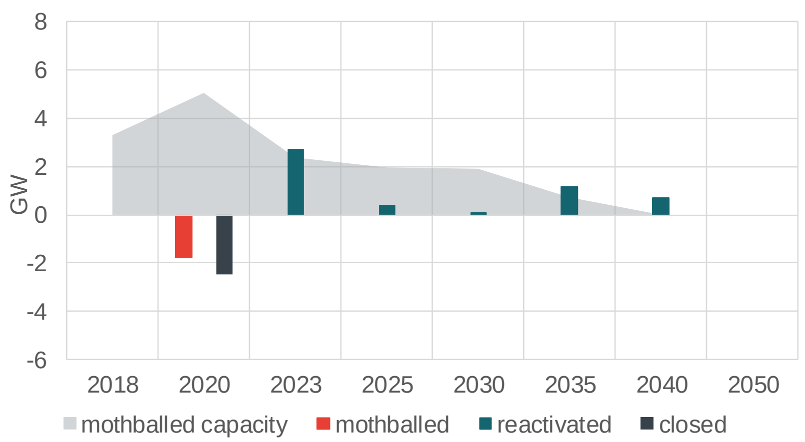
Source: Frontier Economics

3.6.2 Mothballing and reactivation

In the following, we describe the impact of the policy measures on the economics of CCGTs by analysing the mothballing and reactivation of plants in the policy scenarios.

- **Coal ban –** Due to the limited impact on the operation of gas-fired generation in the Netherlands, the reactivation of mothballed capacity until 2030 changes slightly: Plants are reactivated earlier (**Figure 21**). The level of mothballed capacity decreases from 2020 onwards as 2.5 GW gas capacity is closed and 3.1 GW gas capacity is reactivated between 2023 and 2030, so that ca. 2 GW mothballed capacity remains in 2030.

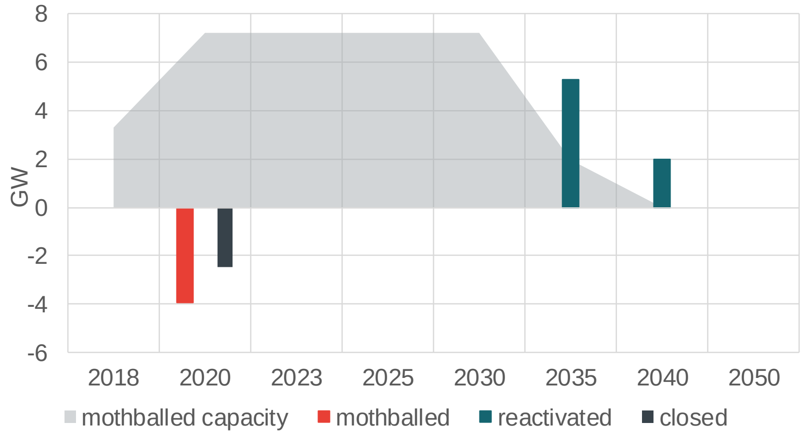
Figure 21 Mothballing and reactivation – Coal ban



Source: Frontier Economics

- **CPF & Coal ban –** The above mentioned negative impact on profitability of CCGTs translates into additional mothballing compared to the Reference Case. Reactivation of mothballed assets takes place in later years when the impact of the CPF diminishes. The level of mothballed capacities amounts to 7 GW from 2020 until 2035 (**Figure 22**).

Figure 22 Mothballing and reactivation – CPF & Coal ban



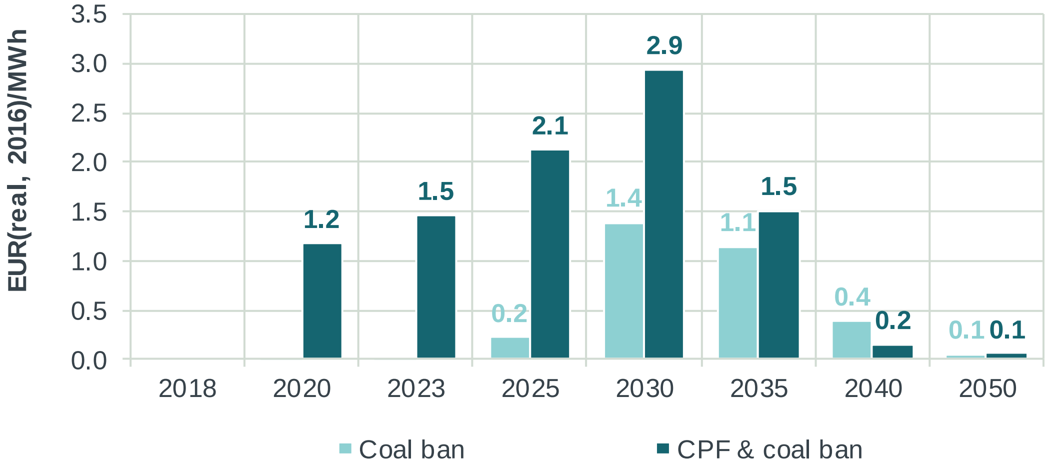
Source: Frontier Economics

3.7 Policy measures: Impact on power prices

In this section, we describe how Dutch wholesale power prices are affected by the introduction of the policy measures.

- **Coal ban –** Power prices increase by 1.4 €(real, 2016)/MWh or 3% compared to the Reference Case in 2030.
- **CPF & coal ban** – The CPF goes into effect earlier than the coal ban, consequently, prices increase already in 2020 (+1.2 €(real, 2016)/MWh). The highest difference in 2030 amounts to 2.9 €/MWh or 6% compared to the Reference Case.

Figure 23 Impact on power prices



Source: Frontier Economics

Note: All values expressed in real terms (base year 2016).

EXCURSUS – IMPACT OF A CPF ASSUMING ALTERNATIVE POLICIES IN FOREIGN COUNTRIES

The impact of measures taken within the Netherlands is influenced by the policies in neighbouring countries. Therefore, we analysed the impact of introducing a carbon floor price in the Netherlands, while Germany and France also implement new policies in the energy sector, which tighten the market further. We assume that Germany accelerates the phase-out of lignite and hard coal plants, while France accelerates the phase-out of nuclear power. In the following we compare:

- The alternative policy in CWE and a coal ban in NL; and
- The alternative policy in CWE and a coal ban & a carbon price floor in NL.

The main mechanisms of the alternative policy scenario are similar to those of the scenario of a CPF and coal ban assuming the reference policy framework in foreign countries. The effects of the analysed alternative foreign policies is moderate (for details see **Annex D**):

- **Power generation** in the Netherlands is lower assuming a CPF and coal ban; the reduction in domestic generation is replaced by generation abroad from lignite, coal and gas plants. The CPF reduces power generation in the Netherlands to a slightly higher extend than in the reference policy scenario: In the alternative policy scenario, the market is tighter even without the CPF and power generation in the Netherlands is higher. Therefore, there is more room for a decrease in power generation in the Netherlands caused by the introduction of a CPF in the alternative policy scenario.
- The introduction of the CPF in case of a CWE policy change and a coal ban leads to an additional reduction of **domestic emissions** of up to 14 mn. tCO_2 in 2025, which is slightly higher than the reduction in the reference policy scenario of 12 mn. tCO_2 in 2025. However, emissions in the model-region as a whole increase as Dutch generation is replaced by generation from plants with higher specific emissions outside the Netherlands.
- As a result of lower coal capacities and more mothballing of gas capacities from 2020 onwards, the **imports** increase significantly, and the **capacity margins** fall. The calculated **Adequacy Reserve Margin** becomes negative in the model periods 2025 and 2030 (slightly less negative than in the reference policy framework).
- The CPF lowers the profitability of **gas-fired power plants** as higher prices within the Netherlands are overcompensated by higher generation costs. Despite higher scarcity in the CWE region, the CPF leads to a long period of mothballing of gas capacities.
- The impact on **power prices** is smaller than in the reference policy framework and power prices increase by up to 1.8 €/MWh in 2025.

The impact of the policy measures taken within the Netherlands thus depend to some extent on the policies implemented in other CWE countries. However, the alternative policies assumed here only have a minor impact on the effects of a CPF. Yet this picture can change if other alternative policies in neighbouring countries are assumed.

ANNEX A COMPARISON TO NEV 2017 ASSUMPTIONS

The National Energy Outlook 2017[21] (NEV 2017), which is an important source for our analysis, is based on market data from 2016/17. Some of the assumptions of the NEV 2017 are therefore not in line with actual market data; in the meantime, projections for coal prices (e.g. IEA WEO 2017) have increased and gas-price forecasts have decreased for the long-run. At the same time, market reforms of the EU ETS have been implemented and CO2 prices have increased considerably.

In the following table, we summarise the potential impact of differences in assumptions between the NEV 2017 and our assumptions (Frontier 2018).

[21] ECN / PBL (2017), Nationale Energieverkenning.

Table 5 Impact of alternative fuel price, CO_2 price, demand and generation assumptions

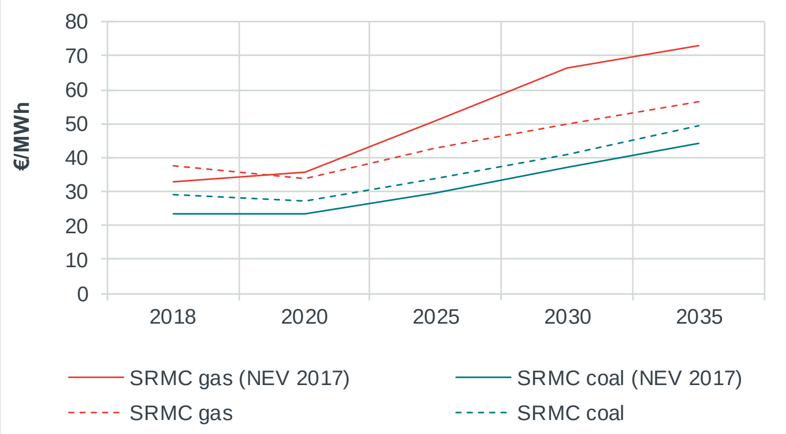
Input	Difference between NEV 2017 and Frontier 2018	Assessment of the impact on results
Gas and coal price	▪ Gas price has fallen since 2016/17, so that the gas price in Frontier 2018 is up to 10 €/MWh_th (in 2030) lower than in NEV 2017 ▪ Coal price has increased, so that the coal price of Frontier 2018 is slightly higher (+2 €/MWh_th in 2030)	▪ Power generation from gas is higher and generation from coal lower in Frontier 2018 ▪ The impact of the policy measures can be expected to be higher applying NEV 2017 assumptions since market prices constituted a less favourable environment for gas-fired plants
CO_2 price	▪ CO_2 prices and futures have increased in 2018, so that the price in Frontier 2018 is up to 8 €/MWh higher (in 2030)	▪ Higher CO_2 prices have a stronger impact on coal relative to gas, due to higher emission intensity of coal ▪ The impact of the policy measures can be expected to be lower applying Frontier 2018 assumptions
Demand	▪ NEV 2017 assumed a long-term decrease in demand, while Frontier 2018 assumes increase in demand (based on TenneT 2017)	▪ Higher demand in Frontier 2018 increases power prices, Dutch generation and thereby Dutch emissions ▪ The power market is tighter applying Frontier 2018 assumptions so the impact of the policy measures on security of supply is more significant, even though the economic situation of gas-fired plants may slightly improve
Generation from renewables	▪ Generation from wind and solar are very similar; Frontier 2018 assumes slightly faster growth in wind offshore generation until 2025, but later levels are similar again ▪ No difference in biomass generation in 2018-2023; thereafter biomass generation is a higher in Frontier 2018 as a result from modelling	▪ More generation from renewables in Frontier 2018 puts downward pressure on power prices and may lead to lower conventional (reliable) power capacities ▪ However, differences between NEV 2017 and Frontier 2018 are moderate, so the impact from generation from renewables is likely to be negligible

Source: Frontier Economics, ECN / PBL (2017), Nationale Energieverkenning

EXCURSUS – IMPACT OF ALTERNATIVE FUEL AND CO2 PRICES

The figure below compares the short-run marginal costs of an exemplary coal-fired plant with 41% efficiency and an exemplary gas-fired plant with 58% efficiency, based on the fuel and CO2 prices underlying this study and the NEV 2017. Overall, the situation for gas plants relative to coal-fired power plants has improved. Consequently, gas-fired power plants play a more important role in our analysis in the medium-term than in the NEV 2017.

Figure 24 Comparison of short-run marginal costs (NEV 2017)



Source: Frontier Economics

Note: All values expressed in real terms (base year 2016).

ANNEX B REFERENCE CASE ASSUMPTIONS

In this annexe, we provide detailed information on the assumptions of the Reference Case.

As described in **section 2.3**, the Reference Case is based on the current and intended policy framework in the Netherlands and in North-Western Europe. It represents a scenario which is built upon a combination of current market expectations, e.g. regarding fuel prices and CO2 prices, and political targets, for example for the development of renewable generation capacities. However, we only take those policy decisions into account which are defined in an operational manner and are officially decided.

B.1.1 Fuel and CO_2 price assumptions

The fuel and CO_2 prices affect the variable costs of generation and therefore the power prices and profitability of generation units. The development of the fuel and CO_2 prices as well as the underlying assumptions are outlined in **Section 2.3.1**. **Table 6** below provides an overview of the underlying values for the fuel, CO_2 prices and the Carbon Floor Price in the Netherlands, which apply to all scenarios.

Table 6 Fuel and CO_2 prices

Parameter	Unit	2018	2020	2023	2028	2030	2035	2040	2050
Natural Gas	€ (real, 2016) /MWh_th*	20.7	18.2	20.1	22.7	25.5	27.9	29.9	33.9
Hard coal (CIF ARA)	€ (real, 2016) /MWh_th*	10.0	8.9	9.3	10.2	11.2	11.8	12.3	13.1
Biomass	€ (real, 2016) /MWh_th*	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9
CO2 (EU ETS)	€ (real, 2016) / tCO2	12.8	12.3	14.2	17.2	24.8	32.4	40.0	79.0
Carbon Price Floor	€ (real, 2016) / tCO2	-	18.0	25.5	30.5	43.0	43.0	43.0	-

Source: Natural Gas and Hard coal are based on IEA WEO 2017 New Policies and extrapolated by Frontier Economics. Biomass prices are based on current future prices in real terms. CO_2 prices are based on IEA WEO 2017 New Policies and the EU Reference Scenario 2016. The Carbon Price Floor is based on Coalition Agreement Rutte III

*Note: * Lower heating value.*

ANNEX C IMPACT OF CPF AS AN ISOLATED MEASURE

C.1 Context and assumptions

In addition to the scenarios presented in **section 3** of this report, we have analysed the introduction of the CPF as an isolated measure, without the introduction of a coal ban. In this scenario a CPF as shown in **Figure 11** is introduced and the development of conventional thermal power plants in the Netherlands is an outcome of the model optimisation. Nevertheless, known investment/divestment decisions as well as mandatory phase out schemes (nuclear or coal) are taken into account.

C.2 Results of the analysis

Table 7 Key indicators for CPF scenario (compared to Reference Case)

	Carbon Price Floor
Domestic CO_2 emission reduction (NL)	▪ 2020: - 10 mn. tCO_2 ▪ 2025: - 15 mn. tCO_2 ▪ 2030: - 17 mn. tCO_2
Net-reduction of CO_2 emissions (EU*)	▪ 2020: + 1 mn. tCO_2 ▪ 2025: 0 ▪ 2030: + 1 mn. tCO_2
Impact on import/exports of power	▪ + 32 TWh imports in 2030
Impact on ARM** and import contribution***	▪ ARM negative in 2025 / 2030 ▪ Utilisation of interconnector in peak hours doubles compared to Reference Case[22] ▪ Import contribution in peak hours grows from 29% to 52% in 2030
Impact on capacity margins and CCGTs****	▪ CPF lowers the profitability of gas plants ▪ Prolonged mothballing of gas capacities
Impact on power prices in 2023/2030	▪ 2023: + 1.5 € ▪ 2025: + 2.2 € ▪ 2030: + 2 €

Source: Frontier Economics

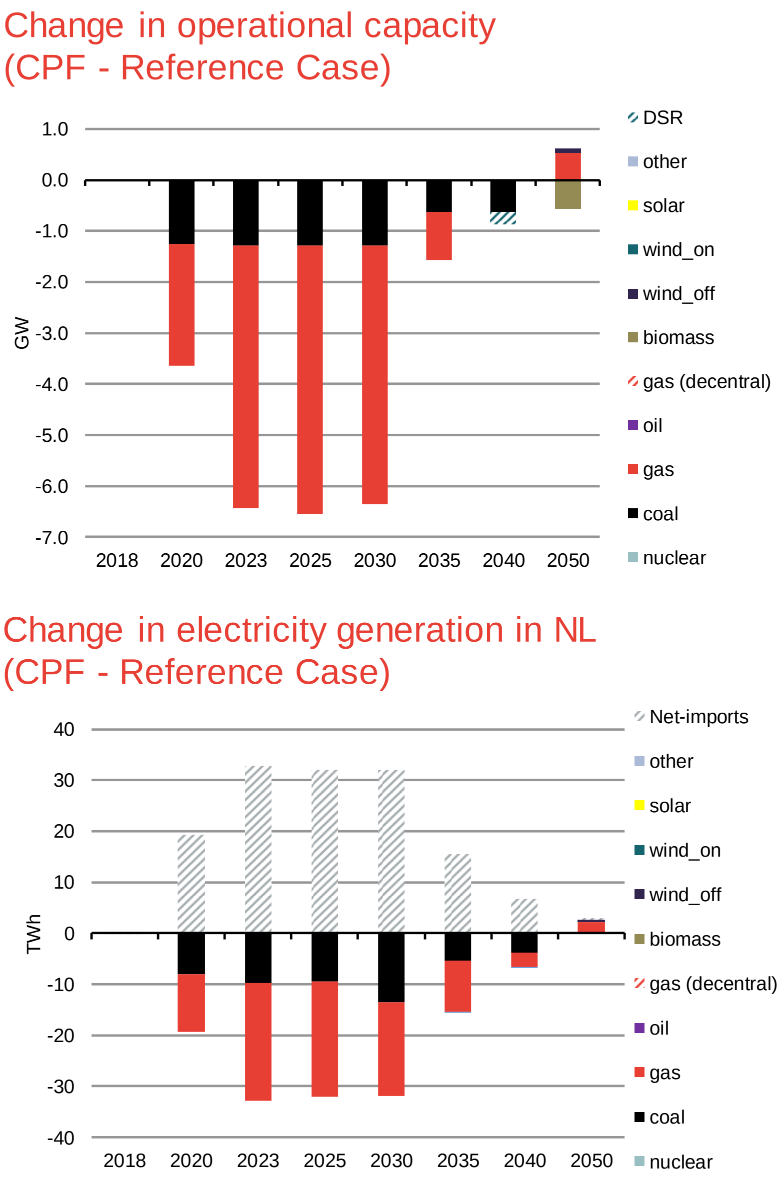
Note: All values shown are differences to the Reference Case.
** Modelled: NL, DE, BE, FR, DK, CZ, PL, GB, IT;*
*** ARM = adequacy reserve margin (ARM = de-rated capacity + de-rated IC capacity - peak load);*
**** Contribution of imports to meet peak residual load (average over 10 highest residual load hours);*
***** CCGT = Combined-Cycle Gas Turbine.*

- **Impact on electricity supply** – The carbon price floor increases thermal generation costs in the Netherlands compared to the Reference Case. Therefore, less electricity is generated nationally and is replaced by power generation abroad from lignite, coal and gas.

[22] Average import capacity utilisation in ten peak residual load hours.

- There is no additional conversion of coal to biomass plants before 2050. As some coal capacities are closed earlier with a CPF (2020 and 2023), there are lower coal capacities available for biomass conversion in 2050 compared to the Reference Case.

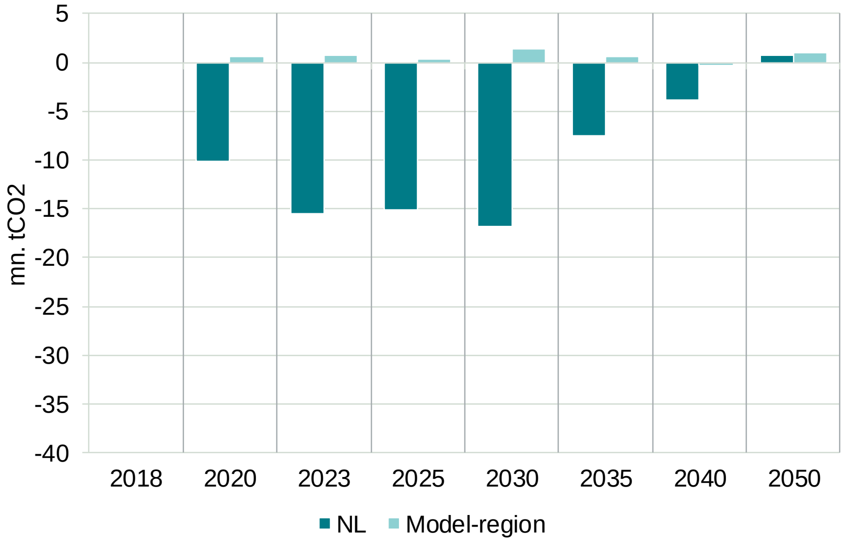
Figure 25 CPF - Impact on operation capacity and electricity supply in the Netherlands



Source: Frontier Economics

- **Impact on power-related emissions of CO_2** – The CPF lowers Dutch emissions in 2030 by 17 mn. tCO_2 compared to the Reference Case. The emission in the total model-region increase compared to the Reference Case as emission intense power generation in neighbouring countries replaces gas fired power generation in the Netherlands.

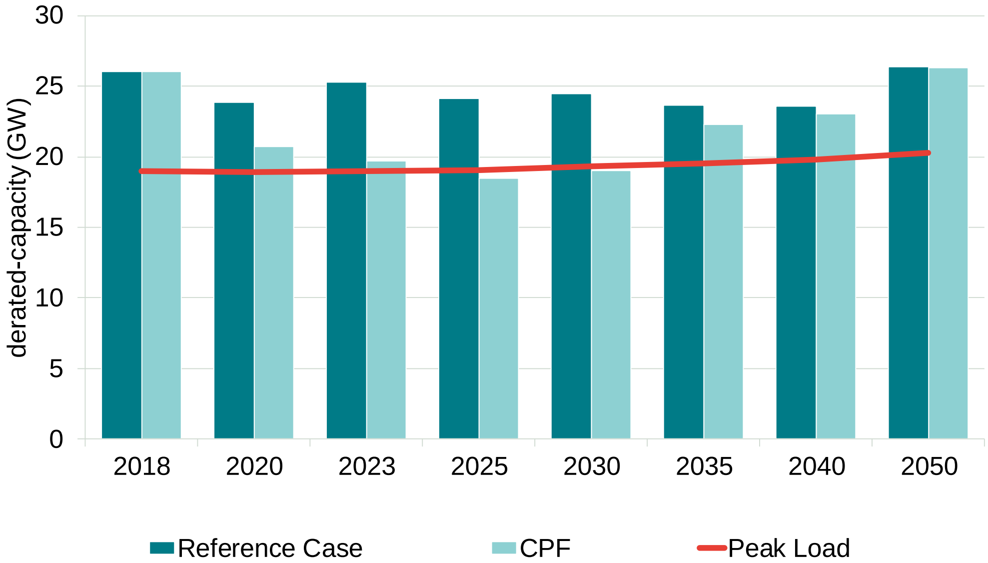
Figure 26 CPF – Domestic and net-effect on emissions



Source: Frontier Economics

- **Impact on ARM –** As a result of lower coal capacities and more mothballing of gas capacities from 2020 onwards, the import dependency increases significantly and the capacity margins fall compared to the Reference Case.

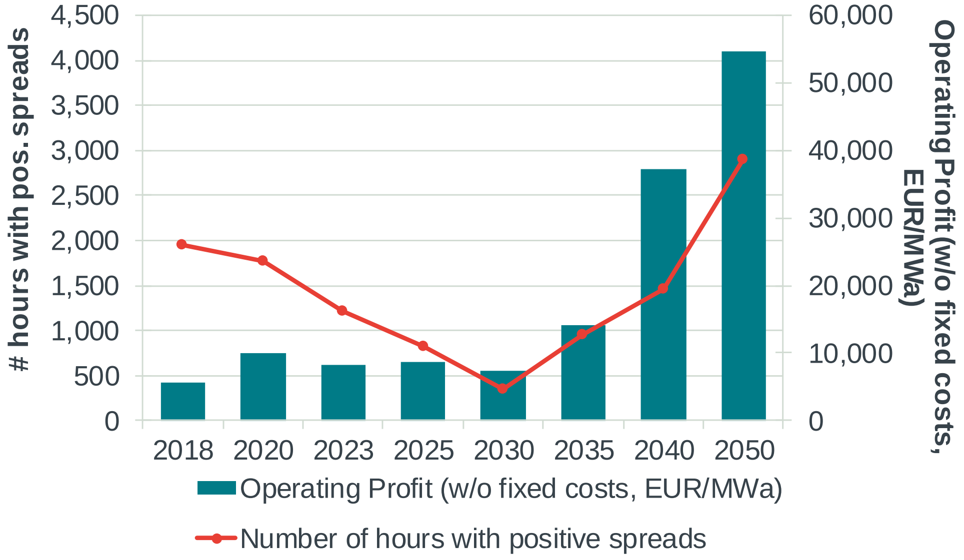
Figure 27 CPF – De-rated capacity vs. peak load



Source: Frontier Economics

- **Economics of CCGTs –** The CPF lowers profitability of gas-plants as higher prices within the Netherlands are overcompensated by higher generation costs.

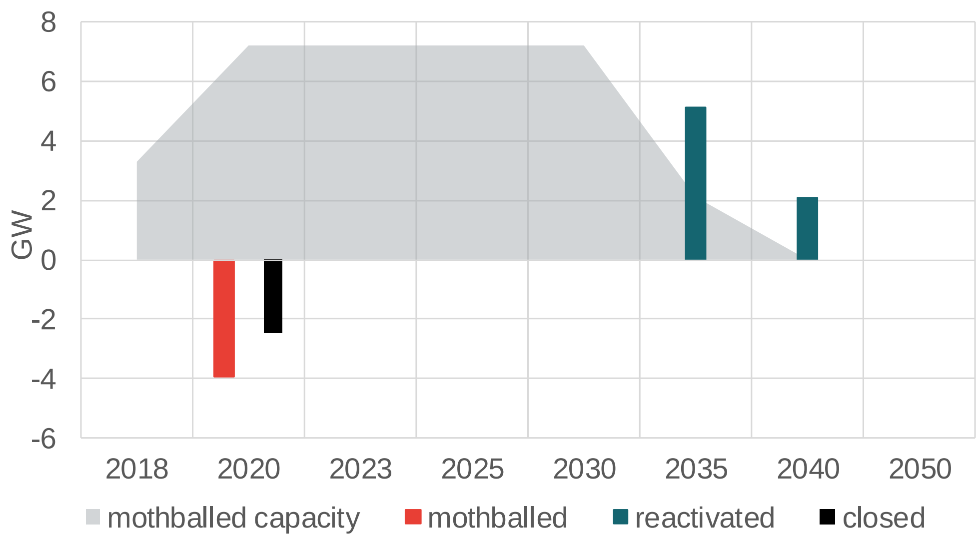
Figure 28 CPF – Running hours and operating profit



Source: Frontier Economics

- **Impact on Mothballing –** The CPF leads to more mothballing in the short-term and an extended period of mothballing before plants are reactivated.

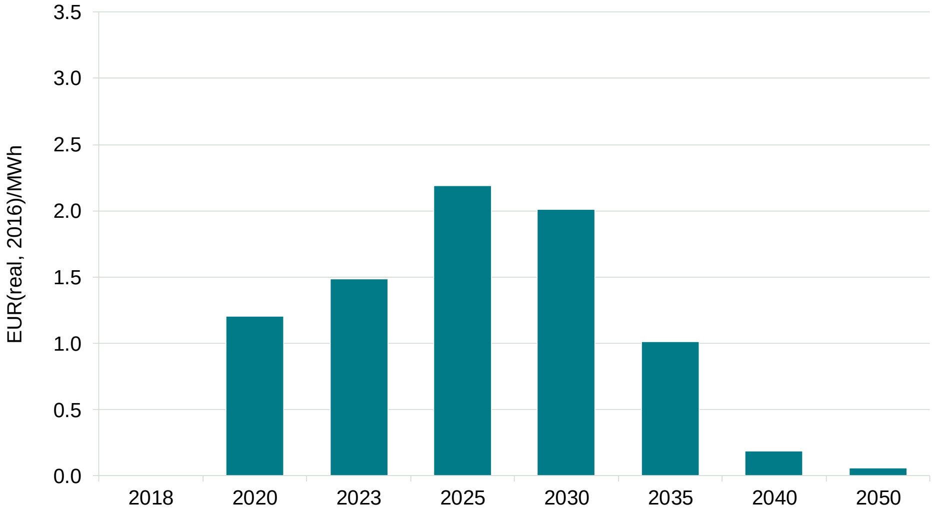
Figure 29 CPF – Mothballing and reactivation



Source: Frontier Economics

- **Impact on power prices –** The CPF has a moderate impact on power prices in the Netherlands. Prices increase by up to 2.2 €/MWh in 2025. The upwards price pressure caused by the CPF is attenuated through higher imports from neighbouring countries.

Figure 30 CPF – Impact on power prices



Source: Frontier Economics

ANNEX D SENSITIVITY: IMPACT OF FOREIGN POLICY ON MEASURES IN NL

D.1 Context and assumptions

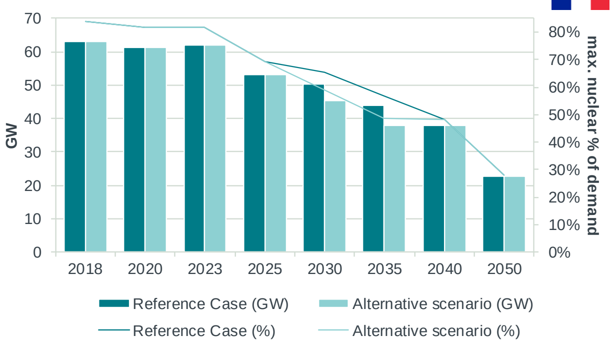
The Reference Case describes the most likely policy framework in CWE from today's perspective. This includes actual decisions about a nuclear phase out in Belgium until 2025 and the current state of climate policies in Germany, which does not include a mandated coal phase out.

In a second set of scenarios, we analyse how changing policies in neighbouring countries and an increase in scarcity may influence the effects of a carbon price floor in the Netherlands. We modify the assumptions on the policy framework in Germany and France in the following way:

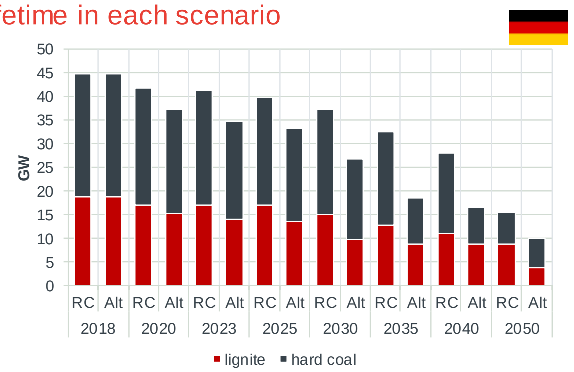
- **Germany: Accelerated phase out of lignite and hard coal electricity supply** – In the Reference Case, we assume that German lignite and coal plants are allowed to operate until the end of an extended lifetime of 55 (hard coal) and 60 (lignite) years. For this, the plants have to undergo an extended maintenance procedure (retrofitting) at the end of their regular technical lifetime of 40-45 years. In the alternative scenario, we assume that retrofitting lignite and coal plants is not possible. This difference leads to a potential gap of 14 GW in 2035 of generating capacity in Germany, assuming that all plants undergo retrofitting in the Reference Case.
- **France: Accelerated phase-out of nuclear power** – The French government decided to postpone the partial nuclear phase-out until 2025, due to concerns regarding the security of supply. In the Reference Case, we assume that the envisaged reduction from 75% to 50% nuclear share of total generation will be completed until 2040. In the alternative scenario, we assume that the reduction to ca. 50% nuclear is completed until 2035, with an accelerated phase out after 2028.

Figure 31 Alternative policy scenario

FR nuclear capacity and max. nuclear share of demand (%)



DE coal and lignite capacity based on maximum lifetime in each scenario



Source: Frontier Economics

Note: DE: The model closes capacities before the end of their technical lifetime, if there is overcapacity. Actual differences between the scenarios are much lower (ca. 8 GW).

Based on the policy framework described above we analyse the following scenarios:

a. **Scenario "Alternative Policy in CWE / NL coal ban":** Policy change in the neighbouring countries and ban of coal in the Netherlands;

b. **Scenario "Alternative Policy in CWE / NL coal ban & CPF":** Policy change in the neighbouring countries and ban of coal in the Netherlands & carbon price floor.

D.2 Results of the analysis

The table below summarises the analysis of how changes in foreign policies change the impact of measures within the Netherlands. It provides a comparison of the two scenarios described above: both scenarios assume a policy change in CWE and a coal ban in the Netherlands. The difference between the two scenarios is the introduction of a carbon price floor in the Netherlands.

Table 8 Key indicators for alternative policy scenario including a CPF within the Netherlands (compared to Alternative Policy in CWE / NL coal ban)

	Alternative Policy in CWE / NL coal ban & CPF
Domestic CO_2 emission reduction (NL)	▪ 2020: - 12 mn. tCO_2 ▪ 2025: - 14 mn. tCO_2 ▪ 2030: - 10 mn. tCO_2
Net-reduction of CO_2 emissions (EU*)	▪ 2020: + 3 mn. tCO_2 ▪ 2025: + 4 mn. tCO_2 ▪ 2030: + 4 mn. tCO_2
Impact on import/exports of power	▪ + 34 TWh net-imports in 2023 ▪ + 29 TWh net-imports in 2030
Impact on ARM** and import contribution***	▪ ARM negatively affected ▪ Reliance on imports in 2030 increases from 40% to 60%
Impact on capacity margins and CCGTs****	▪ CPF lowers the profitability of gas plants ▪ Prolonged mothballing of gas capacities
Impact on power prices in 2023/2030	▪ 2023: + 1.6 € ▪ 2025: + 1.8 € ▪ 2030: + 1.2 €

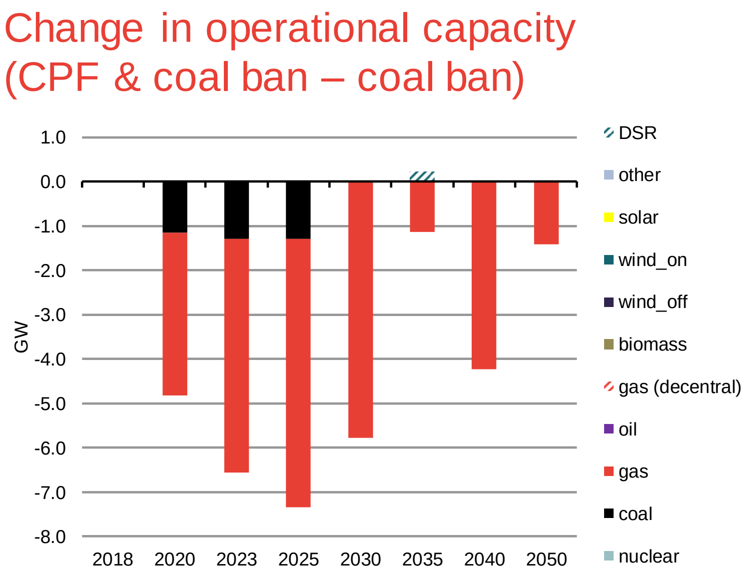
Source: Frontier Economics

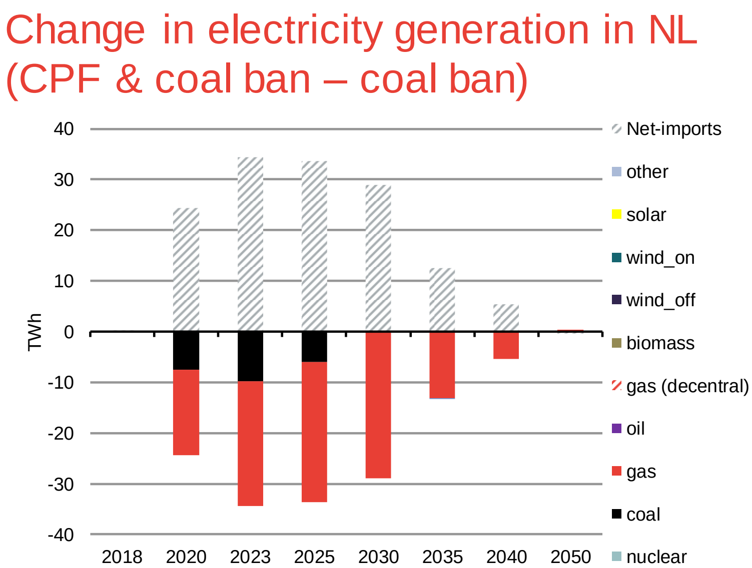
Note: All values shown are differences to the Reference Case.
** Modelled: NL, DE, BE, FR, DK, CZ, PL, GB, IT;*
*** ARM = adequacy reserve margin (ARM = de-rated capacity + de-rated IC capacity - peak load);*
**** contribution of imports to meet peak residual load (average over 10 highest residual load hours);*
***** CCGT = Combined-Cycle Gas Turbine.*

- **Impact on electricity supply –** In case of a CWE policy change and a ban of coal, the CPF increases thermal generation costs in the Netherlands. Less electricity is generated nationally and power generation in the Netherlands is replaced by power generation abroad from lignite, coal and gas.

- The introduction of the CPF leads to more mothballing and later reactivation of gas capacities.
- In addition, 1.3 GW of coal and 1.8 GW of gas capacities are closed in the model years 2020 and 2023.

Figure 32 CPF - Impact on operation capacity and electricity supply in the Netherlands (under the assumption of coal ban and alternative policies in CWE)

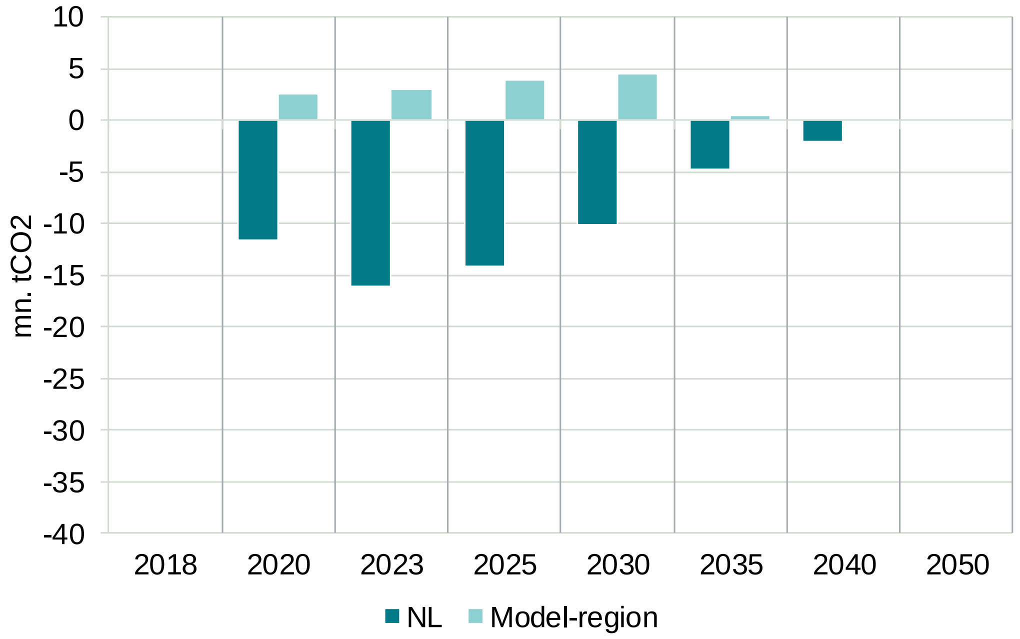




Source: Frontier Economics

- **Impact on power-related emission of CO_2** – The introduction of the CPF in case of a CWE policy change and a coal ban leads to an additional reduction of domestic emissions by up to 14 mn. tCO_2 in 2025. However, the net-change of emissions in the model-region is positive as Dutch generation is replaced by generation from plants with a higher emission intensity outside the Netherlands.

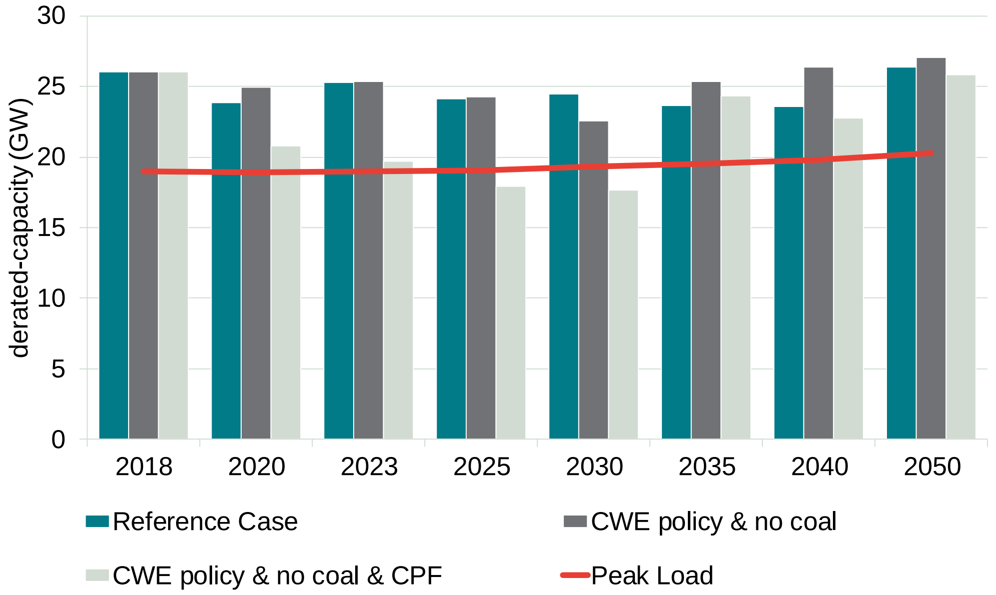
Figure 33 Impact on emissions in NL and in model-region (CPF & coal ban – coal ban, alternative policies CWE)



Source: Frontier Economics

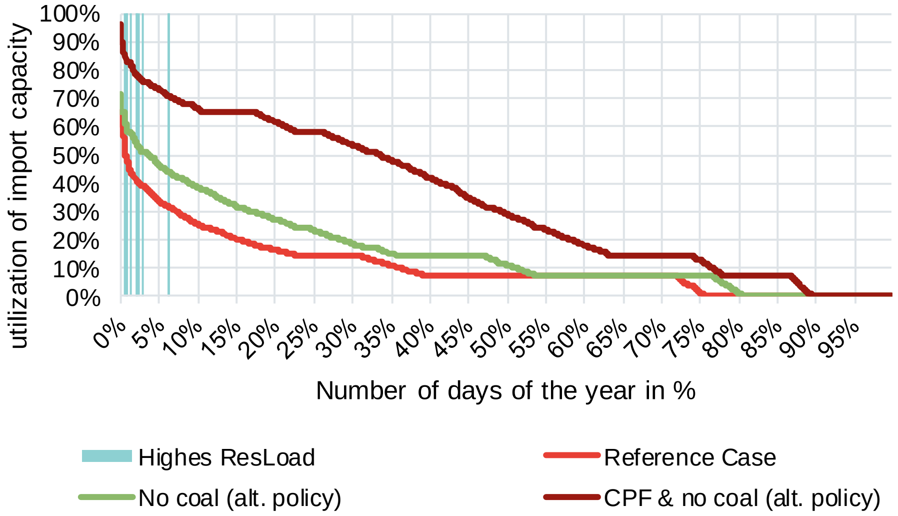
- **Impact on ARM and import contribution –** As a result of lower coal capacities and more mothballing of gas capacities from 2020 onwards, the import dependency increases significantly, and the capacity margins fall compared to the CWE policy scenario with a coal ban. As a result, there is a negative ARM, even though scarcity in CWE is higher than in the Reference Case. Without CPF, capacity levels increase compared to the Reference Case, as incentives to provide reliable capacity increase.

Figure 34 Impact on de-rated capacity – CPF & coal ban / Coal ban (alternative policies)



Source: Frontier Economics

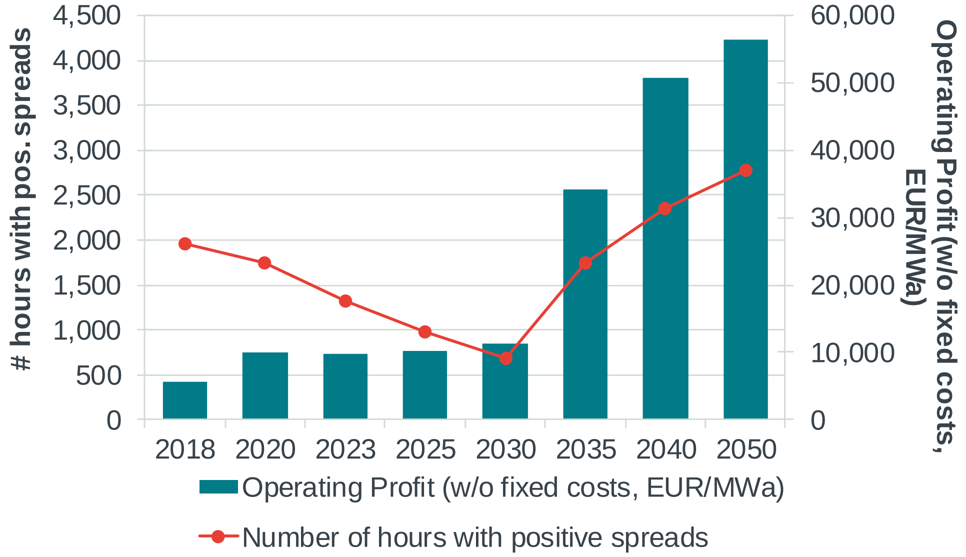
Figure 35 Utilisation of import capacity (alternative policy in CWE)



Source: Frontier Economics

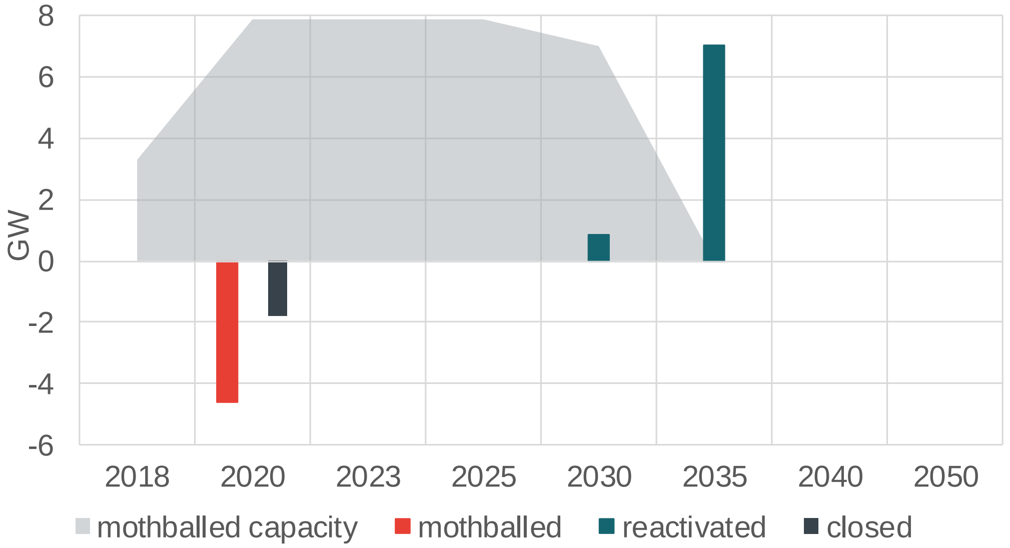
- **Mothballing and the economics of CCGTs** – The CPF lowers the profitability of gas-fired power plants as higher prices within the Netherlands are overcompensated by higher generation costs. Despite higher scarcity in the CWE region, the CPF leads to a long period of mothballing, and gas plants are only reactivated in 2030 and 2035.

Figure 36 Running hours and operating profit – CPF & Coal ban (alternative policies)



Source: Frontier Economics

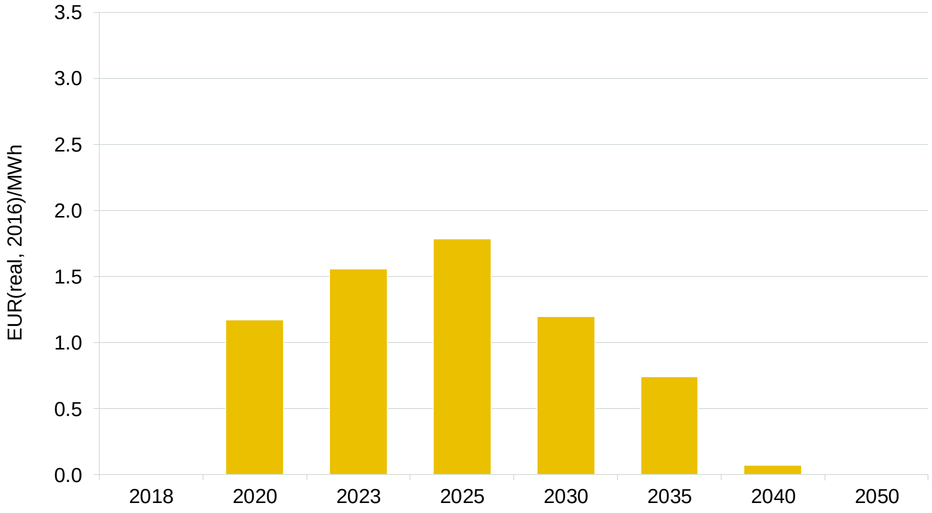
Figure 37 Mothballing and reactivation – CPF & Coal ban (alternative policies)



Source: Frontier Economics

- **Impact on power prices** – The impact on power prices is smaller than in the reference policy framework. Power prices increase by up to 1.8 €/MWh in 2025.

Figure 38 Impact on power prices (CPF & coal ban vs. coal-ban, alternative policies)

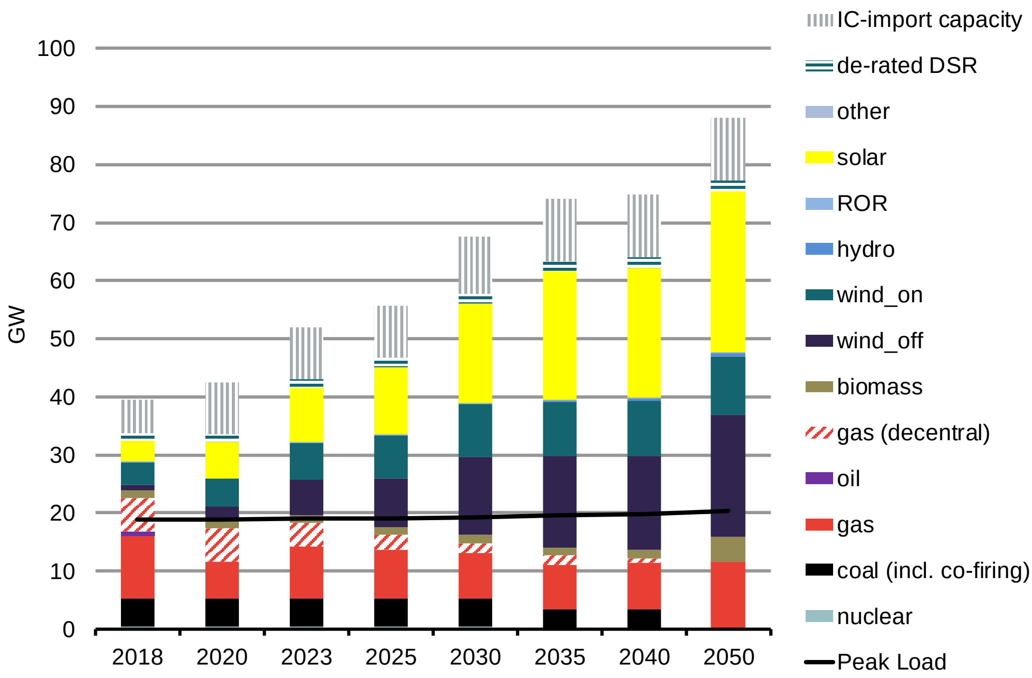


Source: Frontier Economics

ANNEX E DETAILED SCENARIO RESULTS

E.1 A – Reference Case

Figure 39 Operational capacities in NL



Source: Frontier Economics

Table 9 Reference Case: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	4.7	4.7	4.7	4.7	3.4	3.4	0.0
Gas	10.9	6.4	9.0	8.4	7.9	7.6	8.1	11.6
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.0
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	1.3	1.4	1.4	1.4	4.3
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

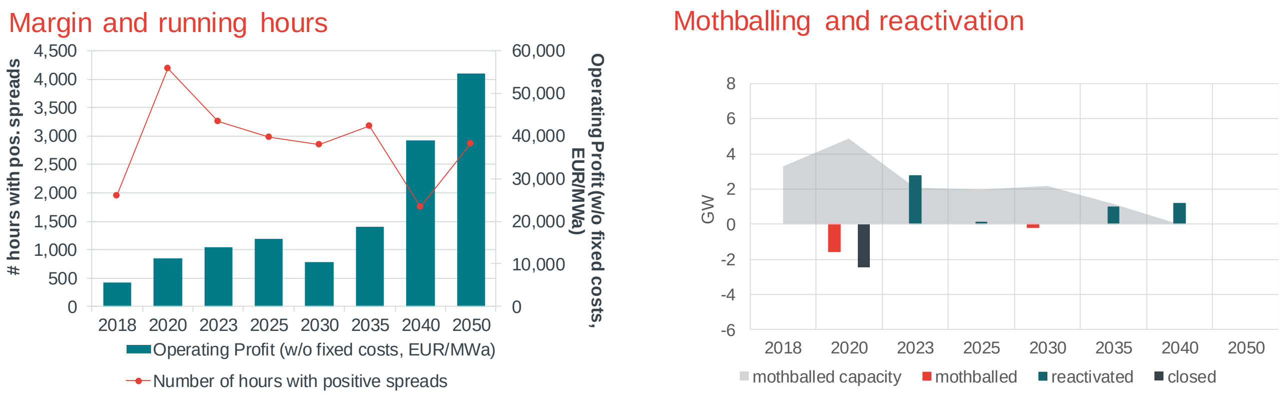
Source: Frontier Economics

Table 10 Reference Case: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	23.5	23.2	22.6	26.4	19.2	18.5	0.0
Gas	32.0	27.9	37.8	35.3	28.8	27.9	26.6	22.0
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	78.6
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.4	15.6	15.5	8.2	8.2	8.3	25.7
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.0

Source: Frontier Economics

Figure 40 Operating profit and mothballing – Reference Case



Source: Frontier Economics

E.2 B – Carbon Price Floor

Table 11 Carbon Price Floor: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	3.4	3.4	3.4	3.4	2.7	2.7	0.0
Gas	10.9	4.1	3.9	3.1	2.8	6.7	8.1	12.1
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.1
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	1.3	1.4	1.4	1.4	3.8
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

Source: Frontier Economics

Table 12 Carbon Price Floor: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	15.5	13.3	13.1	12.8	13.7	14.7	0.0
Gas	32.0	16.6	14.8	12.7	10.5	17.9	23.8	24.2
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	78.9
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.6	15.7	15.6	8.2	8.2	8.3	22.7
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.0

Source: Frontier Economics

E.3 C – Coal ban

Table 13 Coal ban: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	4.7	4.7	3.4	0.0	0.0	0.0	0.0
Gas	10.9	6.2	8.8	8.4	8.2	8.1	8.1	12.2
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.2
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	2.0	2.3	2.5	3.7	3.7
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

Source: Frontier Economics

Table 14 Coal ban: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	23.5	23.2	17.8	0.0	0.0	0.0	0.0
Gas	32.0	27.1	36.7	36.0	33.5	31.4	27.3	24.6
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	79.0
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.4	15.6	16.9	13.1	12.8	19.9	22.3
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.0

Source: Frontier Economics

E.4 D – Carbon Price Floor & Coal Ban

Table 15 Carbon Price Floor & Coal Ban: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	3.4	3.4	2.1	0.0	0.0	0.0	0.0
Gas	10.9	4.1	3.9	3.1	2.8	6.8	8.1	12.1
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.2
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	2.0	2.5	2.5	3.7	3.7
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

Source: Frontier Economics

Table 16 Carbon Price Floor & Coal Ban: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	15.3	13.3	11.7	0.0	0.0	0.0	0.0
Gas	32.0	16.5	14.8	12.7	10.9	18.7	24.1	24.6
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	79.0
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.6	15.7	16.9	13.2	13.7	19.9	22.3
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.0

Source: Frontier Economics

E.5 E – CWE-Policy: Coal ban

Table 17 CWE-Policy - Coal ban: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	4.7	4.7	3.4	0.0	0.0	0.0	0.0
Gas	10.9	7.7	9.1	9.2	9.5	10.6	12.3	12.9
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.1
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	2.0	2.4	3.7	3.8	3.8
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

Source: Frontier Economics

Table 18 CWE-Policy - Coal ban: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	23.6	23.4	18.0	0.0	0.0	0.0	0.0
Gas	31.8	33.4	39.7	40.6	43.0	40.1	32.0	29.5
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	78.8
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.4	15.6	16.9	13.2	17.6	20.7	22.7
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.1

Source: Frontier Economics

E.6 F – CWE-Policy: Carbon Price Floor & Coal Ban

Table 19 CWE-Policy - Carbon Price Floor & Coal Ban: Operational capacities in the Netherlands (GW)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0
Coal	4.7	3.5	3.4	2.1	0.0	0.0	0.0	0.0
Gas	10.9	4.1	3.9	3.1	3.7	9.5	8.1	11.5
Gas (decentral)	5.8	5.8	4.0	2.6	1.8	1.8	0.8	0.0
Wind-offshore	1.0	2.5	6.1	8.5	13.5	15.8	16.3	21.1
Wind-onshore	3.9	4.8	6.5	7.4	9.0	9.3	9.6	10.1
Solar PV	3.6	6.2	9.4	11.6	17.0	22.0	22.3	27.8
Biomass	1.3	1.3	1.3	2.0	2.4	3.7	3.8	3.8
Other	0.0	0.0	0.1	0.1	0.3	0.4	0.5	0.6

Source: Frontier Economics

Table 20 CWE-Policy - Carbon Price Floor & Coal Ban: Net electricity supply in the Netherlands (TWh)

	2018	2020	2023	2025	2030	2035	2040	2050
Nuclear	3.9	3.9	3.9	3.9	3.6	0.0	0.0	0.0
Coal	26.0	16.1	13.5	12.0	0.0	0.0	0.0	0.0
Gas	31.8	16.6	15.2	12.9	14.0	27.0	26.6	29.9
Gas (decentral)	20.1	20.1	13.0	8.6	6.2	6.2	3.1	0.0
Wind-offshore	3.7	9.3	22.8	31.7	50.4	58.8	60.7	78.8
Wind-onshore	9.2	11.1	15.2	17.1	21.0	21.8	22.3	23.5
Solar PV	3.0	5.1	7.7	9.5	13.9	18.0	18.2	22.8
Biomass	13.3	15.6	15.7	17.0	13.3	18.2	20.8	22.6
Other	0.1	0.1	0.3	0.3	0.7	0.8	0.9	1.1

Source: Frontier Economics

ANNEX F LIST OF REFERENCES

- International Energy Agency (2017): World Energy Outlook.
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