CARBON PRICE FLOOR FOR ELECTRICITY GENERATION AND INDUSTRY

A study for the Dutch Ministry of Finance
The customer tax, customs, and international tax directorate

05 JUNE 2023

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EXECUTIVE SUMMARY

In 2022 the Netherlands introduced a carbon price floor (CPF) as a complement to the European Union Emissions Trading System (EU ETS). The CPF is intended to provide additional economical certainty for investments in sustainable technologies. The definition of the CPF was made at a time when the EU ETS price was significantly lower than today. Currently, an update of the CPF level is considered.

We, Frontier Economics and CE Delft, were commissioned by the Ministry of Finance to analyse potential CPF levels with regards to their impact on the electricity, discussing potential benefits and downsides.[1] The impact of a potential CPF in the industry sector will be analysed in a sensibility analysis. The focus of the analyses is on the period until 2030, including an outlook until 2040.

To determine the potential effects of an updated CPF on the electricity and industry sectors, we undertake three analytical steps:

- First, we develop a probabilistic analysis of future carbon prices: We employ a stochastic mean reversion model to estimate future carbon price developments. The model is calibrated using historical carbon price movements for the price volatility and the trend towards the long-term mean. Additionally, we use a reference price for future EU ETS development based on the KEV 2022 main scenario. The results serve as an input for the following steps (Frontier Economics).
- Second, we analyse the impact of different CPF options on the electricity sector by comparing market outcomes with and without a CPF. We use a stochastic version of Frontier's electricity market model which is an integrated investment and dispatch model for the European power sector (Frontier Economics).
- Third, we conduct a sensibility analysis on the impact of different CPFs on the industry sector using the energy version of the WorldScan model which covers emissions of all Greenhouse gases. This version has a sectoral coverage that includes the agricultural sector, the fossil fuel markets, oil, gas, and coal, as well as the electricity market, including all major renewable technologies and carbon Capture and Storage (CCS) (CE Delft).

The development of the Dutch electricity market can be characterised by a number of important trends. Next to a large increase in renewable generation capacities it is likely that additional storage capacity will be built to accommodate the intermittent electricity production. Coal plants will be phased out by 2030 so that renewable generation is in the medium to long term complemented by largely gas and storage capacities. However, the profitability of gas fired power plants remains weak even without a CPF. The changes in the power plant park will lead to a strong decline in domestic emissions on the path towards climate neutrality. The modelling results indicate that these changes in the power

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[1] In line with the predecessor study (Frontier Economics (2018): “Research on the effects of the minimum CO_2 price”) and as instructed, our assumptions are based on the report ‘Klimaat en Energieverkenning’ as published by the Netherlands Environmental Assessment Agency (PBL), including for fossil fuel and carbon prices. Assumptions are complemented by additional sources were necessary and do not necessarily reflect Frontier’s best guess.

plant park could lead to a stable reserve margin until 2030, which could decline in the period until 2040. The profits for renewable plants are likely going to decrease throughout the modelled period, with increasing renewable capacities and falling electricity prices.

CPFs constructed as a lower bound for EU ETS prices

The principal benefit of a CPF as constructed in this study is to provide a lower bound for carbon emission prices provided by the EU ETS: If EU ETS prices develop as expected (based on current assumptions regarding the future economic environment and current market indicators), the CPF should not be binding. Thus, it should not impose additional emissions costs on domestic market participants.

If the EU ETS price falls below a certain threshold, the CPF results in additional emission costs, so that a pre-defined minimum carbon emission price is maintained. This could increase the investment security for low-carbon technologies.

Our analysis shows that, contrary to the time of the first introduction of a CPF in the Netherlands, renewable technologies in the electricity sector, in particular utility scale solar PV and onshore as well as offshore wind, are significantly more competitive towards fossil fuel-based technologies than they used to be. Already at, compared to today, low carbon price levels, renewable energies appear profitable. This reduces the need for additional support in form of a CPF close to the current EU ETS price level.

CPFs likely to have no impact if EU ETS prices remain above the floor price

A CPF could impact the electricity and industry sectors even if it does not become binding. Actors in both sectors take into account potential future price and profitability developments when making decisions regarding for example new investments or the retirement of generation capacity. However, our results from the electricity market analysis show no significant impact of the analysed CPF scenarios for the case that EU ETS prices develop according to the reference scenario and CPFs do not become binding.

Also for the industry sector we believe that a non-binding CPF will have an insignificant impact on investments. This is because investments will anyway bias towards higher long-term Emission Trading Scheme (ETS) prices that align with the near-zero emission targets set for 2040. Moreover, subsidies in place up to 2030, as part of the Dutch Industrial Policy Package (see also KEV 2022), to finance industrial emission reductions further support this trend.

CPFs could have an impact on the power sector if EU ETS prices develop substantially lower than expected

In case of a substantially lower than expected EU ETS price, a CPF results in higher generation cost for fossil fuel plants. However, our analysis shows that this only partially supports the profitability of renewables. The impact of a binding domestic CPF is significantly diluted by the strong integration of the Netherlands into the European market. Higher domestic generation costs of fossil fuel plants translate only to a small extent into higher wholesale electricity prices - and therefore into only a slightly improved economic outlook for renewables. The effect on carbon emissions is likely to be very small on the European level as domestic fossil generation is replaced to a large extent by carbon intensive plants in other European countries.

On the other hand, a national CPF comes along with potential negative side effects. The magnitude of the effects depends heavily on the chosen CPF: While a lower CPF (e.g. at 40% below the expected EU ETS price) has a rather small impact on the Dutch electricity sector and the Dutch industry, an ambitious CPF (e.g. 10% below the expected EU ETS price) can have a considerable impact on the electricity sector and the industry if the EU ETS price decreases significantly. These include (compared with a situation without a CPF) reduced domestic production of electricity and goods from the industry, reduced electricity generation capacity and therefore potential adverse effect on security of supply, and carbon leakage.

The following table summarises the main results of the report:

Table 1 Summary of potential impacts of a Carbon price floor

Policy dimension	Key findings
Investment security for sustainable technologies	■ Investments in (utility scale) solar PV, onshore and offshore wind appear to be already profitable and competitive with fossil fuel-based electricity generation for the analysed fuel prices and a wide range of possible EU ETS price scenarios. ■ The overall benefits of a CPF for investment security in renewables are limited as expected profits (across potential carbon emission price paths) of new investments are only marginally higher with a CPF compared to the case without a CPF.
International competitiveness	■ A CPF could worsen the competitiveness of domestic fossil fuel plants in case it becomes binding. However, our results indicate that the presence of a CPF does not result in capacity retirements if it does not become binding. ■ A binding CPF could result in declining fossil fuel plant capacity and domestic generation being replaced by imports. ■ A binding CPF would result in a decline of investment, production, jobs in the industrial sector, and GDP. However, these are largely offset by additional investments in lower-carbon production processes and have no impact on total labour supply as labour shifts in favour of non-industrial carbon-extensive sectors.
Sustainability	■ A non-binding CPF is unlikely to have an effect on carbon emissions.

Policy dimension	Key findings
	■ A binding CPF could reduce emissions in the Netherlands, but the net effect in Europe is likely to be small. ■ If a CPF becomes binding, leakage of industrial emissions will be for 2030 around 20%. Leakage occurs to countries that have no binding emission ceilings or relatively low carbon intensity targets.
Affordability	■ A non-binding CPF is unlikely to impact electricity prices. ■ The impact of higher domestic carbon prices in case of a binding CPF only partially translates into higher electricity prices.
Security of supply	■ A non-binding CPF does not seem to impact security of supply. ■ A binding CPF could result in lower security of supply, particularly in the short to medium term.

Source: Frontier Economics

The following table summarises the key figures of our electricity market analysis for the impacts of the different CPFs in the scenario with a low EU ETS price:

Table 2 Summary: Impact of CPFs on the power system in the low EU ETS price case

Indicator	Year	CPF -10%	CPF -25%	CPF -40%
Generation capacities	**2027**	-3.6 GW	-2.3 GW	0.0 GW
	2030	-1.4 GW	-1.2 GW	-0.6 GW
Domestic dispatch	**2027**	-22.0 TWh	-12.1 TWh	0.0 TWh
	2030	-4.2 TWh	-3.2 TWh	-1.5 TWh
Emissions in NL (modelled region)	**2027**	-46% (1.5%)	-23% (-0.3%)	0% (0.0%)
	2030	-12% (-0.1%)	-10% (-0.1%)	-5% (0.0%)
Electricity price	**2027**	+3.2%	+1.7%	0.0%
	2030	+0.4%	+0.4%	+0.1%
Security of supply - Adequacy Reserve Margin (ARM)	**2027**	ARM turns negative	ARM declines to close to zero	ARM remains almost unchanged
	2030	ARM declines slightly but remains positive	ARM declines slightly but remains positive	ARM remains almost unchanged
CCGT profits	**2027**	moderate negative impact	low negative impact	minimal impact
	2030	high negative impact	moderate negative impact	minimal impact

Source: Frontier Economics

Note: Generation capacities indicate total installed and active capacities. The ARM (Adequacy Reserve Margin) is calculated as the difference between a), the de-rated generation and import capacity and b), the peak demand.

The following table summarises the key figures of our industry sector analysis for the impacts of the different CPFs in the scenario with a low EU ETS price:

Table 3 Summary: Impact of CPFs on industry in the low EU ETS price case in 2030

Indicator	CPF -10%	CPF -25%	CPF -40%	Notes
Carbon leakage rate*	20%	20%	12%	Emission increases in developing countries not only restricted to highly carbon-intensive industrial goods, but also indirect leakage of demand for fossil-based electricity and gasoline-based transport services.
Carbon emission reduction**	28% (0.4%)	17% (0.2%)	2% (0.0%)	Additional carbon cost from CPF -10%, CPF -25%, CPF -40% is equal to 33, 19, and 2 EUR/tCO_2eq, respectively. Abatement curve (marginal cost of emissions reductions vs abatement) is strongly convex.
GDP loss	0.2%	0.1%	0.0%	GDP losses from costly emission reductions, production losses are partly compensated by gains in service sectors and a terms-of-trade gain.
Production loss	1.3%	0.8%	0.0%	Energy bill is only part of production processes, and costs from carbon pricing can be significantly avoided by emission reduction (abatement curve is convex as they include CCS as low-merit order options).
Employment loss (‘000)	1.9	1.1	0.0	At the macro-level, there is zero impact on labour supply – non-labour supply policies have never proven to have an impact on labour supply.
Investment loss	8%	4%	0%	Investment by industry drops more than production since production drops especially in highly capital-intensive sectors (chemicals, rubber and plastics, metal). Investment increases in non-industry sectors, and at the macro-level the increase is more than the losses in industry.

Source: *CE Delft*

Note: ** Carbon leakage rate is the % emission increase outside NL divided by emission reduction inside NL.*

*** Emission reduction is reported for the Netherlands and the EU (between brackets).*

1 Introduction and objective

On the 4th of April 2022, the ‘Wet minimum CO_2-prijs voor elektriciteitsopwekking’ (carbon price floor for electricity generation act) has come into force. The aim of this legislation is to provide an incentive for environmentally sustainable investments by giving certainty about the minimum carbon price (carbon price floor, CPF). The CPF was set at 14.90 EUR/tCO_2eq in 2022 and 31.90 EUR/tCO_2eq in 2030. From 2030 onward the CPF was set to continue at a price of 31.90 EUR/tCO_2eq. This price path was chosen in a period when the EU ETS price was between 10 and 30 EUR/tCO_2eq. Since then the EU ETS price has risen to between 90 and 100 EUR/tCO_2eq in early 2023.

The strong increase of the EU ETS price has decreased the relevance of the current CPF, so that an update of the floor price is considered. In Dutch parliament the evaluation term of the measure was shortened from five to three years through an amendment on the legislative proposal, and it was agreed that there will be a supplemental earlier evaluation of the price path. The updated price path should be put into force through the yearly legislative tax proposal (Belastingplan 2024).

In addition to the CPF for electricity generation, the coalition agreement contains the introduction of a CPF for industrial companies. The CPF for industry should be same as the one for electricity generation.

As a result of these political developments, Frontier and CE Delft were commissioned by the Ministry of Finance to analyse the potential impact of a revised CPF on the electricity sector and the impact of the introduction of a similar CPF in the industrial sector. The objective of the study is to estimate the effects of different CPF options in the period between 2024 and 2030, with an outlook on the period until 2040. While the principal analyses focus on the impact on the electricity sector, a sensibility analysis for the impact on the industrial sector is also conducted.

The effects of different potential CPFs will be studied with regards to the following policy dimensions:

- For the electricity sector:
    - Investment security;
    - International competitiveness;
    - Sustainability;
    - Affordability;
    - Security of supply;
- For the industrial sector:
    - International competitiveness and carbon leakage;
    - Investments;
    - Employment effects;
    - Macro-economic indicators.

1.1 Structure of the report

The report is structured as follows:

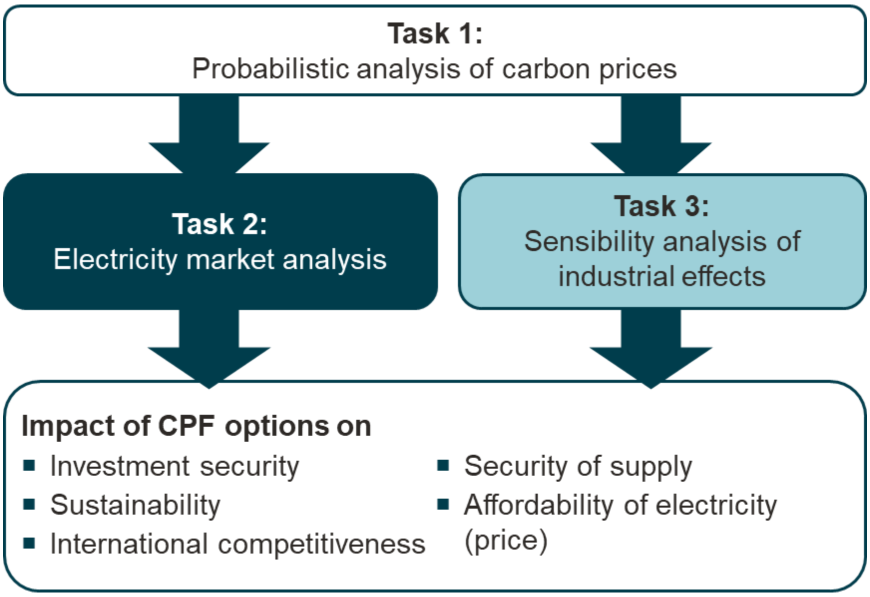
- Description of the approach and definition of the analysed scenarios (section 2);
- Probabilistic analysis of future carbon prices (section 3)
- Analysis of the impact of CPFs on the electricity sector (section 4);
- Sensibility analysis of the impact of CPFs on the industrial sector (section 5); and
- Annexes with detailed assumptions and supplementary results.

2 Approach and methodology

To determine the potential effects of an updated CPF on the electricity and industry sectors, we undertake the analyses in three tasks (see Figure 1):

- First, we perform a probability analysis of potential developments of future carbon prices in the EU ETS system (**Task 1**). This analysis is based on statistical analyses and a Monte Carlo simulation.
- The results from Task 1 feed into **Task 2**, in which we analyse the impact of different CPF options on the electricity sector by comparing market outcomes without a CPF with the outcomes if the different CPF options apply. We use Frontier's stochastic electricity market model for the analysis which takes probabilistic carbon price scenarios into account.
- In **Task 3**, we analyse the impact of different CPFs on the industry sector. Based on the results from Task 1 and 2, which will be used as inputs for the industry model, we calculate deterministic scenarios for the impact of the various CPFs on the industry.

Figure 1 Overview of the analytical approach



Source: Frontier Economics

We evaluate the modelling results from Tasks 2 and 3 with respect to a set of key indicators. These indicators will then be used to draw conclusions with regards to a set of policy dimensions, including investment security, sustainability, international competitiveness, security of supply and affordability.

2.1 Carbon price floor scenarios

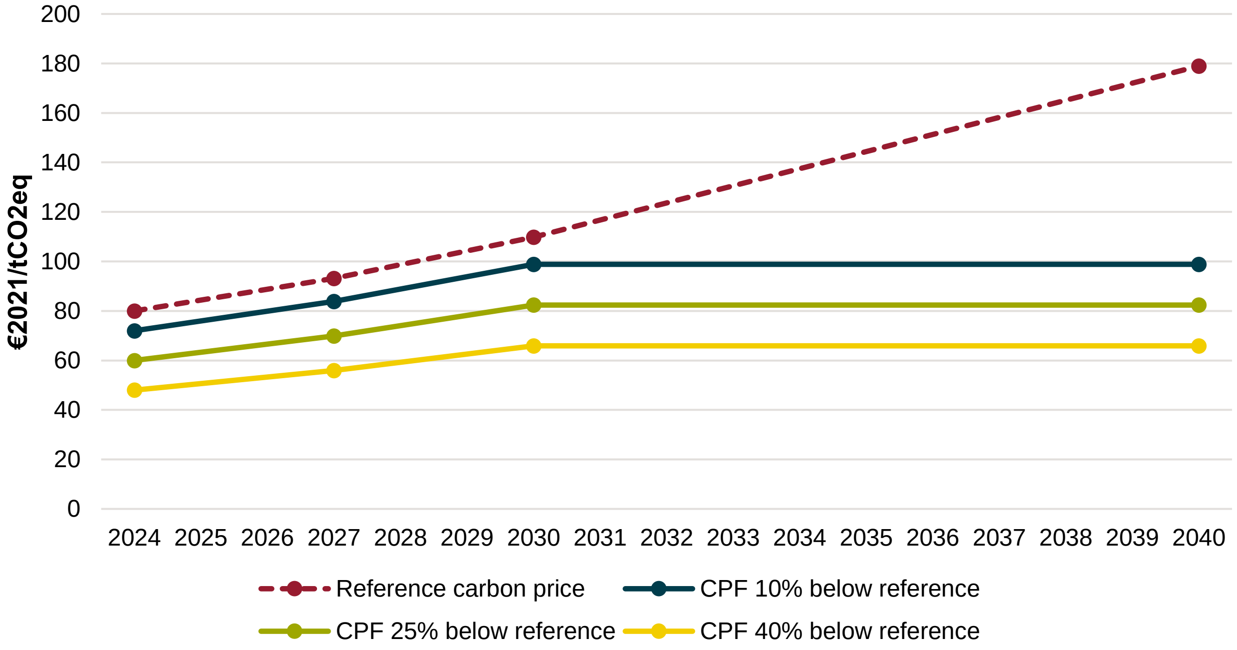
This study analyses the impact of different options for future CPF paths. The CPF path options are defined relative to an “expected EU ETS price.” The expected EU ETS price is based on the price of traded EU ETS futures (EU CO_2 allowances) and the ETS price outlook provided in the report ‘Klimaat en Energieverkenning’ (2022) published by the Netherlands Environmental Assessment Agency (PBL).

The following CPF paths are analysed (see Figure 2):

- CPF at 10% below the expected price;
- CPF at 25% below the expected price; and
- CPF at 40% below the expected price.

All CPF paths are assumed to remain constant from 2030 to 2040, which is in line with current legislation.[2]

Figure 2 Analysed CPF options and “expected EU ETS price”



Source: Frontier Economics based on Ministry of Finance (2022), PBL (2022)

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[2] Within this study all prices are shown in real 2021 terms (which is also the case for the KEV 2022 which was used as a basis for fuel prices, carbon prices and other exogenous inputs). Within the text we use EUR/tCO_2eq for simplicity to describe carbon prices in EUR2021/tCO_2eq. The depiction in real 2021 terms applies to modelling assumptions (e.g. EU ETS prices and CPF options) and to modelling outputs (e.g. electricity market price). The model outcomes are independent from the future development of inflation. As all prices are equally affected by inflation, the relative costs remain equal and thus also the assessment regarding the policy indicators (e.g. security of supply) remains unchanged. To obtain values in real terms, the prices shown in the report have to be adjusted by applying the respective inflation between the base and target year.

Note: Depicted prices for 2024 could be below current (nominal) EU ETS prices since they are shown in real 2021 terms and are based on market prices from January 2023, when assumptions were fixed.

The analysed options for the CPF paths remain below the expected EU ETS price. This is in line with the political objective of the measures to stimulate environmentally friendly investments by providing a lower bound for greenhouse gas (GHG) emission costs and therefore investment security for “green investments.” The instrument is not intended to induce additional carbon costs in case the EU ETS price develops as currently expected.

2.2 Modelling of uncertainty in future EU ETS prices

EU ETS allowances (EUA) are traded on wholesale markets, their price reflects the balance between demand and supply. Both the demand and the supply side of EUA are subject to uncertainties that can impact the future price of allowances. For example, a reduction in newly auctioned certificates will increase the price, lower than expected economic activity as predicted will dampen it. Actors in the electricity market take these uncertainties into account when making investment decisions in new generation capacity, batteries, or flexibility measures. In order to do so, investors have to form an opinion on possible future carbon price levels and their likelihood.

EUA futures deliver reliable market expectations of carbon prices in the short and medium term. We will therefore rely on EUA Futures to estimate carbon prices in 2023 and 2024 in our analysis.[3] To form an expectation about future prices and their likelihood from the year 2025 onwards, we employ a stochastic mean reversion model to estimate future carbon price developments – a method routinely used to model commodity and carbon prices.[4]

The objective of this task is thus to describe the uncertainty around the carbon price development by a stochastic model, which can be used to assess the potential impacts of different CPFs. The specific output from Task 1 are carbon price probability distributions for each year under consideration, which are used to inform the following analyses for the electricity (Task 1) and industry sector (Task 2).

2.2.1 Input for the analysis

The employed model simulates potential future carbon prices based on a historical price development and a forward-looking element. The historical data is used to deduct uncertainties in the carbon price development, while the forward-looking element includes expectations regarding the development of carbon prices. Specifically, our model estimates future carbon prices and their likelihood based on:

- **Outlook on basic carbon price development:** To capture expected changes in the price level of the EU ETS price, we take the price development as estimated in KEV 2022[5] main scenario

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[3] Futures retrieved on 30.01.2023.

[4] For a similar approach see e.g. Graham, Reedman, Lo & Zhu (2009): “A scenario-based integrated approach for modelling carbon price risk”, Dannenberg & Ehrenfeld (2011): “A Model for the Valuation of carbon Price Risk”, Chang, Wang & Peng (2013): “Mean reversion of stochastic convenience yields for carbon emissions allowances: Empirical evidence from the EU ETS”

[5] PBL (2022). Unless otherwise noted we also refer to the KEV main scenario.

into account. This price path describes a general trajectory for carbon prices, without considering short-term uncertainty (volatility).

- **Historical market data on price volatility and reversion speed:** We analyse historical carbon price movements with regards to price volatility[6] and the time frame to revert to the observed long-term mean ("reversion speed"). These parameters are derived from historical data and are then used to model future volatility. The use of historical data thereby implicitly assumes that the structural price formation in terms of volatility and reversion speed remains similar in the future.[7]

The inputs from historical market data (volatility, reversion speed) depend on the chosen time period (i.e., the years incorporated in the analysis) and temporal granularity of price signals ("time interval," for example daily, weekly or monthly averages). The parameters are chosen to be suitable to the purpose of this exercise and the goals of the subsequent electricity market and industry analyses. We therefore use:

- **Monthly (average) prices** as a time interval, given the long-term nature of the modelling; and
- **Prices from 2018 to 2022**, as this time period includes a broad range of price levels that incorporate the impacts of severe external shocks (e.g., the Covid-19 pandemic and the Russian invasion of Ukraine) as well as a period of steady price increase (in 2021).

We conducted a range of sensitivity analyses by testing different time periods and different time intervals to identify a robust set of assumptions. The results for the sensitivity analyses can be found in Annex A .

2.2.2 Employed model for the analysis

To derive a large number of potential price paths for the EU ETS and consequently a distribution of potential future carbon prices (carbon price probability distribution), we use two statistical techniques:

- We employ a standard **discrete time model** to describe the uncertain future development of carbon prices. The time model includes a mean reverting element in order to reflect that specific expectations with regards to the carbon price development exist. Simply speaking, the development of carbon prices within the model depends on the current price, the expected price, and an element of uncertainty. The inputs described above (volatility, reversion speed) are used to inform the parameters of this model.
- In order to form a reliable expectation on the likelihood of a certain future price path to be realised, a multitude of runs of the discrete time model is required. We therefore conduct **Monte Carlo**

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[6] Price volatility in terms of the relative standard deviation of carbon prices in time.

[7] We decrease the reversion speed from 2030 onwards to reflect fundamental uncertainties in long-term forecasts and represent the possibilities of alternative carbon price levels emerging over extended periods of time. See Annex A for more details.

simulations to estimate a large number of potential future price paths (10,000). This allows us to understand the impact of uncertainty and risk through repeated random sampling.[8]

The resulting price paths are then used to derive probability distributions for future prices. We describe the results of this analysis in section 3. Further details on the methodology, including model specifications and sensitivity analyses, can be found in Annex A .

2.3 Electricity market modelling

In this assignment, we use a stochastic version of Frontier's electricity market model already applied in previous studies undertaken on behalf of the Ministry of Economic Affairs and Climate Policy.[9] The model is an integrated investment and dispatch model for the European power sector. The main characteristics of the model can be summarised as follows:[10]

- **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. 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.

- **Temporal resolution** – For this study the model was configured to optimise eight representative days[11] in each year with an hourly resolution. The time horizon for our analysis is from 2024 until 2040. We have modelled the photo years 2024, 2027, 2030 and 2040.

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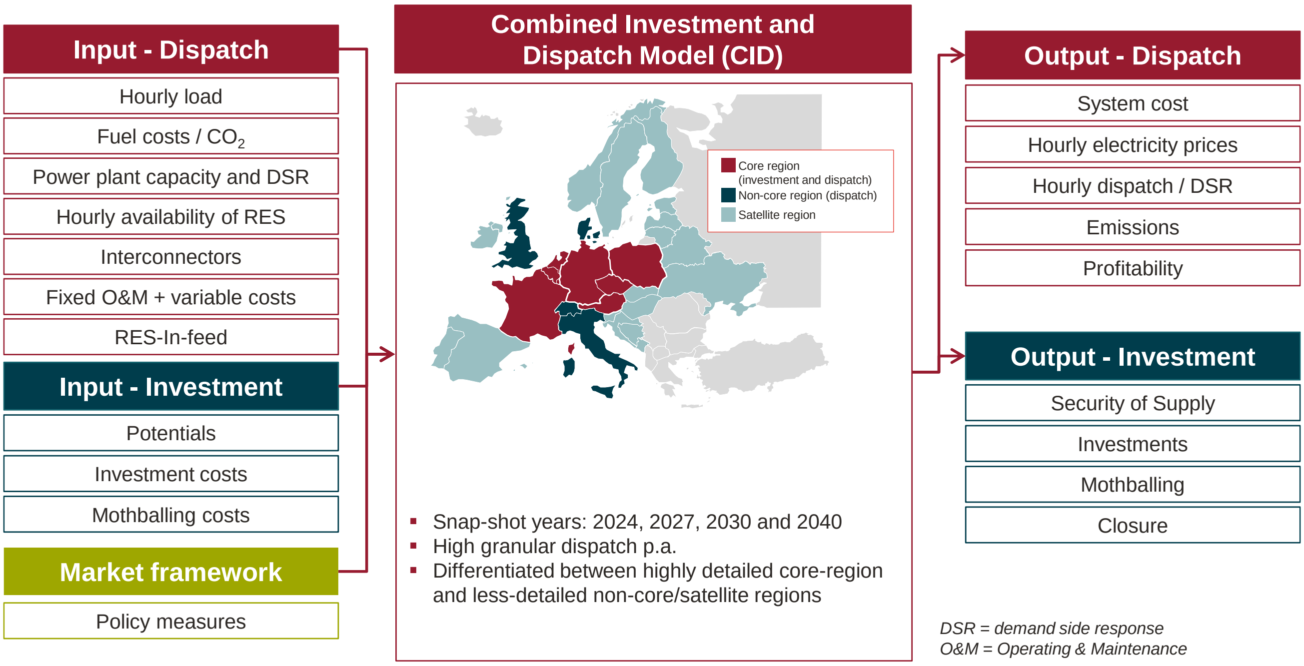
[8] Monte Carlo simulations are often used to simulate probabilistic price movements. See for example Graham, Reedman, Lo & Zhu (2009): "A scenario-based integrated approach for modelling carbon price risk".

[9] Frontier Economics (2015): "Scenarios for the Dutch electricity supply system"; Frontier Economics (2016): "Research of scenarios for coal-fired power plants in the Netherlands"; Frontier Economics (2018): "Research on the effects of the minimum CO_2 price".

[10] For a detailed model description see Annex C .

[11] The representative days were constructed based on historical data and optimised to closely replicate full years.

Figure 3 Frontier Investment and Dispatch 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)
- Snap-shot years: 2024, 2027, 2030 and 2040
- High granular dispatch p.a.
- Differentiated between highly detailed core-region and less-detailed non-core/satellite regions

Output - Dispatch
- System cost
- Hourly electricity prices
- Hourly dispatch / DSR
- Emissions
- Profitability

Output - Investment
- Security of Supply
- Investments
- Mothballing
- Closure

DSR = demand side response
O&M = Operating & Maintenance

Source: Frontier Economics

A central research task of the project is to analyse the effects of introducing a CPF below the expected carbon price path. In other words: Does a CPF have an effect even if it might not be binding, and EU ETS prices remain above the CPF?

To analyse this question, a **stochastic representation of future carbon price developments** in the electricity market model is used. The model optimises investment decisions in the power sector under the uncertainty of the different price paths, thus taking into account possible carbon price paths that might not materialise. We perform model runs for a reference case (without a CPF) and for each of the potential CPFs. By analysing the different outcomes of the model runs, we can investigate the potential impact of the CPF.

2.3.1 Modelling assumptions

In order to analyse the impact of different CPF assumptions, we compare scenarios without a CPF with the CPF scenarios (each CPF modelled as an individual scenario). All assumptions, other than the existence and level of the CPF in the Netherlands, remain the same between all scenarios, so that the impact of the existence of a CPF can directly be analysed.

All scenarios are based on the current and intended policy framework in the Netherlands and in North-Western Europe. They represent a framework which is built upon a combination of current market expectations, e.g. regarding fuel prices and carbon prices, and political targets for example for the development of renewable electricity generation.[12]

In the following, we summarise the main assumptions for the reference case and the CPF scenarios.

Figure 4 Summary of main assumptions

CO_2 prices	▪ Probabilistic representation of future carbon price developments based on output from Task 1 ▪ For the CPF scenarios: CPFs in NL at 10%, 25% and 40% below the “reference EU ETS price”
Fuel costs	▪ Calculation of the scenarios on the basis of the futures prices until 2025 (as of 30.01.2023) and interpolation to the KEV 2022 expectations for 2040
Demand	▪ NL: Medium-term and long-term: Based on main KEV expectations (net demand) ▪ For other countries we follow TYNDP 2022 National Trends, except where specific plans/legislation exists (e.g. in Germany based on Easter package (EEG 2023) and network development plan (NEP))
Generation capacities	▪ NL: We reflect latest plans, e.g. phase-out of coal-firing until 2030 and potential new nuclear capacity ▪ NL renewables: We reflect the capacities stated in the KEV 2022 ▪ For other countries we follow TYNDP 2022 National Trends scenario, except where specific plans/legislation exists (e.g. coal phase-out in Germany)
Interconnector capacity	▪ Until 2030: For NL based on expectations by TenneT, other countries based on TYNDP 2022 ▪ Until 2040: Based on TYNDP 2022

Source: Frontier Economics

Fuel prices

The fuel price projections are based two sources, depending on the timeframe (Figure 5):

- The **short-term** price projection for coal and gas prices is derived from current forward prices (until 2025).
- The **long-term** trend (after 2025) is based on the price development of the KEV 2022.

The price paths for gas and coal both show a return to lower price levels after the strong increase during 2021 and 2022. In the long run, assumed fuel prices show a rather steady path, although prices, in particular for natural gas, remain above long-term projections issued before the energy crisis.

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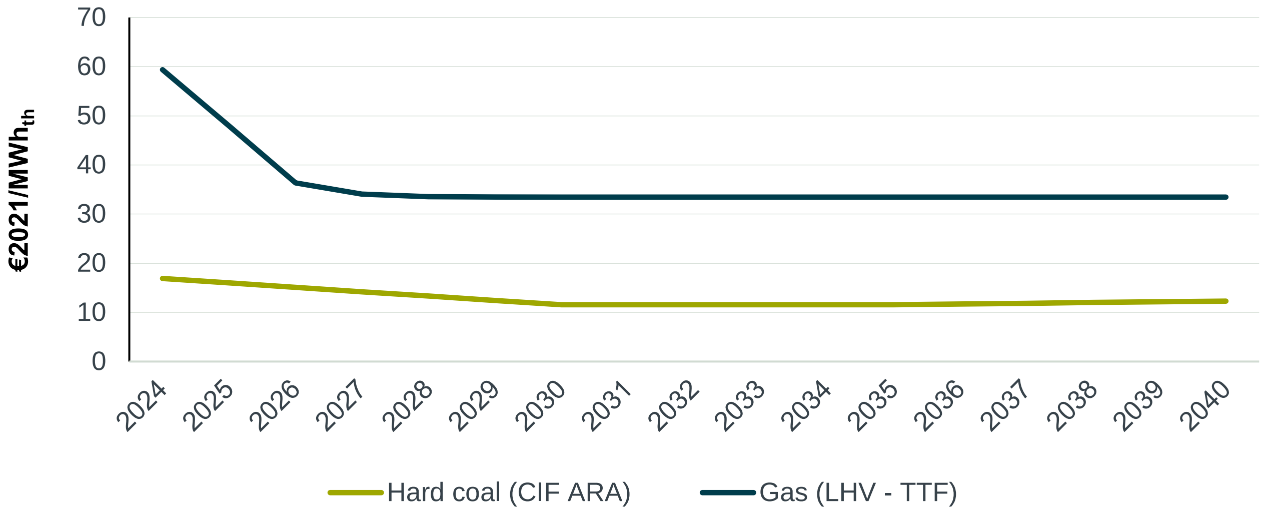
[12] In line with the predecessor study (Frontier Economics (2018): “Research on the effects of the minimum CO_2 price”) and as instructed, our assumptions are based on the report ‘Klimaat en Energieverkenning’ as published by the Netherlands Environmental Assessment Agency (PBL), including for fossil fuel and carbon prices. Assumptions are complemented by additional sources were necessary and do not necessarily reflect Frontier’s best guess.

Figure 5 Fuel price development

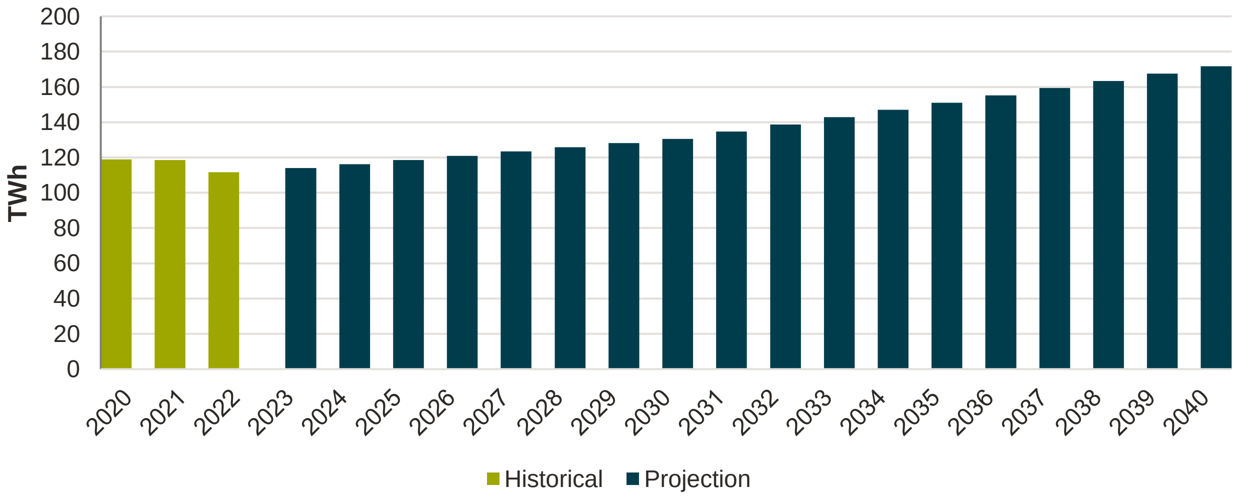


Source: Frontier Economics based on Energate Messenger and PBL 2022

Electricity Demand

Our assumption for the development of power demand is based on the demand projection in the KEV 2022. The report assumes a continuous growth of power consumption until 2040 (Figure 6). Including network losses, net electricity consumption is assumed to increase from 112 TWh in 2022 to 131 TWh in 2030. Demand is expected to increase to 172 TWh by 2040.

Figure 6 Development of electricity demand in the Netherlands



Source: Frontier Economics based on CBS Statline and PBL 2022

Note: Net power demand incl. network loses, excl. own consumption of power plants.

Thermal generation capacities

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

- Coal phase-out in the Netherlands: We assume that the coal phase-out is completed at the latest by 2030.
- Nuclear capacities in the Netherlands: We understand that there is the political intention to maintain nuclear capacities within the Dutch power plant park. We thus assume that some nuclear capacity (ca. 0.5 GW) is in operation throughout the entire modelling period until 2040.
- CHP generation in the Netherlands: Next to their electricity generation, CHP capacities have a commitment for heat generation. Our modelling thus follows the projected path of CHP generation as depicted in the KEV 2022.
- Beyond the developments in the Netherlands, we also reflect other decisions in the modelling regions, for example the reduction of nuclear electricity capacities in Belgium, the nuclear lifetime extensions in France and the German coal phase out.

Renewable generation capacities

The development of renewable energies in electricity supply is to a large extent driven by policies, permits and potentially limited by network capacities (e.g. for Dutch offshore wind). Notably, due to relatively high fuel prices for competing power generation technologies (in particular natural gas), RES-E[13] investments yield a positive rate of return in our model independent of the existence of a CPF or the level of a CPF. This means the extension of renewable power generation capacity is not limited by economic viability in the model, but rather by practical considerations (permits, land availability, grid constraints, etc.). Therefore, we restrict renewable growth to account for these constraints. The assumptions for renewable capacity extensions in the Netherlands are based on the KEV 2022 (Figure 7).

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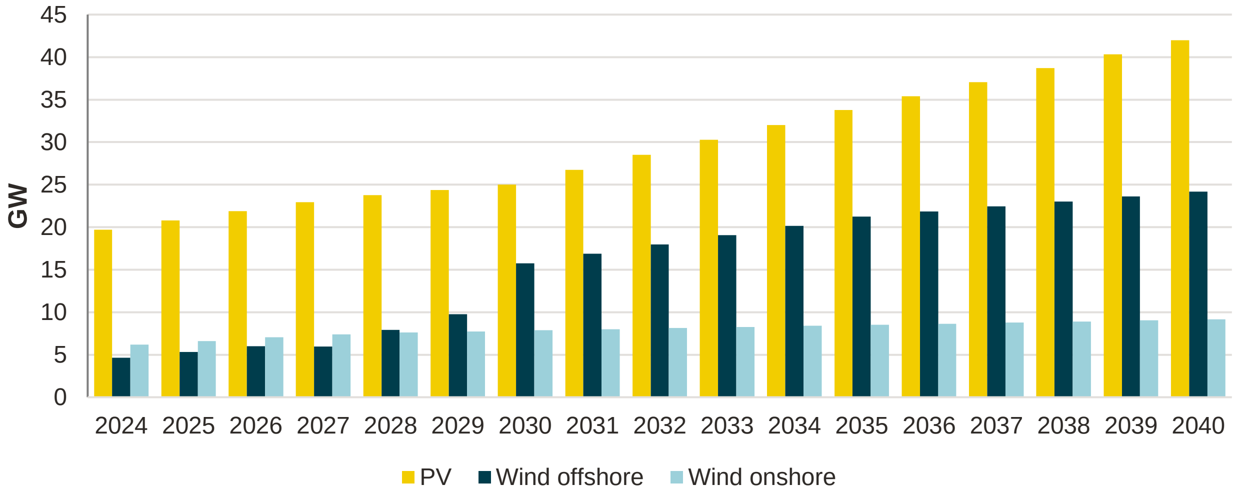
[13] Renewable sources of electricity.

Figure 7 Assumed renewable generation capacity development in the Netherlands



Source: Frontier Economics based on KEV 2022

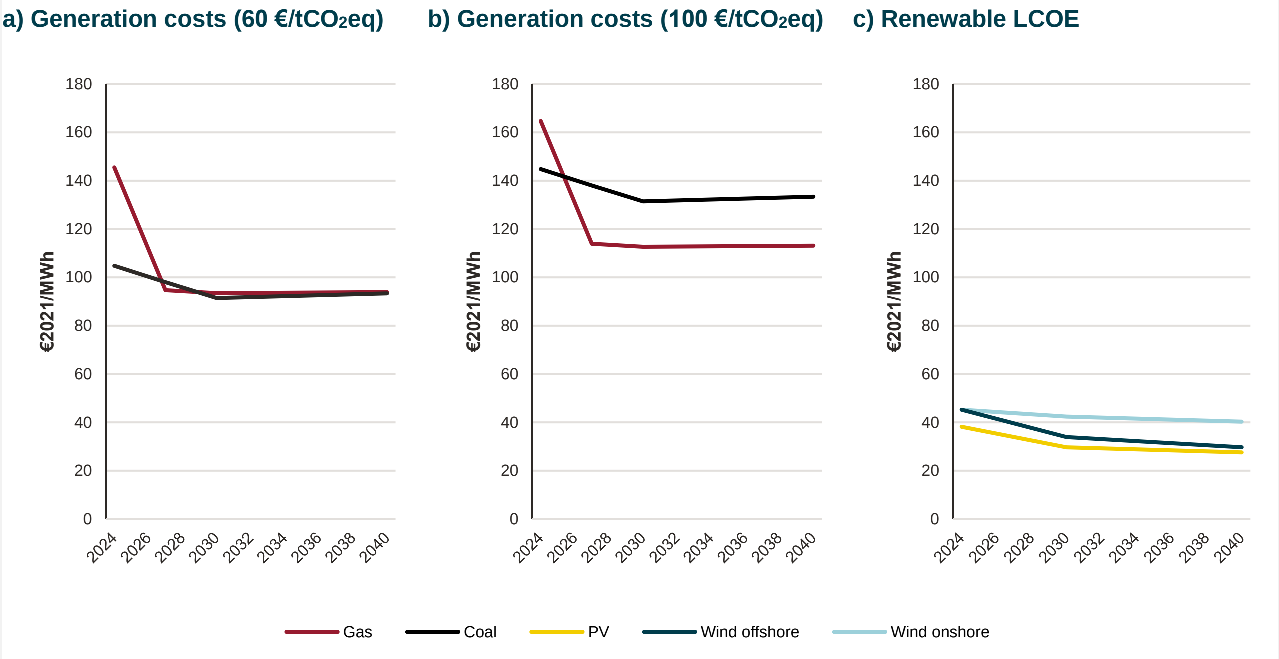
Background: Levelized costs of electricity generation

Fossil fuel prices, in particular natural gas but to a lesser extent also coal, increased significantly in the second half of 2021, a few months before the Russian invasion of Ukraine. This caused the beginning of a global energy crisis. Prices peaked at more than ten times (natural gas) and five times (coal) the average price between 2015 and 2020 in the summer of 2022. Although prices have declined towards spring 2023 (when the study at hand was prepared), the general expectation is that fossil fuel prices will remain elevated compared to pre-crisis levels (and above previous expectations regarding future developments) for many years to come.

At the same time, the costs for renewables energies have declined significantly over the past two decades. From 2010 to 2020 alone, the global average costs of generating electricity with solar PV declined by more than 85%, onshore wind costs declined by more than 60% and offshore wind more than 50%.

Both developments together result in a situation in which renewables have lower total average generation costs (including investment costs) than fossil fuel-based power plants (see Figure 8). For Europe, this is even the case for relatively low EU ETS prices (60 €/tCO$_2$eq).

Figure 8 Fossil fuel generation costs vs renewable levelized costs of electricity



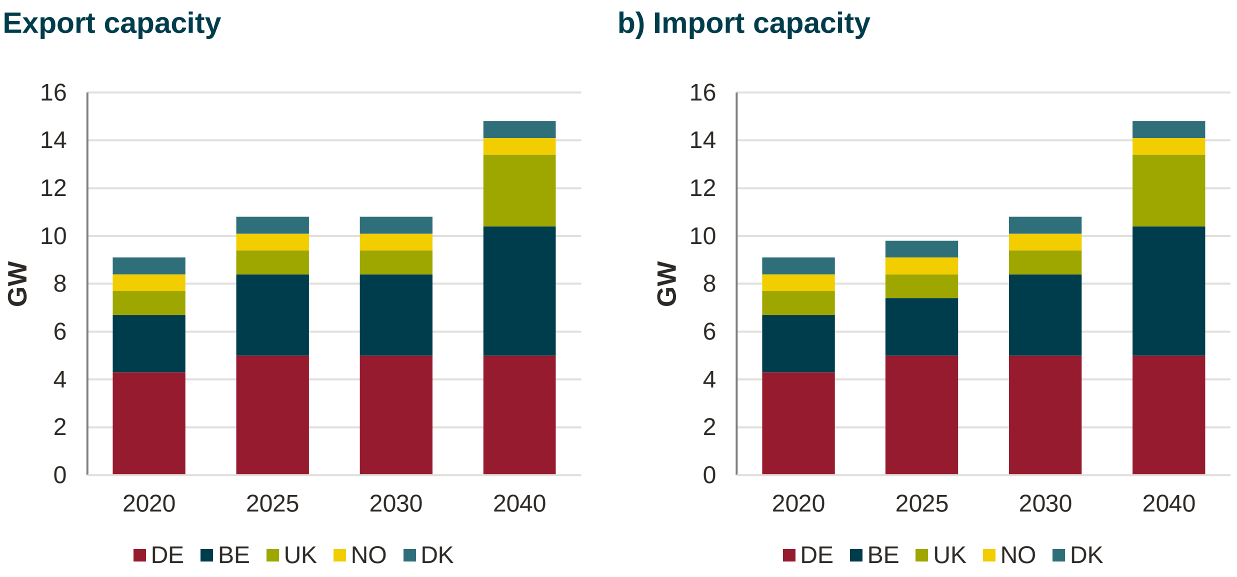
Source: *Frontier Economics, renewables data based on: International Energy Agency (2022), Global Energy and Climate Model Documentation 2022.*

Interconnector capacities

The Netherlands has high interconnection capacity to its neighbouring countries, notably Germany and Belgium. Additional interconnections are in place to Great Britain and Norway. Cross-border capacity will increase further in the next years.

The assumptions regarding the development of interconnection capacity in the Netherlands until 2030 are based on TenneT's Monitoring Leveringszekerheid 2022. The expansion of Dutch interconnector capacities until 2040 as well as the interconnector capacities for all other countries are based on ENTSO-E's Ten-Year Network Development Plan (TYNDP) 2022.

Figure 9 Assumed Dutch interconnector capacity development


a) Export capacity

b) Import capacity

Source: Frontier Economics based on TenneT's Monitoring Leveringszekerheid 2022 and ENTSO-E's Ten-Year Network Development Plan 2022.

2.3.2 Policy dimensions and key indicators

To analyse the effects of an updated CPF in the Netherlands, we will analyse three CPF options as defined in section 2.1. The evaluation of the impacts of the individual CPF options will be mainly based on a comparison between the reference case and the individual CPF options.

Based on the outlined approach, in our evaluation we will focus, inter alia, on the areas and related indicators outlined in Table 4.

Table 4 Policy dimensions of the impact analysis for CPFs for the electricity sector

Policy dimension	Description and key indicators
Investment security for sustainable technologies	This dimension refers to the profitability risk associated with investments in sustainable technologies. In particular, we are analysing the **expected profits** and **profit range** for investments depending on the CPF and EU ETS price scenarios.
Security of supply	Security of supply refers to the ability of the system to serve demand at all times. We evaluate this dimension with two indicators: First, we analyse the **installed capacity** and **Adequacy Reserve Margin (ARM)**, calculated as the difference between a), the de-rated generation and import capacity and b), the peak demand. Second, we analyse the **short-run profitability** of conventional and nuclear power plants to evaluate their economic well-being.
International competitiveness	A CPF in the Netherlands potentially results in higher domestic electricity prices relative to a scenario without a floor price. This could impact the competitiveness of domestic electricity generators. Consequently, domestic electricity generation might be replaced by imports. We measure the international competitiveness of generation in the Netherlands based on the **generation costs** delta as well as **import and export** volumes.
Sustainability	To examine the impact of different CPFs on sustainability, we will compare the **CO_2-emissions** between the different model runs. Apart from the domestic CO_2-emissions in the Netherlands, we will also consider the net-reduction of carbon emissions in the EU as lower emissions in the Netherlands potentially come along with higher emissions in other countries.
Affordability	To assess the impact of a CPF on the affordability of electricity, we analyse how **wholesale power prices** in the Netherlands are affected by a CPF.

Source: Frontier Economics

Additionally, we identify and evaluate **interdependencies and trade-offs** between the policy dimensions.

2.4 Industry sector modelling: Scenarios and data sources

Based on the results of the probabilistic modelling of the EU ETS prices, we calculate deterministic carbon price scenarios, which will be used as inputs for the industry model. The scenarios include:

- a reference scenario in which carbon prices move along the central EU ETS price path; and
- a low price case that results in EU ETS prices (at least temporarily) falling below the CPF.

By comparing the results with and without the CPF in these scenarios, the impacts on the industry can be analysed.

2.4.1 Approach

We analyse the effects of a CPF in the Netherlands for industrial sectors as a sensibility check. We use the WorldScan model simulation outcomes for analysis and restrict the numerical analysis to the year 2030.[14] The impacts that we will present will be based on comparing simulation results with a binding CPF and without a CPF.

The WorldScan model has been developed as a comprehensive tool to construct long-term scenarios for the global economy and to facilitate policy analyses in the field of international economics.[15] The model is a global Computable General Equilibrium (CGE) model in which the aggregation of regions and sectors can be flexibly adjusted. The level of detail is limited only by the detail in the GTAP 9 database, which currently consists of 57 sectors, 140 countries, for example, all EU countries can be distinguished within the world economy. WorldScan offers a modelling framework for addressing policy issues in international economics. All types of taxes/subsidies on inputs of production can be introduced (or removed).

The energy version of the WorldScan model used for simulations presented in this report covers emissions of all GHGs. This version has a sectoral coverage that includes the agricultural sector, the fossil fuel markets, oil, gas, and coal, as well as the electricity market, including all major renewable technologies and carbon Capture and Storage (CCS). In addition, the model covers all major sinks for CO_2, i.e. emissions and removals related to LULUCF, including forestry and agriculture. Thus, WorldScan allows the possibility to assess interactions between climate polices and other policies, in particular policies related to industrial climate policies, renewable policies; energy efficiency objectives; air pollution; land use emissions; energy and resource efficiency; ETS policies and polices leading to increased use of bio-fuels and biomass, and carbon absorption capacities of lands and

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[14] Recent WorldScan simulations of climate policy are reported in Hoogendoorn, S., Trinks, A., and Bollen (2021), carbon pricing and relocation: Evidence from Dutch industry, see voxeu.org. The model is extensively described on its' general properties in Lejour, A., Veenendaal, P. , Verweij, G., and van Leeuwen, N. (2006), WorldScan: a Model for International Economic Policy Analysis, CPB Document No. 111, CPB. The Energy version of WorldScan is described in Bollen (2015), The value of air pollution co-benefits of climate policies: Analysis with a global sector-trade CGE model called WorldScan, Technological Forecasting and Social Change, Volume 90, Part A, 2015, Pages 178-191.

[15] This section is based on Lejour et al, (2006).

forests. In this report, we focus on industrial climate policies, and in particular the introduction of a CPF in the industry.

The sectoral breakdown of the industry in WorldScan is:

- Petroleum and coal products;
- Metals;
- Chemical rubber & plastic products;
- Paper products, publishing;
- Non-metallic minerals (for construction); and
- Processed food.

The Dutch industrial sector is modelled as part of the global market, taking into account the trade linkages between countries and the resulting interdependencies between markets. The regional breakdown of the WorldScan model to simulate the global economy is:

- The Netherlands (NLD);
- Other 26 EU countries (REU);
- USA;
- Rest-of-the OECD (ROE);
- China, incl. Hong Kong (CHI); and
- Rest-Of-the World (ROW).

The primary goal of the analysis here is to better understand the impact of a CPF on the outlook for the industrial sector and carbon emissions (including potential carbon leakages). A CPF may lead in specific sectors to cost increases of inputs to production. This in turn has consequences on competitiveness and supply prices, which in the long run will also lead to structural changes from a reallocation of labour and investments across sectors. The WorldScan model estimates the magnitude of direct major industrial sectors shifting to costly carbon-extensive ways of production. This simulated response simultaneously solves for any production changes resulting from changes in domestic demand or changes in competitiveness in a trade-dependent world (model covers the entire world in predefined regions or countries).

Although the WorldScan model simulates at a time-step of one year until any chosen end-year, we chose here to focus on simulation outcomes of the most policy relevant year of 2030.[16] A more general description of the model can be found in Annex E .

A central research task of the project is to analyse the effects of introducing a CPF below the expected carbon price path. To analyse this question for the industrial sector, we use the EU ETS and CPF paths of Task 1. As stochastic price developments cannot be integrated in the WorldScan approach, we will focus on a predefined low ETS price development with a set of binding CPFs.

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[16] This year 2030 is also used as the end-year to minimize on the complexity of the analysis.

2.4.2 Scenario and data sources[17]

The setup of the baseline simulations in WorldScan aligns with the KEV 2022. This comprises recalibrating model parameters (e.g. total factor productivity, energy demand technologies) to be able to simulate macro and meso-economic growth, energy demand by industrial sectors and GHG emissions, and prices of oil, gas and the EU ETS price as reported in the KEV 2022.

A CPF may change the production processes, thus yielding a switch away from fossil energy to hydrogen and electricity.[18] The model options include different abatement options in terms of abatement potential (in tCO_2eq.) and marginal costs (in EUR/tCO_2eq.) as reported in the Dutch draft climate agreement ("Ontwerp klimaatakkoord").[19]

The report shows that there is hardly any electrification or hydrogen to be expected beyond a carbon price of 55 EUR/tCO_2eq.[20] As based on our probabilistic analysis even low EU ETS price scenarios show a price higher than 60 EUR/tCO_2eq and therefore the vast majority of electrification and hydrogen options will be economical in any case, a CPF is unlikely to drive additional electricity demand even with a low EU ETS price. Thus we do not expect a CPF to result in additional electricity demand and consequently the interaction of the electricity market with the industry does not have to be explicitly modelled.[21]

The KEV 2022 does not include all intended policy ambitions of the coalition, because some policy initiatives are not yet included in the government’s budget or not translated into concrete policy actions. Hence the intention of the coalition is to achieve more emission reductions than reported in the KEV 2022.[22]

2.4.3 Definition of quantitative indicators to analyse impact

We will use the following set of indicators to analyse the effects of a CPF on the industrial sector:

- **International competitive position (carbon leakage):** The impact of a CPF on the competitiveness of the industry will be evaluate using carbon leakage (simulated with WorldScan) as the central indicator. With a binding CPF this means that activities will be reallocated to other countries, which leads to carbon leakage. Part of the leakage will occur to countries outside EU. The leakage will be decomposed to sectors and regions.

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[17] More details on the scenario, both with respect to the assumptions and general trends is presented in Annex D2.

[18] These abatement functions are based on old data and will be updated to the most recent data in the midden database, see van Dam, D., Gamboa Palacios, S., and Wetzels, W. (2021), MANUFACTURING INDUSTRY DECARBONISATION DATA EXCHANGE NETWORK – THE DATABASE, PBL report, The Hague.

[19] See https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord.

[20] See page 87 of the Dutch draft climate agreement.

[21] Later, we will show that electricity price changes in 2030 from a binding CPF are very limited, so we disregard these as well.

[22] See https://www.rijksoverheid.nl/ministeries/ministerie-van-economische-zaken-en-klimaat/documenten/publicaties/2022/11/01/klimaatnota-2022.

- **Investment security:** We will scrutinize sectoral investments and decarbonisation efforts by the different industrial sectors.
- **Sustainability:** We will discuss the impact on GHG-emissions in the Netherlands, the rest of Europe, and the rest of the World.

3 Probabilistic analysis of future carbon prices

In the following, we describe the results for the probabilistic analysis of future carbon prices. To facilitate the understanding of the analyses, we first provide some interim results (section 3.1). Thereafter, we provide the final output of the probabilistic analysis of future carbon prices (section 0), which is used as inputs for the electricity market modelling (results in section 4) and industrial sensibility analysis (results in section 5).

3.1 Interim results: Stochastic representation of future carbon price developments

As described in Section 2.2, we apply a Monte Carlo simulation to our mean reversion model, which describes potential carbon price developments. Using the Monte Carlo simulation we obtain 10,000 possible price developments.[23] Due to the large number of possible price developments for each year between 2024 and 2040, we focus on a subset of the years in the following to describe and show the methodology and (interim) results. The presented approach however remains the same for all of the modelled years.

In Figure 10 we show for illustrative purposes a depiction of 20 randomly selected future price path simulations until the end of 2027. The plot of these interim results shows the following aspects inherent to the analytical approach:

- The depicted potential price paths have (on average) an **upward trend**. This reflects the underlying assumption that in the long run we expect the EU ETS price to increase, as reflected in the KEV main scenario.
- The **spectrum of potential prices widens** over time, for example shown by the distance between the highest and lowest potential price paths. This reflects the fact that further in the future there is more uncertainty about the level of the EU ETS price.
- There is an **increasing (absolute) variation of the prices**, reflecting in "larger price swings" further in the future.[24] This again reflects a larger uncertainty about the prices further in the future.

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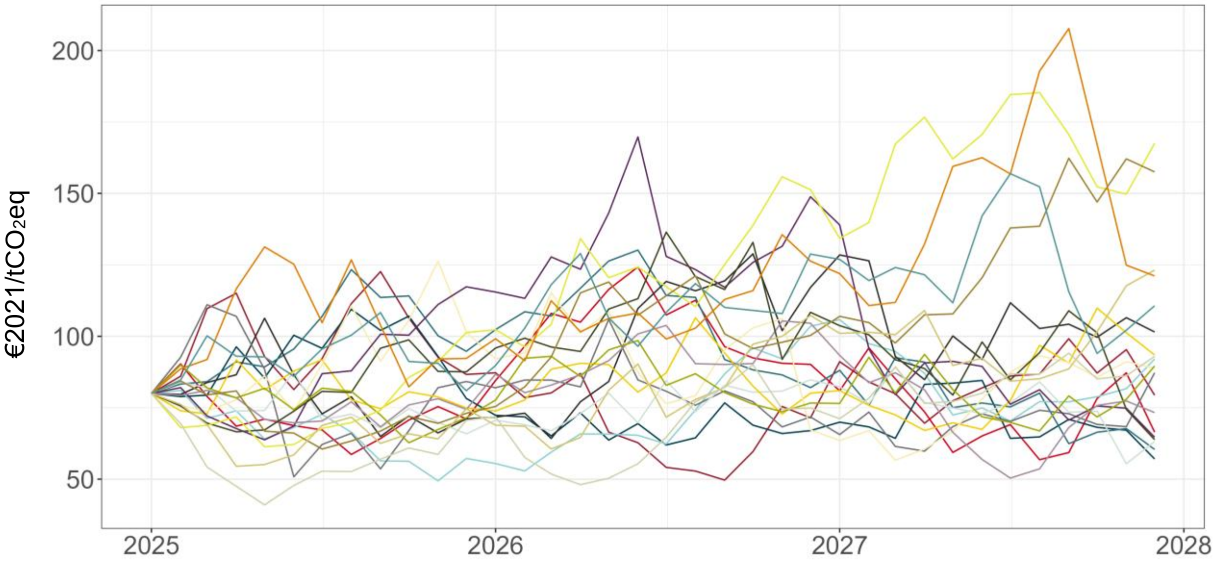
[23] On a month-to-month basis.

[24] Price volatility remains the same in relative terms, leading to an increase in absolute terms as the level of the EU ETS price rises.

Figure 10 Potential carbon price dvelopment: Random sample of 20 simulated future price paths



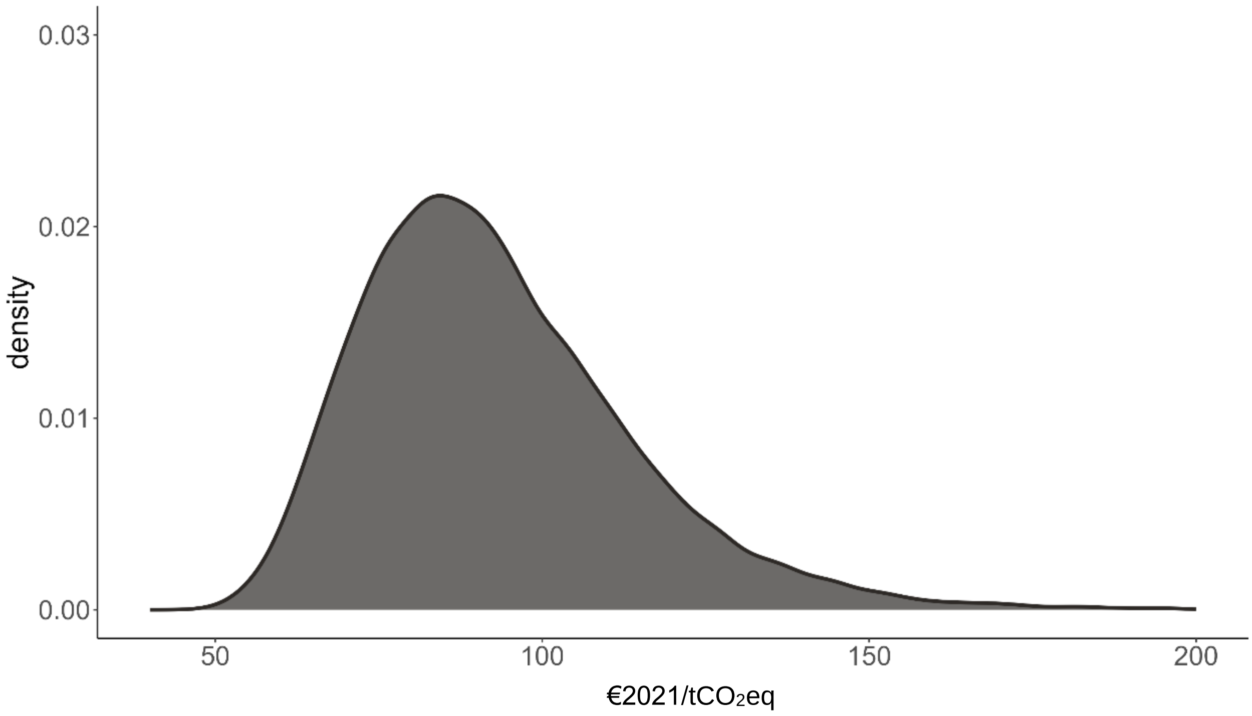
Source: *Frontier Economics*

Note: *Random sample of 20 (out of 10,000) simulated price paths through Monte Carlo simulations on a month-to-month basis from 2025 until the end of 2027, based on our Monte Carlo simulations using a mean reversion model.*

Based on the 10,000 price paths taken from the Monte Carlo simulation we deduct probability distribution for the carbon prices in each of the modelled year. Figure 11 shows such a probability distribution for the year 2027, illustrating the likelihood of different carbon price levels. The probability distribution allows for the following observations:

- The distribution shows that there is **fluctuation around an expected carbon price** (weighted average) of ca. 93 EUR/tCO$_2$eq. The expected price level reflects the reference EU ETS price (as outlined in section 2.2)
- The lower and upper tails of the distribution depict **uncertainty about the potential price level** in 2027, with the highest likelihoods for price levels around the reference EU ETS price.

Figure 11 Probability distribution of carbon prices in 2027



Source: Frontier Economics

Note: The distribution shows the probability of (yearly averaged) prices in 2027 (x-axis is cut off at 40 EUR and 200 EUR respectively for better visibility). The weighted average of (yearly averaged) prices of the entire distribution is 93.2 EUR and therefore in line with a linear interpolation between December 2024 EUA Futures and the long-term expectation of future carbon prices for 2030 in the KEV 2022 main scenario.

In order to analyse the effects of a CPF using the stochastic electricity market model (see section 2.3), the results of the probabilistic analysis of future carbon prices needs to be condensed to a limited set of data points so that it can serve as input to the model. The information displayed as a probability distribution of future carbon prices in Figure 11 is therefore expressed as a probability tree. Thereby the probabilities of different carbon prices are reduced into three possible cases – a central price, a low price and a high price.

In order to reduce the probability distribution to three scenarios, the distribution is “cut” at two different thresholds (into three areas). These reflect the probability of the price being below or above the respective threshold. For each of the three areas the weighted average price of the partial distribution below, above, or in-between thresholds is determined[25] (see Figure 12).

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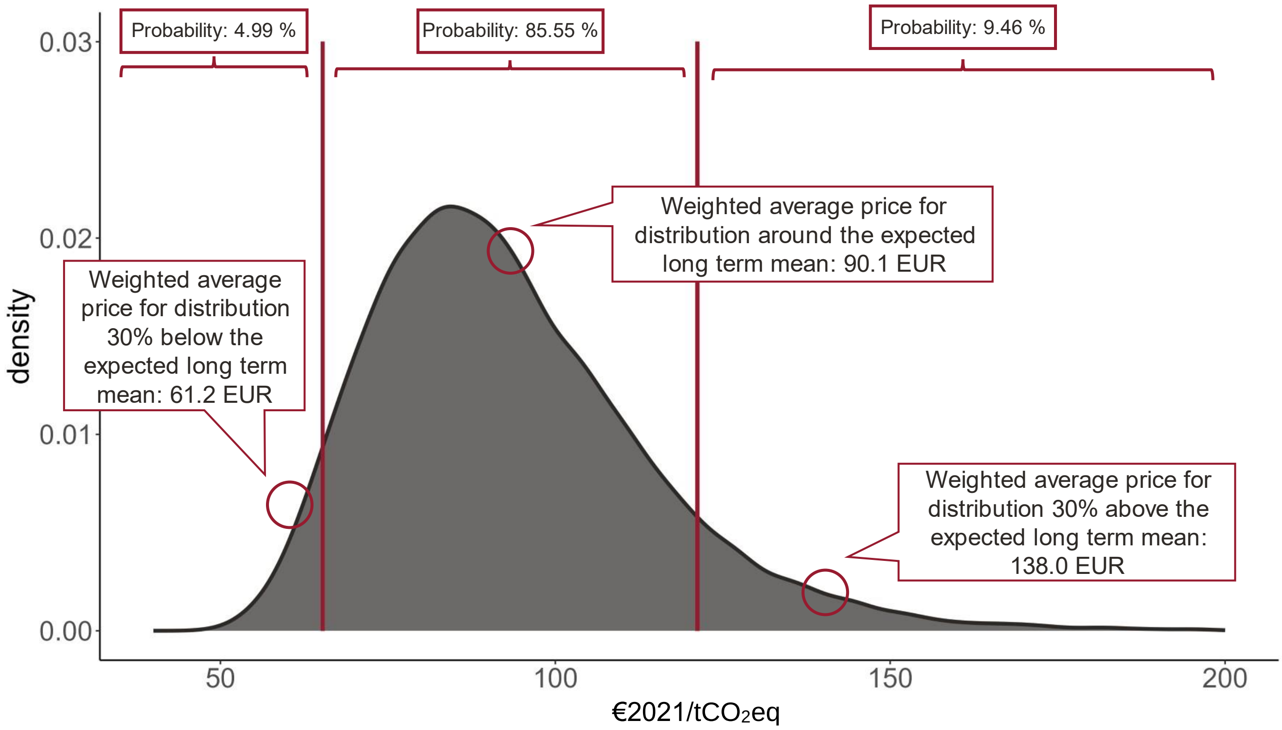
[25] Reference EU ETS prices (yearly average) for the year 2027 are derived as a linear interpolation between December 2024 EUA Futures recorded January 30th, 2023, and the long-term expectation of future carbon prices for 2030 in KEV 2022 main scenario. The expected carbon prices in 2030 (109.82 EUR) and 2040 (178.94 EUR) resemble the estimates in the 2022 KEV main scenario. The thresholds are set at 30 % below and above the reference EU ETS, defining a low and high price scenario. The respective thresholds are thus set at 76.87 EUR and 142.77 EUR in 2030 as well as 125.26 EUR and 232.62 EUR in 2040.

Figure 12 Data condensation into a scenario tree (three nodes)



Source: Frontier Economics

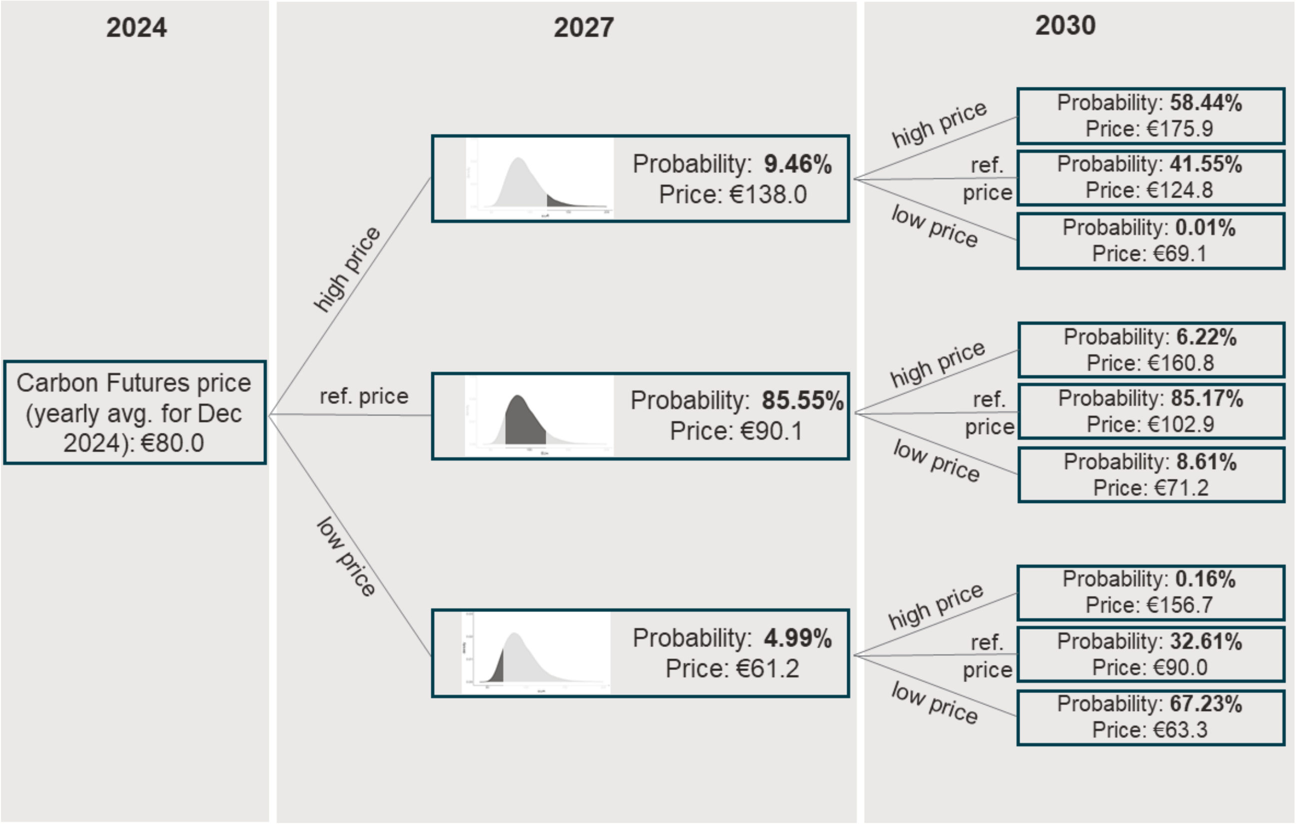
Note: The data is "cut" at the defied thresholds of 65.28 EUR (low price case) and 121.23 (high price case) – 30% below and above the expected long-term carbon price.

The outputs from the probabilistic analysis in Task 1 imply that there is a probability of ca. 5% that the carbon price falls below the threshold of 65 EUR/tCO$_2$eq in 2027. The weighted average price of all price paths that fall within this "low price development" (below the threshold) is ca. 61 EUR/tCO$_2$eq. We will place a particular focus on this potential "low price development" when assessing the potential impact of different CPFs in the electricity market modelling (section 4) and industrial sensibility analysis (section 5).

3.2 Output from probabilistic analysis of future carbon prices

As explained in the section above, the carbon price probabilities are expressed in a three-node scenario tree. Figure 13 shows the condensed information in a "low price development" case, a "medium price development"-scenario and a "high price development"-scenario, showing the chance of the carbon price falling within that scenario and the expected weighted average price of all price paths within that scenario.

Figure 13 carbon price probabilities represented in a three-node scenario tree



Source: Frontier Economics

Note: All prices in €2021/tCO$_2$eq. See Annex B for a full depiction of the scenario tree including 2040.

The scenario tree illustrates a number of characteristics, which are in line with previous observations and expectations:

- There is an expectation that carbon prices follow an **upward trend**.
- However, there is **uncertainty around the carbon price development** as shown in the different levels of prices and probabilities. The spectrum of potential prices widens over time.
- The modelling incorporates a **price path dependency**: For example, price developments up to and throughout the reference year 2027 have a significant impact on the likelihood of prices in the following years. If carbon prices are rather low in 2027 (reflected through the low price case) they have a much higher probability of being low in 2030 (the following modelling year in our analysis), in comparison to scenarios in which the carbon price is on a higher level in 2027.

The probabilities and corresponding prices represented in a three-node scenario tree serve as input for the stochastic electricity market analysis presented in the following section 4.

4 Impact of carbon price floors on the electricity system

In this chapter, we summarise the results of the analysis of the impact of the different CPF scenarios on the electricity sector. We present the results in the following steps:

- **Reference scenario (central carbon price path without CPF):** Based on our stochastic power market modelling, we summarise major future trends in the Dutch power market for a case without a CPF (section 4.1). For this we discuss results for a scenario where the carbon price path develops in line with the central expectations (based on current futures and the KEV 2022 main scenario).

- **Central carbon price path with a non-binding CPF:** The potential CPFs of this study are designed with the intention to remain below the expected price path for CO_2 certificates in the EU ETS (defined as a price path 10% / 25% / 40% below the expected carbon price path). However, since there is a certain probability that future carbon prices may fall below a Dutch CPF, market participants may change their behaviour even if this development does not materialise. The outcome of the stochastic model, which takes these probabilities into account, indicates if a change in behaviour of market participants can be expected due to these uncertainties (section 4.2).

- **Low carbon price path with a binding CPF (compared with low carbon price without CPF):** We summarise the stochastic modelling results for a path in which the potential CPFs of this study become binding. This means that future prices for CO_2 certificates in the EU ETS fall below the respective CPFs in the different CPF scenarios (again 10%, 25%, 40% below the expected EU ETS price path, section 4.3). For the evaluation, we compare the scenarios with a CPF against the scenario without a CPF while focussing on the same carbon price path with low ETS prices.

- **Evaluation:** Finally, we summarise the results based on the key indicators and draw principal conclusions from the model results. The key policy indicators are presented in greater detail in section 4.4.

4.1 Reference scenario: Trends in the Dutch power market (without CPF)

In this section, we summarise the main results of the power market modelling without a CPF.

Table 5 Summary of key results of the reference scenario (without CPF)

Key indicators	Development
Generation capacities	■ Large increase in **renewable** capacities ■ **Storage** capacity of ~6 GW built by 2030 ■ Installed **gas** generation capacity of ~15 GW between 2024 and 2030 (incl. some temporary mothballing)

Key indicators	Development
Domestic dispatch	■ Large increase in generation from **renewables**, which offset coal generation and cover increasing electricity demand ■ In 2030 and 2040 **gas (incl. CHP) and storage** complement renewable generation
Emissions	■ Significant **decline** from ~36 $MtCO_2eq$ in 2024 to ~17 $MtCO_2eq$ in 2030, in particular due to coal phase out, and further decline until 2040
Electricity price	■ **Declining** electricity prices from ~130 EUR/MWh in 2024 to ~100 EUR/MWh in 2030 ■ Further reduction to ~91 EUR/MWh by 2040
Reserve Margin	■ **Increasing peak load and coal phase-out** is met by contribution from largely storages, renewables and imports ■ Towards 2040 **decreasing reserve margins**
Power plant profits	■ **CCGT** (mostly CHP) profits largely increasing between 2024 and 2027, but from 2030 onwards decreasing ■ **Renewables**: decreasing profits throughout the modelled period

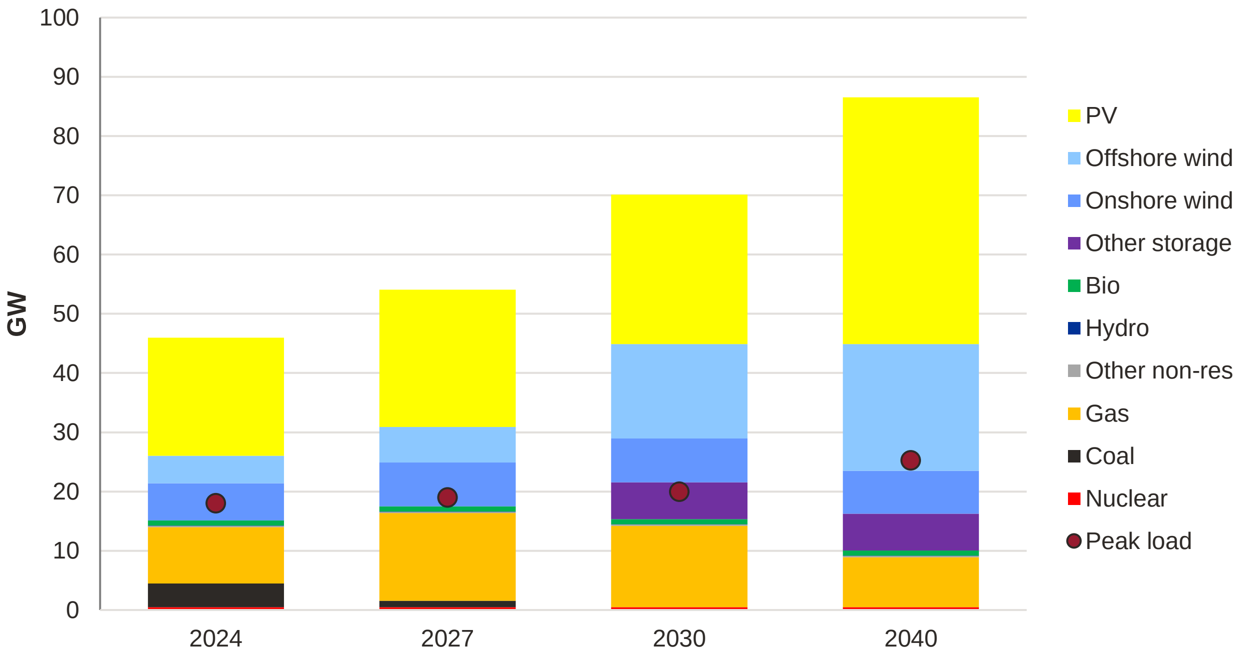
Source: *Frontier Economics*

Note: *The adequacy reserve margin is calculated as the difference between the de-rated available capacity (incl. a share of reliable import capacity) and peak load. Profits are measured as the short-run profits per installed capacity, i.e. wholesale market revenues minus variable production costs.*

4.1.1 Power generation capacities

Figure 14 summarises the main modelling results of the expected future development of power generation capacities in the Netherlands:

Figure 14 Reference scenario: Installed generation capacity



Source: *Frontier Economics*

- **Renewable** generation capacities are likely to increase substantially until 2040. The main capacity additions are offshore wind and PV. Additional wind onshore is expected to be limited, e.g. due to limits in the grid capacity.[26]
- The **coal-fired power generation** is phased out by 2030 as determined by the Dutch climate policy.
- There is an installed **gas generation capacity** of about 15 GW between 2024 and 2030. Some of the capacity is endogenously mothballed temporarily and reactivated in 2027.
- Additional **storage** capacity of about 6 GW is expected to be built by 2030. Alongside mostly gas generation capacities storages will complement the largely intermittent renewable generation.

4.1.2 Electricity generation / power plant dispatch

Figure 15 summarises the main modelling results of the expected future development of power generation in the Netherlands:

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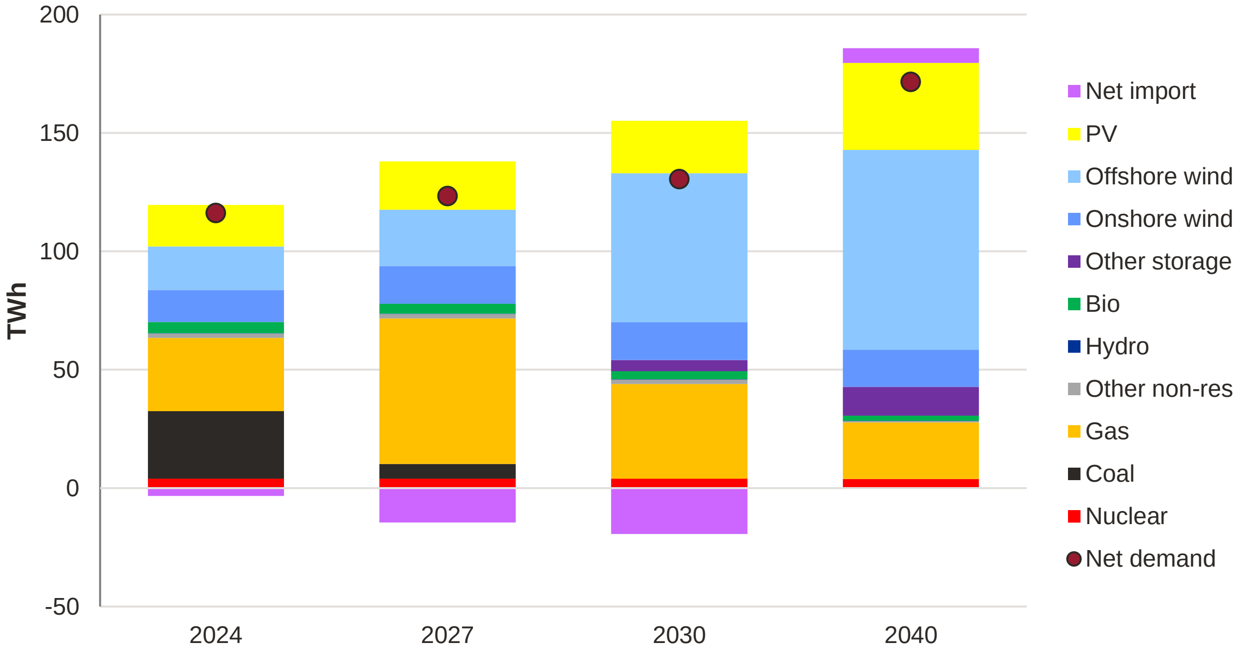
[26] PBL (2022), Klimaat- en Energieverkenning 2022, p. 108.

Figure 15 Reference scenario: Annual dispatch and net imports



Source: Frontier Economics

- **The generation from renewable energy** is increasing and will likely constitute the largest source of domestic electricity generation by 2030. It will likely provide more than 75% of supply by 2040.

- The relevance of **generation from coal** plant declines significantly from ca. 28 TWh generation in 2024 to less than 10 TWh generation by 2027. By 2030 there will be no generation from coal plants anymore.

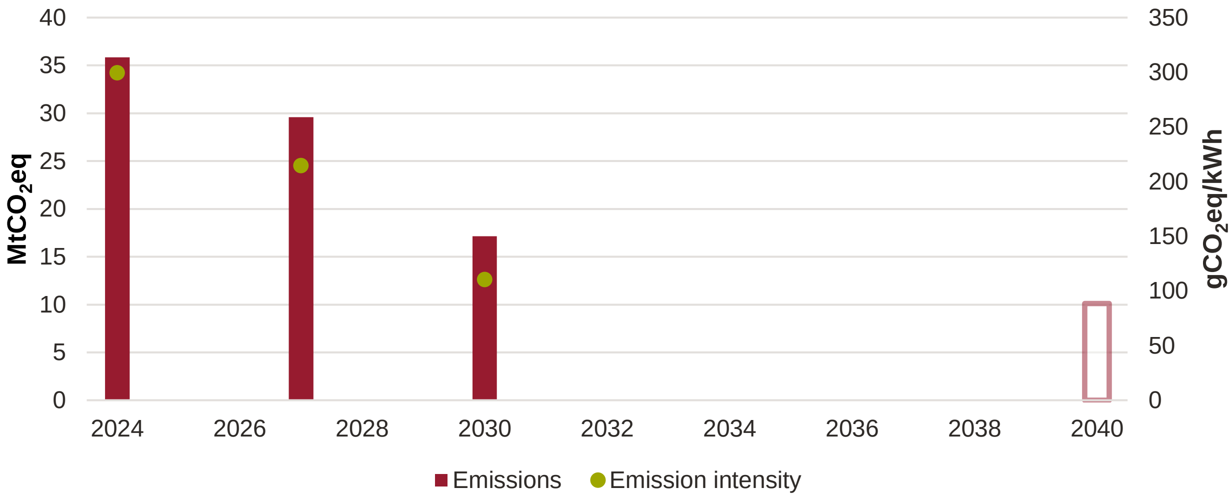
- The share of **gas-fired generation** to total generation increases until 2027, propelled by a domestically declining coal generation. The gas generation declines steadily thereafter, but maintains a generation share of around 15% by 2040 – mostly provided by CHP plants to ensure security of supply of heat.

- Domestic generation grows faster than demand until 2030, resulting in increasing **net exports** of electricity. Demand catches up with domestic generation by 2040, resulting in an almost balanced trade balance.

4.1.3 Emissions in the Netherlands

Figure 18 summarises the main modelling results of the expected future development of carbon emissions and emissions intensity in the Netherlands:

Figure 16 Reference scenario: Emissions and emission intensity



Source: Frontier Economics

- The emissions in the Netherlands are expected to decline significantly until 2030. The development is largely driven by the reduction in **coal-fired generation**, which is replaced by generation from renewable sources and gas plants.

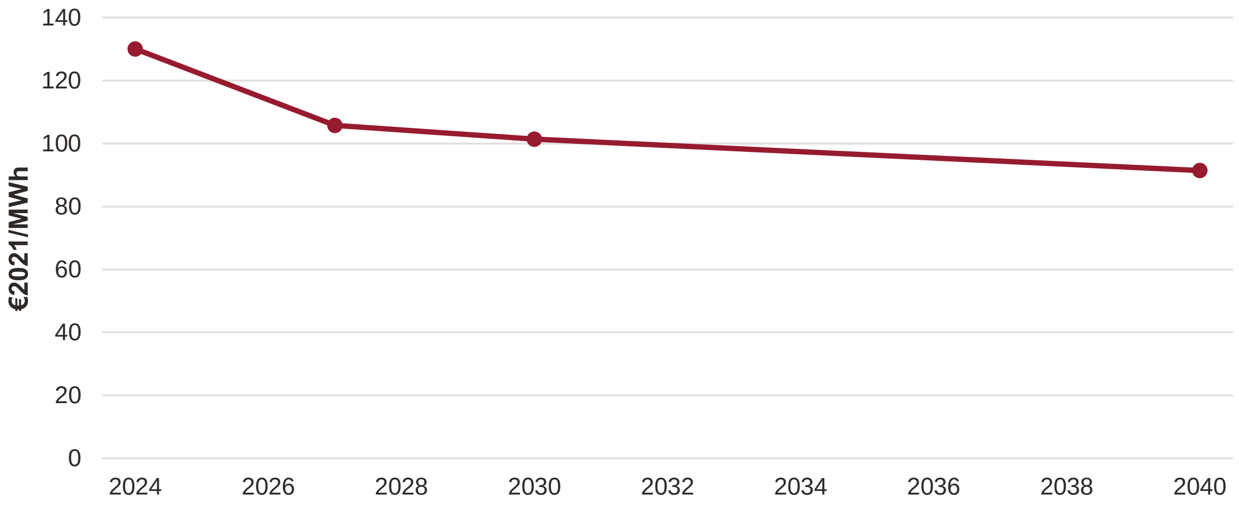
- The Emissions continue to decline with a **slower pace after 2030,** when gas-fired generation is gradually replaced by renewable generation. Potential emissions from the generation of gas-fired plants in 2040, which reflect the need for dispatchable capacities in 2040, can be abated with for example the use of climate neutral gases such as renewable hydrogen.

- The **emissions intensity** of electricity generation declines along a similar path as the absolute emissions.

4.1.4 Wholesale electricity prices

Figure 17 summarises the main modelling results of the expected future development of average wholesale electricity prices in the Netherlands:

Figure 17 Reference scenario: Average wholesale electricity prices



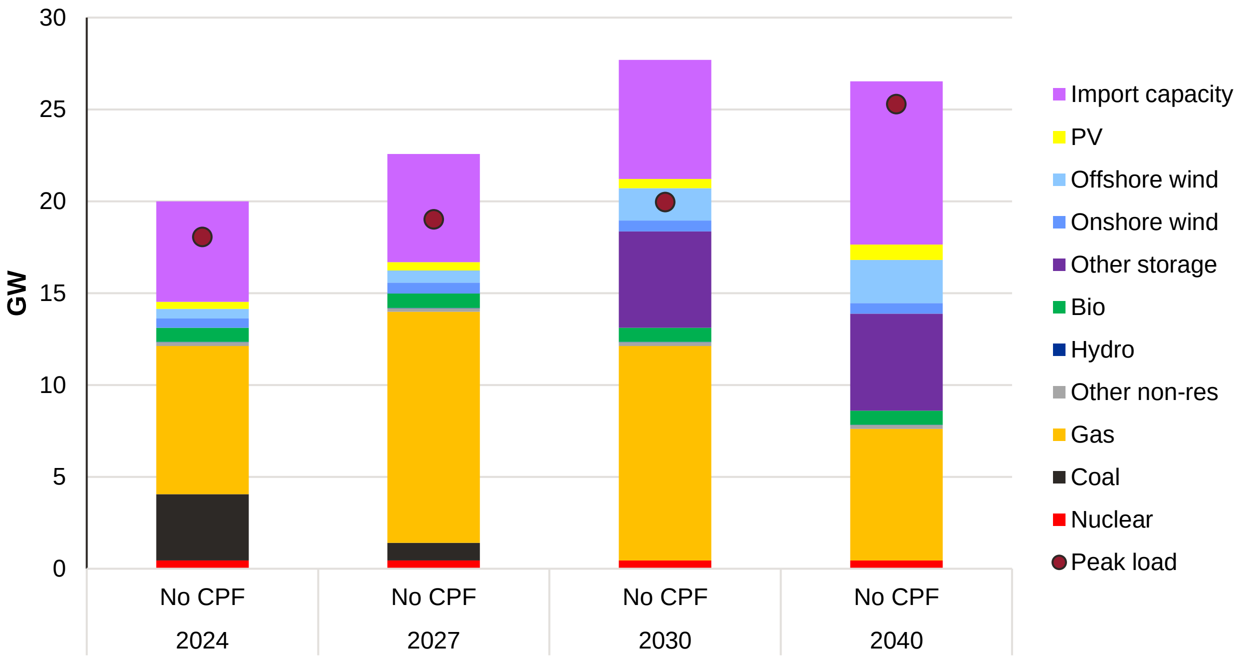
Source: Frontier Economics

- The wholesale **electricity prices decline** from about 130 EUR/MWh in 2024 to about 105 EUR/MWh in 2027. Thereafter there will likely be a slower decline in electricity prices beyond 2030.
- The wholesale price reduction reflects the expected **decline of fossil fuel prices** until 2027. In the long term the cost advantages of increasingly available renewables capacity will come into effect, together with rather steady fuel costs and increasing carbon prices.

4.1.5 Reserve margins

Figure 14 summarises the main modelling results of the expected future development of the adequacy reserve margin in the Netherlands:

Figure 18 Reference scenario: Adequacy reserve margins



Source: Frontier Economics

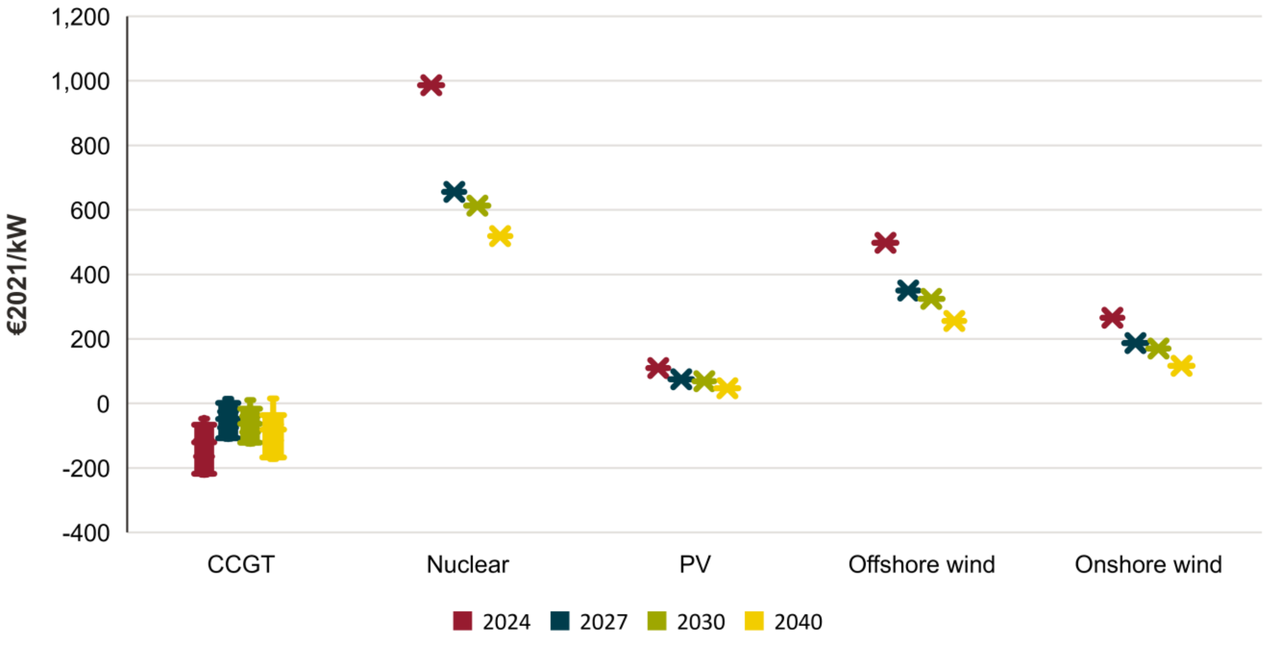
Note: The adequacy reserve margin informs about the level of reliable capacity compared to peak load. It is calculated as the difference between the de-rated available capacity (incl. a share of reliable import capacity) and peak load. We de-rate import capacity with 60%, which corresponds to the lowest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

- The **adequacy reserve margin increases until 2030**. In 2027, additional gas-fired capacity overcompensates the decline in coal capacity. In 2030, mainly new storage capacity provides additional secure capacity, more than compensating declining gas capacity.
- The **adequacy reserve margin declines after 2030**. Increasing contributions from new import capacity and renewables is insufficient to make up for the further decline in gas.

4.1.6 Power plant profits

Figure 19 summarises the main modelling results of the expected future development of power plant profits in the Netherlands:

Figure 19 Reference scenario: Power plant profits



Source: Frontier Economics

Note: Profits are measured as the short-run profits per installed capacity, i.e. wholesale market revenues minus variable production costs.

- Gas-fired CHP **CCGT plants** rely to a large extent on income from heat generation as electricity sales alone do not cover costs. CCGTs without cogeneration have operational profits close to zero, indicating a challenging market environment. While CCGT profits improve by 2027 due to declining coal generation, they degrade again thereafter with increasing generation costs and competition from renewables.

- Profits of **renewables** decline constantly over time, driven by declining wholesale prices and increasing market saturation of renewables. The high simultaneity of renewables results in lower market prices during hours with high generation.

- **Nuclear** profits follow (declining) wholesale price movements closely, owing to their typical operation as base-load plants.

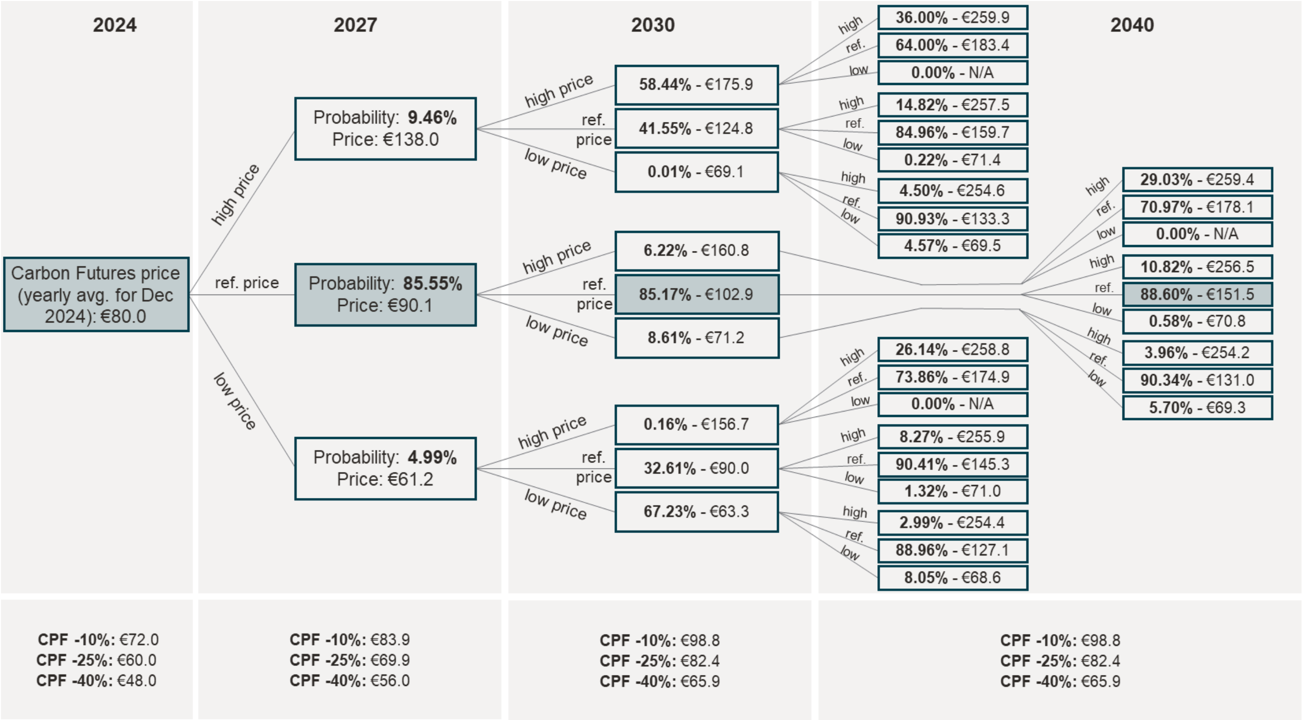
4.2 Central EU ETS price case (with non-binding CPFs)

The analysed CPF scenarios set the floor price for carbon emissions in the Netherlands below the expected carbon price path (CPF defined as prices path at -10%, -25% and -40% below the expected carbon price path, which is based on prices of traded futures and KEV 2022 main scenario).

The relevant carbon price path from the scenario tree is indicated in Figure 20 and represents the most probable future carbon price path ("central EU ETS price case") taken from the analyses in section 3. It has to be noticed that decisions of market participants at any point in time (e.g. in year

2027) take possible outcomes of all potential price CO_2 paths developments (i.e. in model years 2030 and 2040) into account, not only the most probable development (as a deterministic model would).

Figure 20 Central EU ETS price case



Source: Frontier Economics

Note: All prices in €2021/tCO_2eq.

Due to our stochastic modelling approach, the model takes into account the probability that from one representative year to the other the EU ETS price could fall below the CPF. In the following, we analyse to what extent there is a change in behaviour of market participants from the uncertainties regarding the future carbon price. Thus, although the presented results in this section show the outcomes for the EU ETS price following the central price path, they still allow for a deduction of potential changes in behaviour induced by the possibility of a CPF becoming binding.

In the following, we outline the major results for the different CPF scenarios (-10%, -25%, -40%) by using the following key indicators:

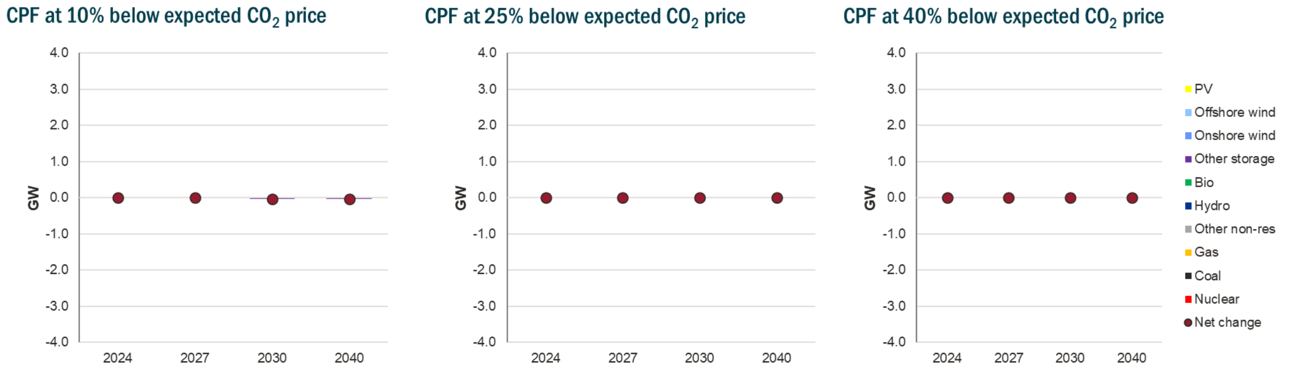
- Power generation capacities; and
- Electricity generation and results for other indicators

4.2.1 Power generation capacities

The introduction of a CPF has a small impact on the expected profits for power plants: While renewables could benefit from a slightly improved profitability expectation resulting from a CPF (see the background box at the end of this section), the contrary holds for fossil fuel plants. Potentially higher emissions costs induced by a CPF and consequently higher variable generation costs in the Netherlands could result in a reduced competitiveness of domestic gas- and coal-fired power plants.

The sheer existence of a CPF (without it being binding) could already have an impact on generation capacity: Compared to a scenario without a CPF, a CPF influences the profitability of power plants in *possible* future carbon price scenarios (*if* the EU ETS falls below the price floor). For example, a plant operator might decide to retire a plant because he *would* make less profits in the future *if* the EU ETS price falls below the CPF compared to the case without a CPF, influencing his *expected* profits today. However, our results for the reference EU ETS price scenario indicate that for the analysed CPF options the impact is not large enough to trigger any changes in the installed capacity of fossil fuel plants (Figure 21).

Figure 21 Central EU ETS price case: Impact on power plant capacities



Source: Frontier Economics

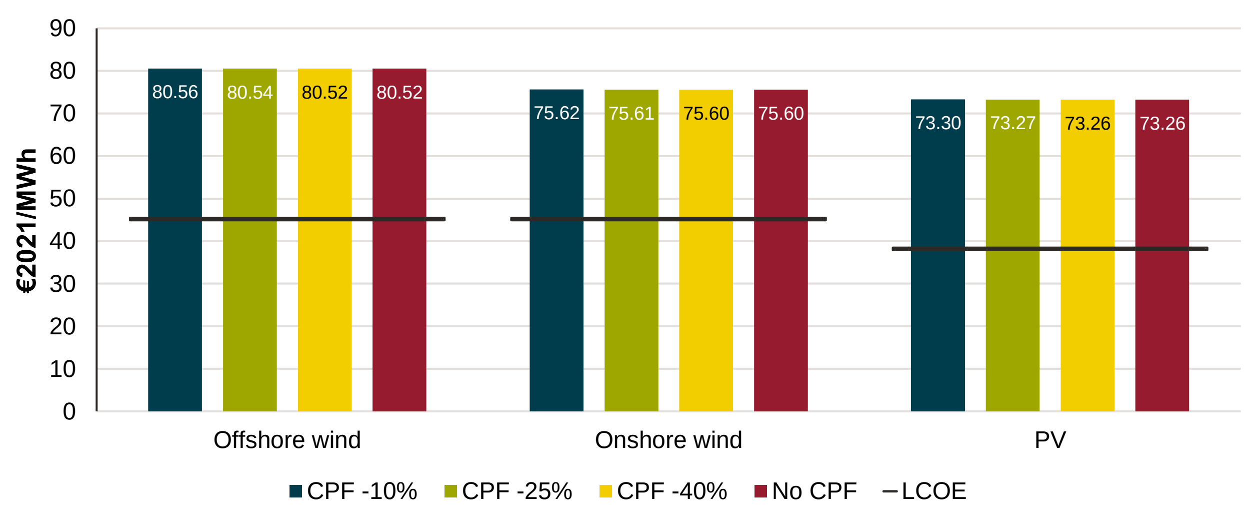
Due to a low probability that the analysed CPFs become binding and a relatively low impact on wholesale electricity prices if they do (see section 4.3.5), the expected profits of renewables are hardly affected by the CPFs. Thus, an impact on low carbon technology investments would be small. However, wind and (utility) solar PV are already profitable and competitive with fossil fuel-based electricity generation without a CPF for the analysed fuel prices and a wide range of possible EU ETS price scenarios. As a result the power plant capacities in the CPF scenarios do not differ from the reference scenario without a CPF.

Background: Impacts of carbon price floors on expected profits for RES-E

For an investment decision in renewable energies, the expected average profit per unit of generation is essential to evaluate whether a project is economical or not. The expected profit can be compared with the Levelized Costs of Electricity (LCOE): If the expected profit is higher than the LCOE, the investment could generate an expected profit.

Figure 22 illustrates the expected average discounted profits of investments in renewables in 2024 over their lifetime for different CPFs. The values represent the expected profits over all EU ETS price scenarios, weighted according to each price path's probability as indicated in the EU ETS price scenario tree (see Figure 13).

Figure 22 Expected discounted profits and levelized costs of electricity (LCOE) of renewable investments in 2024



Source: Frontier Economics

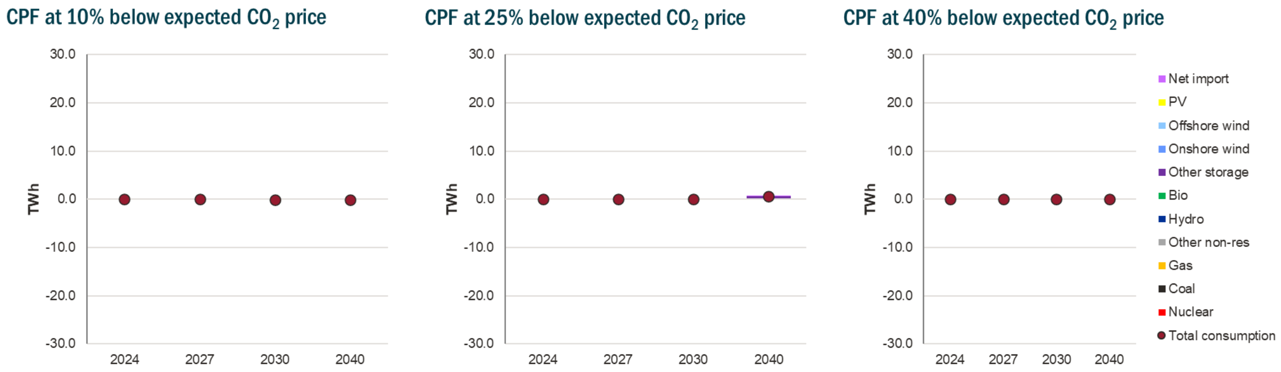
Note: Assuming lifetimes of 25 years and 2% discount rate. Prices assumed constant after 2040.

The discounted profits of renewable investments in 2024 show that the expected profits are hardly affected by the CPFs. A CPF thus does not seem to benefit investment decisions. However, the expected profits are higher than the levelized costs of electricity generation, indicating that renewable investments, under our scenario assumption, are expected to be economical already without additional support.

4.2.2 Electricity generation and results for other indicators

Given that the model results do not indicate a change in installed capacity of fossil fuel plants and that the CPFs are not binding in the reference EU ETS price path (and thus do not impact generation costs), also the electricity generation remains almost unchanged.

Figure 23 Central EU ETS price case: Impact on power generation



Source: Frontier Economics

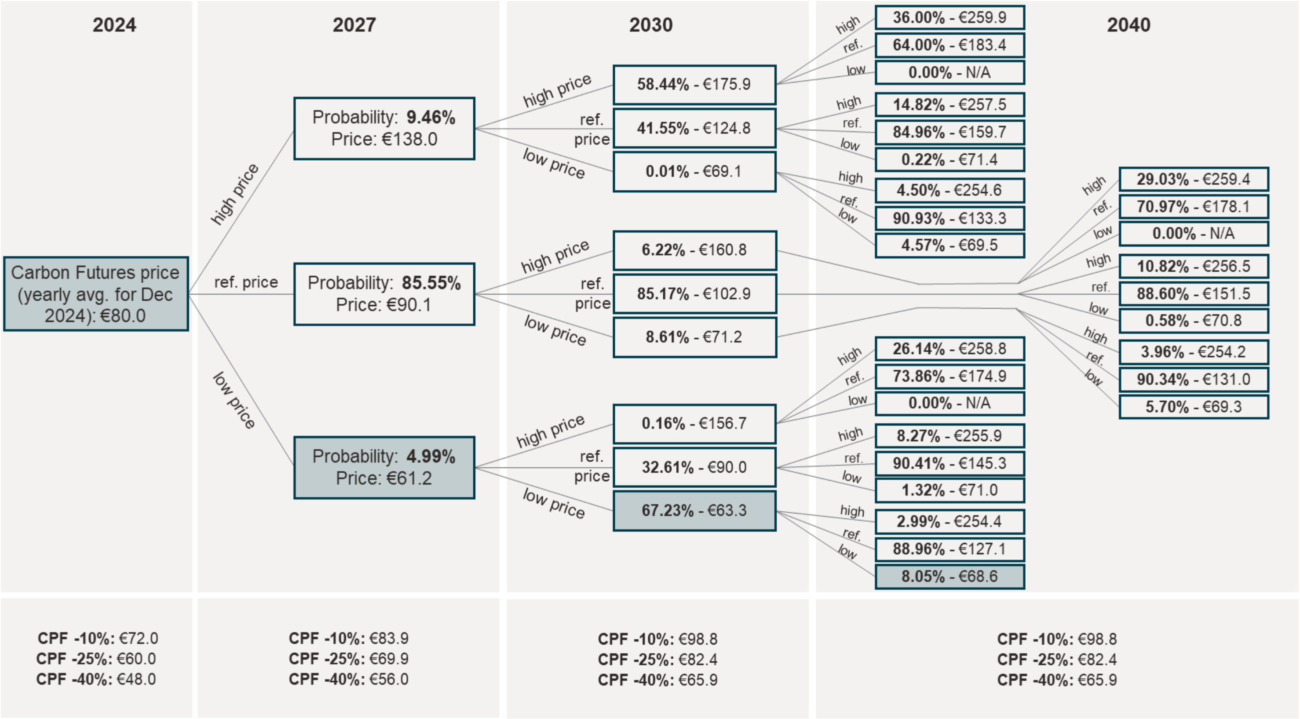
Consequently also all other indicators remain unaffected. This indicates that although a CPF slightly impacts the expected and lower range profits of all generators, the low probability of low EU ETS price scenarios prevents CPFs to pre-emptively result in changing market outcomes.

4.3 Low EU ETS price case (with binding CPFs)

In the following we present the results for low EU ETS price case. This scenario is designed to explore the potential impacts of a CPF in case the EU ETS price deviates significantly downwards from the reference price development. This would case the CPF to impose an additional carbon tax in the Netherlands.

Based on our analysis for the probability distribution of future EU ETS prices, the likelihood associated with this low price case for 2027, representing an EU ETS price of ca. 61 EUR/tCO$_2$eq, is about 5%. For 2030, our probability analysis suggests a 67% probability of continuing on a low price trajectory given that the price in 2027 was already low.

Figure 24 Low EU ETS price case (with binding CPFs)



Source: Frontier Economics

Note: All prices in €2021/tCO$_2$eq.

In the following, we summarise the main results of the low EU ETS price case for the different CPFs (defined as price paths at 10%, 25% and 40% below the expected EU ETS price projection, i.e. “central EU ETS price case”) again by using the following key indicators:

- Impact of low EU ETS price case (with binding CPF) on carbon costs;
- Power generation capacities;
- Domestic dispatch / power generation (and power imports/esports);
- Carbon emissions;
- Electricity prices;
- Reserve Margins;
- Power plant profits.

Table 6 Summary: Impact of CPFs in the low EU ETS price case

Indicator	Year	CPF -10%	CPF -25%	CPF -40%
Generation capacities	**2027**	-3.6 GW	-2.3 GW	0.0 GW
	2030	-1.4 GW	-1.2 GW	-0.6 GW
Domestic dispatch	**2027**	-22.0 TWh	-12.1 TWh	0.0 TWh
	2030	-4.2 TWh	-3.2 TWh	-1.5 TWh
Emissions	**2027**	-46%	-23%	0%
	2030:	-12%	-10%	-5%
Electricity price	**2027**	+3.2%	+1.7%	0.0%
	2030	+0.4%	+0.4%	+0.1%
Security of supply - Adequacy Reserve Margin (ARM)	**2027**	ARM turns negative	ARM declines to close to zero	ARM remains almost unchanged
	2030	ARM declines slightly but remains positive	ARM declines slightly but remains positive	ARM remains almost unchanged
CCGT profits	**2027**	moderate negative impact	low negative impact	minimal impact
	2030	high negative impact	moderate negative impact	minimal impact

Source: *Frontier Economics*

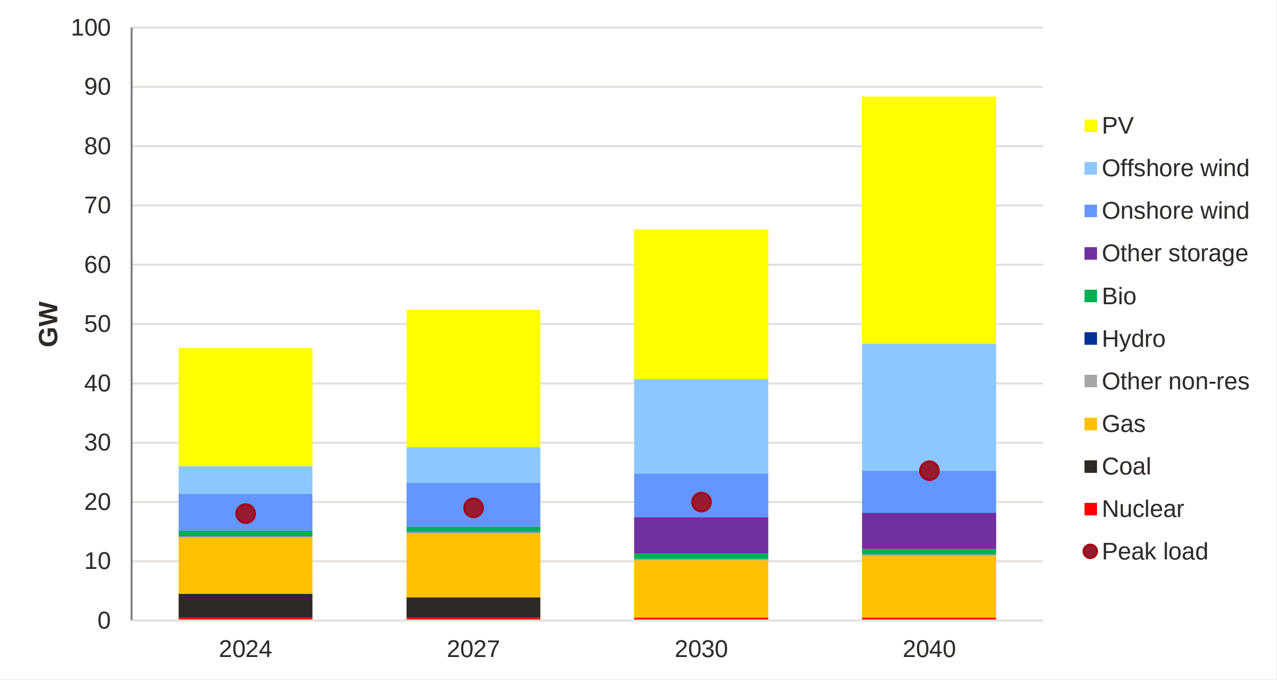
Note: *Generation capacities indicate total installed and active capacities*

Reference (without CPF) for low EU ETS price case

It has to be noted that in a scenario with a low carbon price in the EU ETS and without a CPF, the Dutch power system develops slightly different than in the reference scenario with a central EU ETS price assumption (which is shown in section 4.1). For example, due to the lower carbon price,

- Not all gas-fired power plants are reactivated in 2027; and
- Coal-fired power plants are closed later.

Figure 25 Reference for low EU ETS price case: Installed generation capacity



Source: Frontier Economics

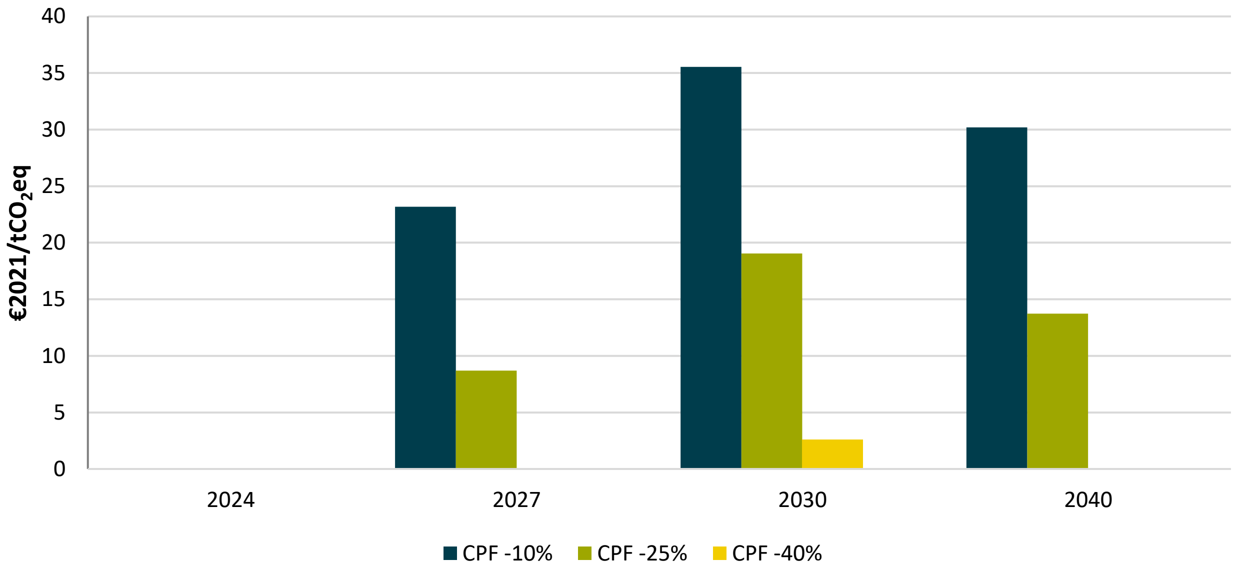
The complete results for the reference scenario (without CPF) for the “low EU ETS price case” can be found in Annex D.1.

In the following, the variations in the results shown relate to the differences in the results of the electricity market model runs with and without the CPFs – in all cases assuming a low EU ETS price development.

4.3.1 Impact of CPFs on carbon costs

The level of the additional emissions costs (costs per tonne CO_2eq emitted in addition to the EU ETS price) is illustrated in Figure 26 for the different CPF scenarios. As the CPFs only influence the emissions costs in the Netherlands, the depicted costs also represent the difference between emissions costs in the Netherlands and neighbouring markets.

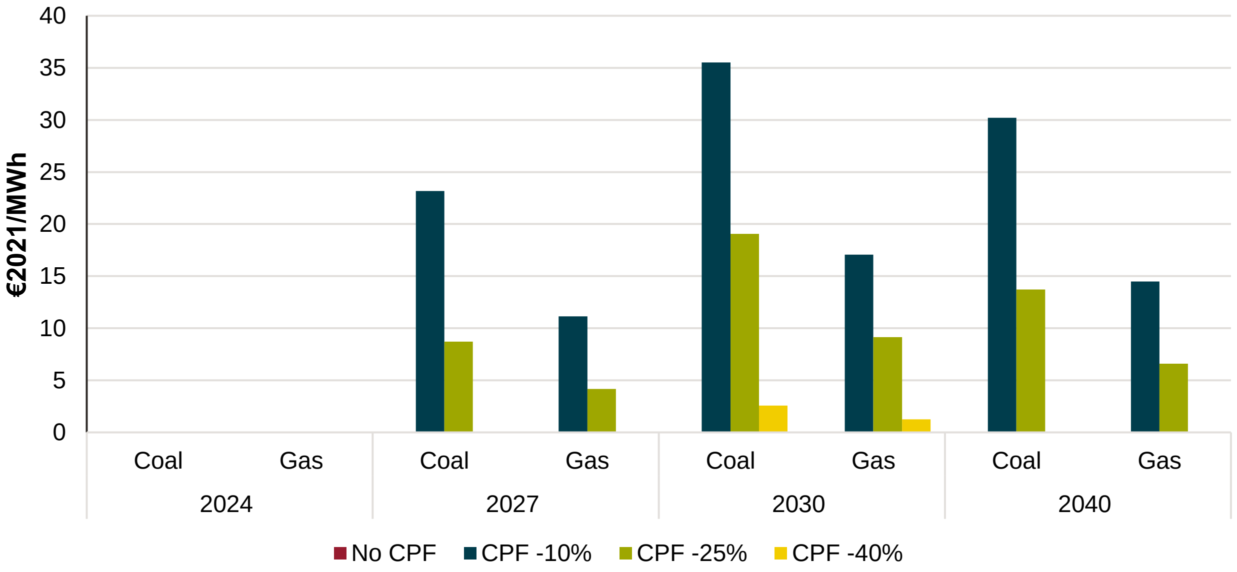
Figure 26 Low EU ETS price case: Carbon costs induced by the analysed CPFs



Source: Frontier Economics

The higher carbon costs in the Netherlands raise generation costs of fossil fuel plants according to their fuel efficiency and the carbon content of the used fuel. In the low EU ETS price scenario, the CPF of 10% below the reference EU ETS price results in between 11 to 17 EUR/MWh higher variable generation costs for a typical gas-fired power plant in the different analysed years (23-36 EUR/MWh for coal), whereas the lowest analysed CPF of 40% below the reference EU ETS price only results in about 1 EUR/MWh (gas) and 3 EUR/MWh (coal) additional variable costs (see Figure 27).

Figure 27 Low EU ETS price case: Generation cost delta between the Netherlands and neighbouring markets



Source: Frontier Economics

Note: Assuming a fuel efficiency of 50% for gas and 40% for coal. Coal generation costs for 2040 only shown for informative purposes as coal is phased out by 2030 within the Netherlands.

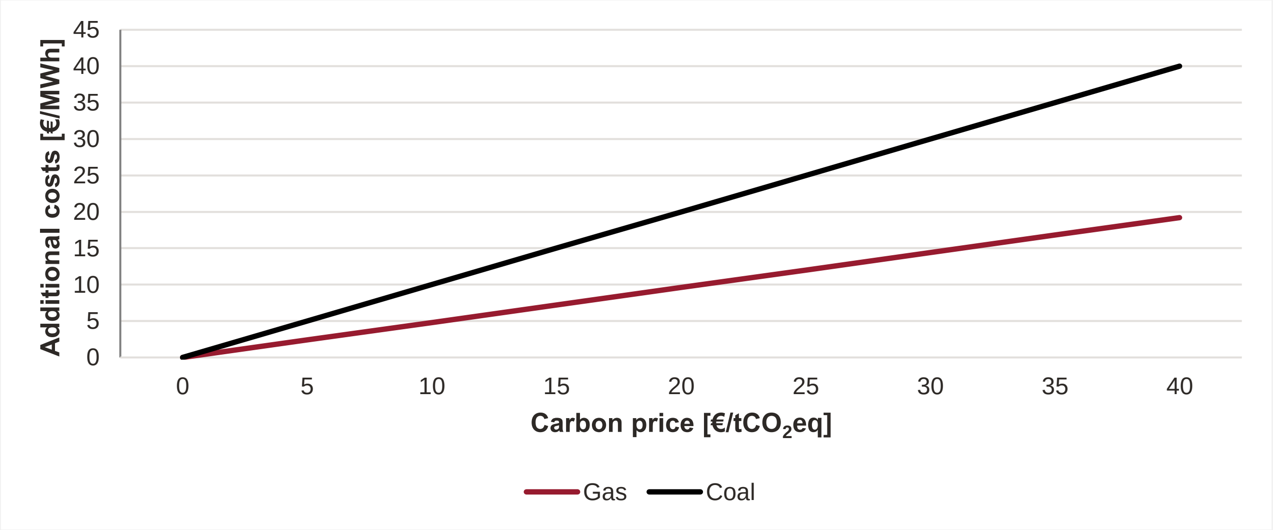
Background: Impact of carbon price on variable generation costs

A CPF results in additional costs for carbon emissions when the EU ETS price falls below the CPF. As the analysed CPF only applies in the Netherlands, this results in higher electricity generation costs domestically than in neighbouring markets for comparable power plants.

The contribution of carbon costs to total short-term generation costs depends on the fuel efficiency of a plant and the carbon content of the used fuel. With fuel and carbon prices as of early 2023, the variable costs of a gas-fired plant consist of about two-third of fuel costs and one-third of carbon emission costs. For coal, the relation is roughly vice versa.

Figure 28 illustrates for reference coal and gas power plants how additional carbon costs translate into additional short-run generation costs. For typical gas fired CCGT power plants, every 1 EUR/tCO_2eq translates roughly in additional generation costs of 0.5 EUR/MWh. For typical coal-fired plants (due to their lower fuel efficiency and higher carbon content of the fuel), generation costs increase by about 1 EUR/MWh for every 1 EUR/tCO_2eq.

Figure 28 Impact of carbon price on coal- and gas-fired power plant generation costs



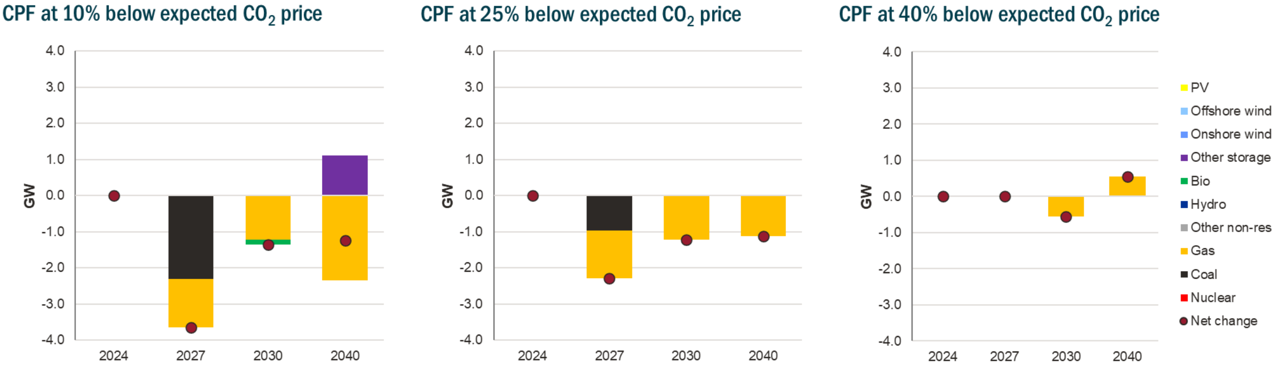
Source: Frontier Economics

Note: Assuming a fuel efficiency of 40% (coal) and 50% (gas) of electricity generation.

4.3.2 Power generation capacities

The low EU ETS price path assumed in this scenario results in higher generation costs for domestic fossil fuel-based power plants. This weakens the competitive position of these plants compared to power plants in neighbouring markets. This again could result in lower domestic capacity, triggered by domestically lower new construction of power plants, earlier retirement, mothballing or non-reactivation of previously mothballed capacity.

Figure 29 Low EU ETS price case: Impact of different CPF levels on installed capacity in the Netherlands



Source: *Frontier Economics*

Figure 29 summarises the impact of the introduction of different CPF levels on capacity compared to the reference case without a national CPF:

- **A CPF at 10% below the reference EU ETS price could result in significant fossil fuel plant retirements in the short-term, while the CPF -40% is likely to have no effect.** The additional carbon costs in the CPF -10% scenario result in a significant reduction of coal (down 68%/2.3 GW) and gas (down 12%/1.3 GW) capacity in 2027 compared to the reference case without CPF. Coal-fired plants would have to retire in any case by 2030 due to the national coal phase-out. With a CPF at 10% below the reference EU ETS price, capacity leaves the market earlier as it is not able to recover the increased generation costs. The CPF -40% scenario does not result in additional emissions costs in 2027 as it is still below the low EU ETS price scenario. Consequently the results do not indicate a change in capacity.

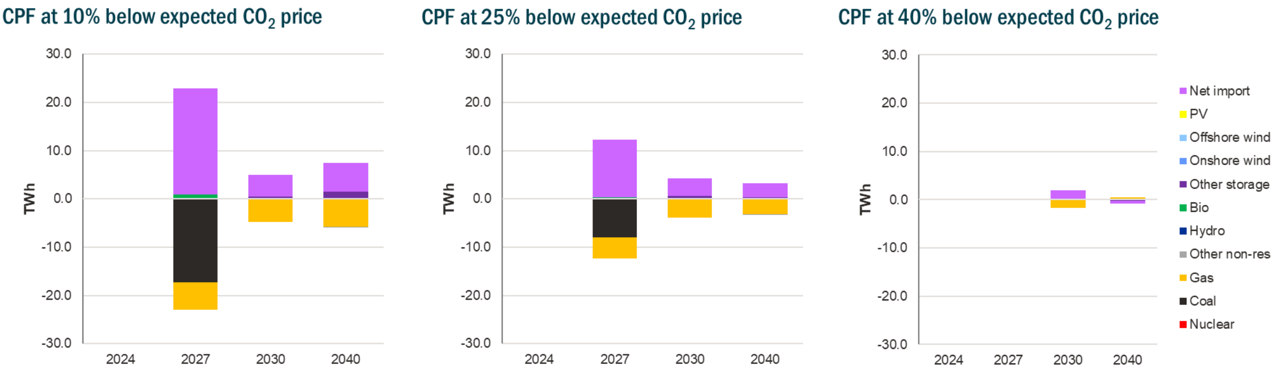
- **The different CPF scenarios result in smaller capacity differences in 2030 than in other years.** In the analysed CPF scenarios, the total capacity reduction compared to the base case without CPF varies between 1.1 GW (CPF -10%) and 0.6 GW (CPF -40%) in 2030 (with no capacity increase of individual technologies, e.g. storage). As coal-fired plants are phased-out by 2030 in the Netherlands, the vast majority of the decline comes from lower gas-fired capacity. The relatively small difference between the scenarios is due to the significant share of gas plants combining heat and power generation and thus being needed for heat generation. For this study, we assume that those plants are able to compensate their worsened competitive position induced by higher domestic carbon costs with their heat production capabilities.

- **CPFs could support battery storages to integrate renewable energies.** By 2040, in the base case without CPF, previously mothballed gas capacity in the Netherlands is reactivated to account for capacity retirements in neighbouring markets improving revenues for domestic generators. With a CPF -10%, this reactivation does not take place. Instead, about 1 GW of battery storage capacity is additionally built, supporting the integration of renewable energies into the electricity system.[27]

4.3.3 Electricity generation / power plant dispatch

Higher costs associated with carbon emissions in the Netherlands, induced by a binding CPF, put domestic electricity generation of fossil fuel-based plants at a disadvantage compared to those in neighbouring markets. This is already reflected in declining generation capacity. Furthermore, the impact can also reflect in the changes regarding domestic electricity generation as well as imports and exports.

Figure 30 Low EU ETS price case: Impact of different CPF levels on electricity generation in the Netherlands


CPF at 10% below expected CO_2 price

CPF at 25% below expected CO_2 price

CPF at 40% below expected CO_2 price

Source: *Frontier Economics*

The key observations can be summarised as follows:

- **A high CPF could result in a significant replacement of domestic coal- and gas-fired generation by imports in 2027.** In the case a CPF in the Netherlands results in additional carbon costs for fossil fuel-based electricity generation, domestic generation could be replaced by imports. In our scenario with the highest CPF, more than 20 TWh of domestic generation (~16% of demand) is replaced by imports in 2027, mainly from Germany. The majority of reduced domestic generation would stem from coal-fired power plants (down 17.2 TWh / 78.8%) which experience a higher increase in generation costs than gas-fired plants due to the higher emissions intensity of electricity generation. Gas-based generation declines by 5.7 TWh / 15.6%, with a majority of the remaining generation coming from CHP plants.

- **For 2030 and 2040, heat demand could limit the decline in domestic gas generation caused by a binding CPF.** Following the national regulation, coal power plants will be phased-out by 2030 in the Netherlands. While a significant share of the overall impact of the CPFs in 2027

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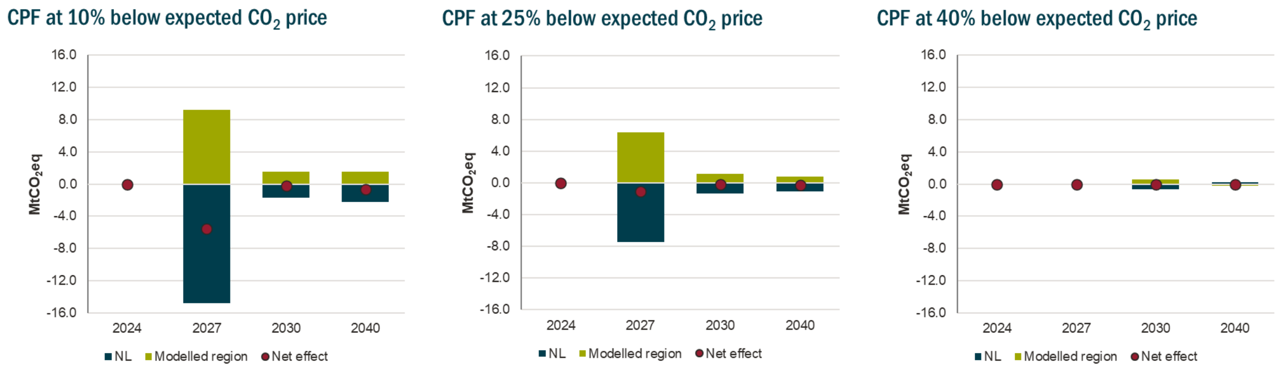
[27] However, due to their different technical characteristics (e.g. strong focus on short-term flexibility of batteries), the capacity of storages and thermal plants cannot be directly compared (in the sense of “replacing” each other).

results from changes in coal-fired generation, this is naturally no longer the case in 2030 due to the phase-out. Additionally, CHP plants constitute a large share of the domestic gas-fired plant fleet particularly in 2030. CHP plants have to run to satisfy heat demand and are therefore less impacted by higher generation costs. Consequently, in 2030 and 2040, in the CPF -10% and CPF -25% case, domestic electricity generation declines less than in 2027. For the CPF -40% scenario, the expected impact of is relatively small, in line with the lower additional emissions costs than with the higher CPFs.

4.3.4 Carbon emissions

As previously discussed, a CPF in the Netherlands, if becoming binding, results in higher emissions costs in the Netherlands and consequently in reduced electricity generation from fossil fuel-based plants. Domestic emissions decline. However, this does not necessarily result in an overall decline of emissions in the whole system. The net effect depends on how the reduced fossil fuel-based generation in the Netherlands is compensated.

Figure 31 Low EU ETS price case: Impact of different CPF levels on carbon emission in the Netherlands and sourrounding markets



Source: Frontier Economics

The key observations can be summarised as follows:

- **A CPF at 40% below the expected EU ETS price is unlikely to have an effect on carbon emissions.** As the low CPF scenario would only slightly elevate the domestic carbon costs even assuming a low EU ETS price scenario, and therefore capacity and generation remain mostly unchanged, also carbon emissions remain stable.

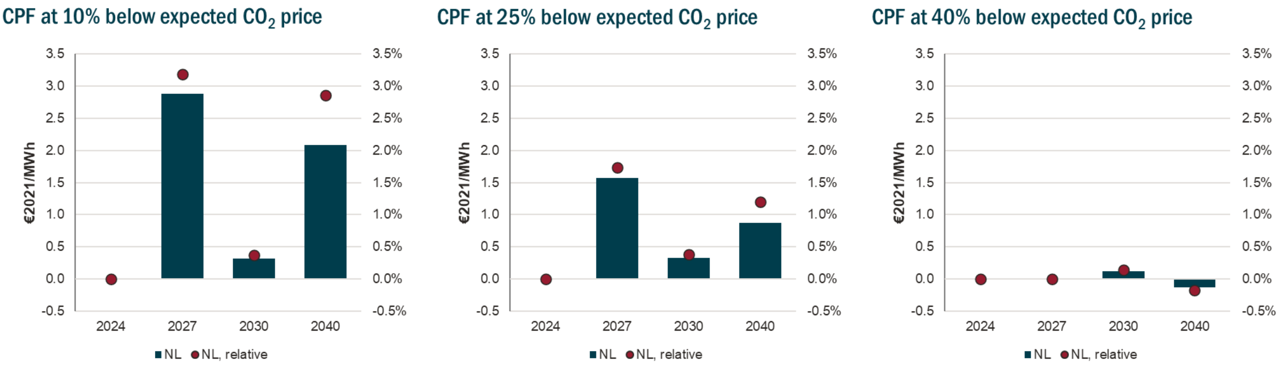
- **The largest domestic emission reductions could potentially occur before 2030.** A CPF, if resulting in additional emissions costs for domestic electricity generation, could have the largest impact on carbon emissions by impacting coal-fired electricity generation as they emit about twice as much per generated unit of electricity than gas-fired power plants. This is confirmed by the model results showing the largest impact in 2027 when active CPFs reduce coal-fired generation. From 2030 on however, when coal power plants are phased out, the maximum annual emission reduction in the Netherlands over all CPF scenarios in the modelled years is ~2.2 $MtCO_2eq$ or 17.8% of the total domestic electricity sector emissions in that year.

- **Reduced emissions caused by higher domestic carbon costs are largely compensated by increasing emissions in neighbouring markets.** Adding to the limited impact of a CPF on carbon emissions in later years is the leaking of emissions into neighbouring markets. While fossil-fuel based generation would decrease in the Netherlands with additional carbon costs, this is compensated by imports – and thus the net effect on emissions depends on the emissions intensity of the imported electricity. Our results show that the imported electricity is produced by a mix of gas, coal, and bio plants, resulting in a net negative effect of overall emissions in the electricity sector in 2027 in the CPF -10% case and to a lesser extent in the CPF -25% case. For later years however, for which domestic gas-generation and no longer coal has to be replaced in the Netherlands, the net effect is close to zero.

4.3.5 Wholesale electricity prices

A CPF can impact electricity prices due to its impact on generation capacity and on short-run generation costs of fossil fuel fired power plants. However, the magnitude of the impact depends on the overall system including the interaction with neighbouring markets and is therefore a priori unclear.

Figure 32 Low EU ETS price case: Impact of different CPF levels on wholesale prices in the Netherlands



Source: Frontier Economics

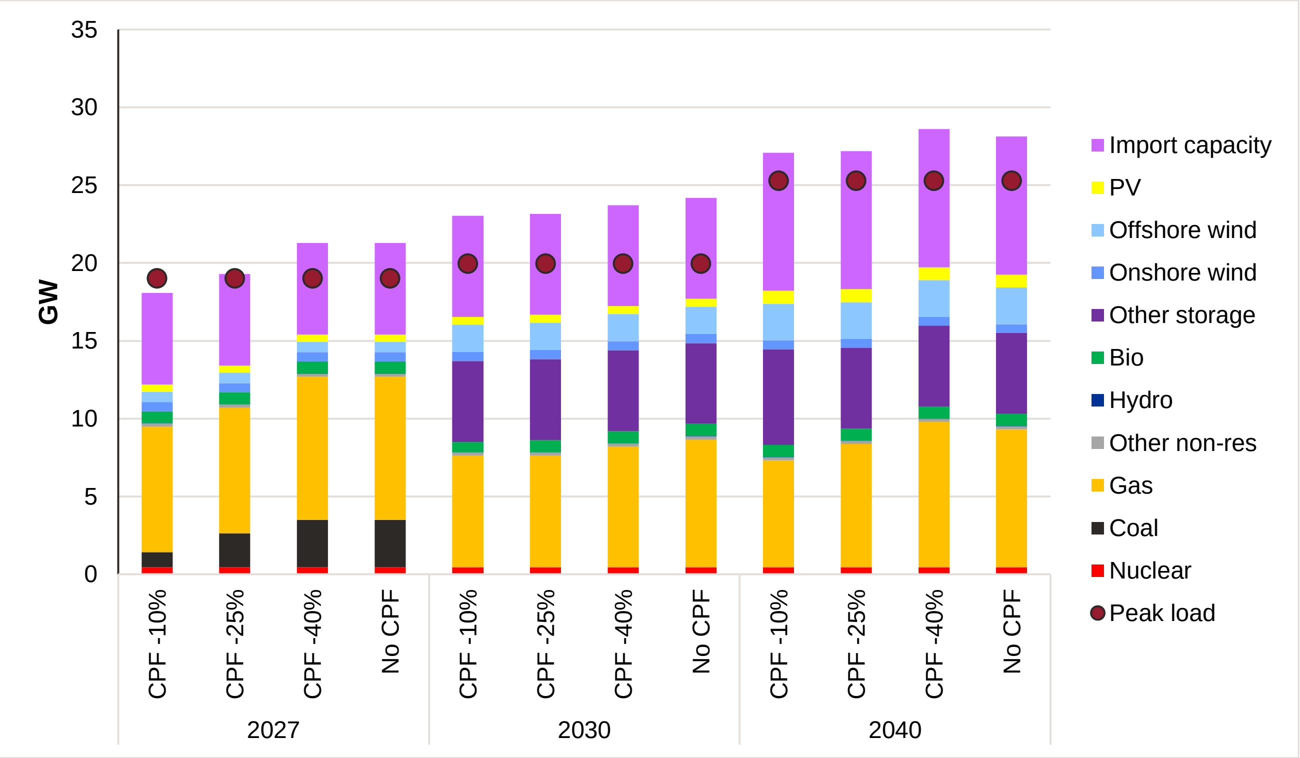
- **While a low CPF would only marginally impact wholesale prices, higher CPFs could have a noticeable impact.** In the CPF -40% scenario, wholesale electricity prices are hardly affected even in our low EU ETS price scenario and for all reference years. In the CPF -10% case, the impact on wholesale electricity prices is most pronounced. In 2027, prices in the low EU ETS price scenario increase by close to 3 EUR/MWh (3.2%). The effect of the CPF -25% ranges between the other scenarios.

- **While the wholesale price effect of CPFs declines until 2030, it increases again in the longer term.** After the relatively strong wholesale price impact in 2027, all CPF scenarios show only a limited impact in 2030. This is because coal-fired plants are phased out by then and generations costs of gas-fired plants are less impacted by emissions costs. While the potential wholesale price effect declines by 2030 due to the phase-out of coal power plants, it is higher again in 2040, since a larger share of gas plants in 2040 passes through higher costs to the electricity price.

4.3.6 Adequacy reserve margins

The different levels of available electricity generation capacity have implications for security of supply. To assess the impact of the different CPF scenarios, we calculate the Adequacy Reserve Margins (ARM), defined as the difference between reliable generation and (derated) import capacity minus peak load (illustrated in Figure 33).

Figure 33 Low EU ETS price case: Impact of different CPF levels on peak demand and de-rated generation and import capacity



Source: Frontier Economics

Note: 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. Deriving exact values for de-rating would need extensive probabilistic analyses of availability of foreign generation capacities and the interconnectors which is not subject of this study.

Although the ARM is a simplified measure that, for example, does not take into account the probabilistic (and time-varying) nature of generation from variable renewables and the time-varying availability of import opportunities, nor intertemporal dependencies (in particular relevant for the ability of storage to contribute to security of supply), it provides valuable indications on how different scenarios compare to each other in terms of security of supply. For more detailed absolute statements regarding security of supply however, a more detailed (probabilistic) analysis is required.

- **A CPF close to the reference EU ETS price for 2027 could result in a further decline of already potentially tight supply capacity**. In the scenario with the highest CPF -10%, the sum of the derated generation and import capacity in 2027 falls short of the assumed peak demand by about 940 MW (5% below peak demand), indicating a potential supply shortage. This in mainly due to the early retirement of coal capacity. In the CPF -25% scenario, the gap closes between peak demand and derated supply, still indicating a rather tight level of secure capacity. For the CPF -40% case, the ARM is the same as in the scenario without a floor price, with derated supply being 2.3 GW above peak demand.

- **Small scenario differences for the Adequacy Reserve Margin in 2030, assuming that gas-fired CHP plants remain available with higher CPFs.** For 2030, all CPF scenarios show a similar level of secure supply capacity above peak demand, with a significant share of the capacity is provided by storages, interconnectors and, to a lesser extent, offshore wind. Although in particular the CPFs at 10% and 25% below the reference EU ETS result in significantly increased costs for gas plants, their capacity is almost equal across all scenarios. This follows from the assumption that combined heat and power plants, which constitute the majority of capacity in the market, are supported by income from heat generation and thus are less susceptible to the increase in generation costs.

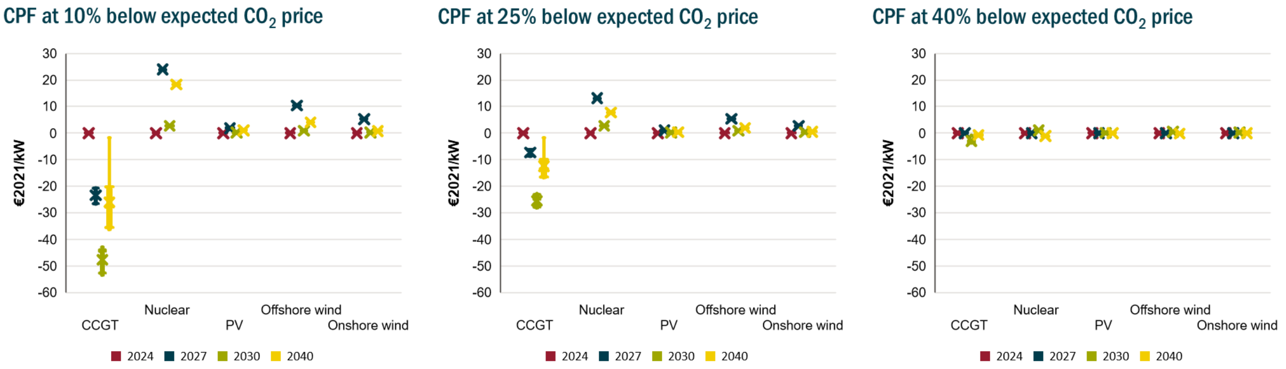
- **For the long term, the relative contribution of gas-fired plants to secure capacity declines but is still significant.** With an expected increasing electrification of energy consumption (for example due to increasing numbers of electric cars and heat pumps), also peak electricity demand is likely to increase. While renewables and storages are expected to provide a larger share of secure capacity, our results indicate that gas-fired plants (potentially operated with defossilised gases) could still play a significant role in 2040. Although the secure capacity remains in a CPF scenarios above the assumed peak demand, the CPF -10% and CPF -25% scenarios show a lower reserve margin than the CPF -40% scenario.

4.3.7 Power plant profits

While additional costs for carbon emissions induced by a CPF result in higher average wholesale prices, the total impact on profits varies between different types of electricity generation. Generation costs of renewables and nuclear are not affected by increasing carbon costs. Also they have low variable generation costs such that they produce close to the technical maximum. They thus generally benefit from the change in wholesale prices.

Fossil fuel-based power plants have to bear the higher carbon costs and are typically marginal producers. Thus, they adjust their generation level to the respective wholesale price and competitive position towards other generators (domestically and internationally). However, this can be different for CHP plants for which the generation level can depend on the heat demand.

Figure 34 Low EU ETS price case: Impact of different CPF levels on power plant profits



Source: *Frontier Economics*

Note: *Profits are measured as the short-run profits per installed capacity, i.e. wholesale market revenues minus variable production costs.*

- **A low CPF is unlikely to have a strong effect on generators' profits.** In the CPF -40% scenario, profits for all technologies remain almost unchanged. This is consistent with the impact on the other key indicators: As carbon costs are only slightly raised (if at all) the impact on all aspects of the electricity system remains small.

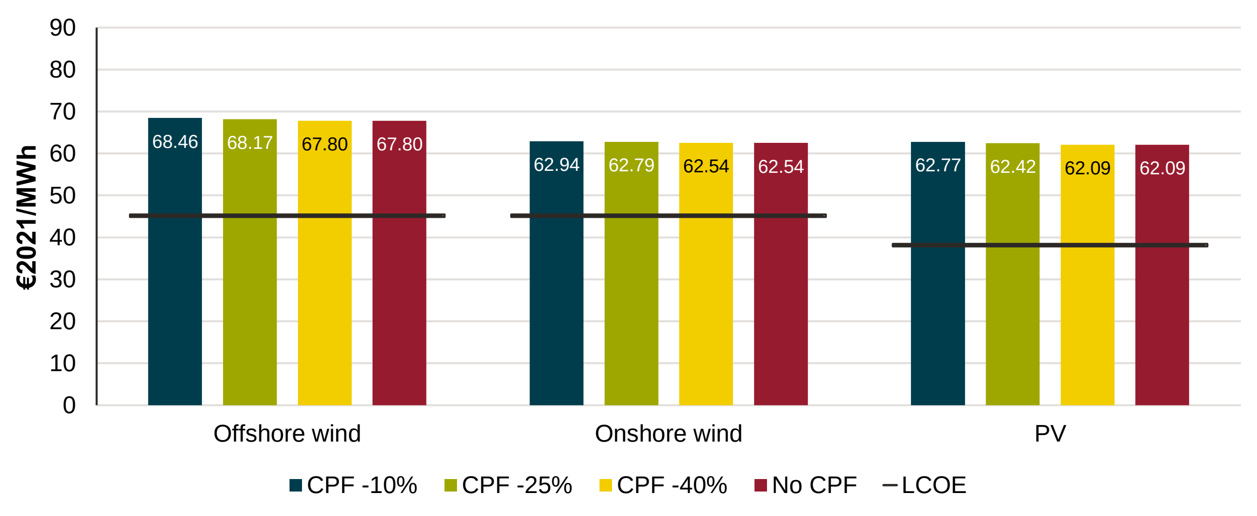
- **Gas-fired power plants could see an additional decline in profits in an already difficult competitive environment.** Although annual operating hours for gas -fired plants are only slightly affected by CPFs (lower generation volumes are served by reduced capacity), annual short-run profits decline as generation costs are increasing more than wholesale electricity prices. The effect increases the higher the added carbon costs of a CPF are.

- **Renewable energies could benefit slightly from a binding CPF.** Renewable energies could slightly benefit from a higher wholesale price induced by a binding CPF as their production volumes remain unchanged.

Background: Impact of CPFs on minimum profits for RES-E (the low CO_2 scenario)

A CPF affects the possible profits of renewables. In particular with low EU ETS prices, wholesale prices would be low (as price setting fossil fuel plants have lower costs) and thus renewables profits would be low. A CPF would prevent carbon prices in the Netherlands to fall a certain threshold and thus support wholesale prices and profits of renewables. In Figure 35, the minimum discounted profits of selected RES-E technology investments in 2024 over their lifetime are shown for the different CPF scenarios. Additionally, the Levelized Costs of Electricity (LCOE) are displayed for comparison.

Figure 35 Discounted profits of renewable investments in the low CO_2 scenario in 2024



Source: Frontier Economics

Note: Assuming lifetimes of 25 years and 2% discount rate. Prices assumed constant after 2040.

In our scenarios, the minimum discounted profits for all considered renewables are above their Levelized Costs of Electricity. This means that investments appear, given the scenario assumptions, to be profitable. This is already the case without a CPF.

A CPF could, depending on its level, further increase the minimum expected profitability of renewables investments. Compared to the scenario without a CPF, the highest analysed CPF of 10% below the reference EU ETS price would increase the minimum profits by around 1%.

4.4 Evaluation of the impact of CPFs on the key policy indicators

In the following, we summarise the finding of the electricity market scenario analysis with respect to the key policy dimensions. We do this by highlighting the impact of the CPF on the key indicators for the electricity sector.

4.4.1 Investment security for renewable energies

A CPF results in a lower limit of electricity generation costs for fossil fuel-based power plants and thus guarantees a certain level of competitiveness of renewable energies in the Netherlands. However, the benefits appear limited.

- **Investments in (utility scale) solar PV, onshore and offshore wind appear to be profitable and competitive with fossil fuel-based electricity generation for analysed wide range of possible EU ETS price scenarios.** This follows from our analysis of the Levelized Costs of Electricity (LCOE) and the expected captured prices by renewables, given prevalent fossil fuel price expectations. Thus the profitability of renewables does not appear to be a major barrier for investments in most case. Higher capacity additions than assumed in the modelling exercise are thus rather contingent on non-financial constraints like the availability of transmission infrastructure and land, the speed of permitting, sufficient labour, the overcoming of supply chain constraints and other non-economical constraints than the profitability outlook.
- **The overall benefits for investments in renewables are limited.** Additional to renewable energies being likely to be profitable without a CPF, our analysis shows that the impact of a binding domestic CPF in the Netherlands is significantly diluted by the strong integration of the country into the European market (reflected in the large increase of imports and relatively small impact on wholesale prices). A CPF that raises generation costs of fossil fuel plants in the Netherlands does only to a small extent translate into higher wholesale electricity prices and therefore an improved economic outlook for renewables.

4.4.2 International competitiveness

For the electricity sector we evaluate the international competitiveness of the Netherlands based on the impact of a CPF on installed generation capacity as well as imports and exports. Our analysis shows that although a non-binding CPF does not appear to have an effect, the competitiveness of domestic fossil fuel-based generation could be noticeably reduced by domestically higher emission costs.

- **Although a CPF could worsen the competitiveness of domestic fossil fuel plants, this does not seem to pre-emptively result in capacity retirements.** Our results of the central EU ETS price case do not show a difference in installed electricity generation capacity between the different analysed CPF scenarios including the scenario without a CPF. This indicates that the sheer existence of a floor price (that does not become active and thus not result in higher domestic carbon costs), and therefore only the possibility of it becoming active, does not have an impact on the development of capacity and therefore the competitiveness of domestic generation.

- **An active CPF could result in declining fossil fuel plant capacity and generation.** If a CPF becomes active, it puts fossil fuel fired power plants at a disadvantage compared with their counterparts in other markets. This results in domestic generation being replaced by imports. The worsened competitiveness not only result in a reduced dispatch of domestic carbon intensive plants but also in a lower installed capacity compared to a scenario without a floor price. The magnitude if the impact depends on the additional cost level imposed on domestic generators and the year (and therefore the cost difference towards foreign capacity). In 2027, the impact could be the largest given that coal-fired plants are particularly affected by higher carbon costs. The magnitude of the capacity effects declines in the medium term, as coal-fired plants are phased out by 2030 in any case.

4.4.3 Sustainability of the electricity sector, i.e. impact on carbon emissions

Although an active CPF could result in lower carbon emissions in the Netherlands, at least some of the decline is compensated by increased emissions in other EU ETS countries.

- **An inactive CPF is unlikely to have an effect on carbon emissions.** Following the absence of a capacity and generation change in the reference EU ETS price scenario (in which the analysed CPFs do not induce additional carbon costs), also emissions in the electricity sector remain unchanged. This is because the impact on *expected* technology profits is too low to trigger capacity changes. Additionally, renewable investments appear already competitive without a CPF and are thus rather restricted by exogenous capacity constraints than their economics.

- **An active CPF could reduce emissions in the Netherlands, but the net effect in Europe is likely to be small.** For the cases in which the EU ETS price falls below the floor price, the reduced fossil fuel-based electricity generation in the Netherlands results in lower domestic emissions. However, this is at least partly compensated by additional emissions in neighbouring countries. Only in the short term, when more carbon intensive electricity from coal power plants is substituted, the model results show a net reduction in total electricity system emissions (including those in other countries). For later years, when coal plants are already phased out, no meaningful net effect can be observed.

4.4.4 Affordability of electricity

An increase of emissions costs induced by a CPF only partially translates into higher wholesale electricity prices. The impact on final consumption would be even lower.

- **An inactive CPF is unlikely to impact electricity prices.** In the analysed EU ETS and CPF scenarios, electricity prices do not change as long as EU ETS prices remain above the CPF.

- **The impact of potentially higher domestic carbon prices only partially translates into higher electricity prices.** Although generation costs of fossil fuel fired power plants could be significantly elevated by a CPF if the EU ETS price falls below the floor price (compared to a scenario without a floor price), the effects on the wholesale price are smaller. Even with the highest analysed CPF and in the low EU ETS price scenario (resulting in an increase of carbon costs for power generators between 20 and 40 EUR/tCO_2eq), the maximum increase of the average wholesale price across all CPF scenarios and years is about 3 EUR/MWh (about 3% compared to no CPF). The price increase is dampened by imports of electricity and, particularly in later years, the increasing share of renewables.

4.4.5 Electricity security of supply (i.e. impact on reserve margin)

A CPF can negatively impact security of supply if resulting in decreasing dispatchable capacity. Our results show that this is particularly the case if the CPF becomes binding and adds significant extra costs to domestic carbon emissions.

- **A non-binding CPF does not seem to impact security of supply.** The impact of a CPF on security of supply is closely connected to its impact on installed capacity. As long as a CPF does not result in additional carbon costs (because the EU ETS price is above the floor price), our scenario analysis shows no impact on installed capacity. Consequently, the level of security of supply remains unchanged.
- **A binding CPF could result in lower security of supply, particularly in the short term.** For the coming years, fossil fuel fired power plants provide the majority of secure capacity. At the same time, the model suggests that a CPF, if binding, could have the largest impact on fossil fuel capacity in 2027 when in the base case there is still significant coal capacity in the Netherlands. As a consequence, our analysis of the Adequacy Reserve Margin (ARM) indicates that a high CPF could potentially cause a capacity shortage. Also, this could exacerbate security of supply concerns for years towards the end of this decade as identified by the national transmission system operator in a recent security of supply report[28]. For later years, when storages and renewables provide more secure capacity, the impact of a CPF is reduced.

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[28] TenneT: Monitoring Leveringszekerheid 2022.

5 Impact of carbon price floors on Industry (sensibility check)

In the following, we summarise the analyses (sensibility check) on potential impacts of different CPFs on the Dutch industry. The analyses are undertaken for the low EU ETS price path as defined in chapter 3 of this study (probability of ca. 5% in the stochastic electricity market analysis in section 4). We apply CE Delft's WorldScan model, a computational general equilibrium (CGE) model, which estimates the macroeconomic effects of economic developments and policy decisions e.g. regarding GDP, employment, investments, carbon leakage (detailed description in Annex D).

For the analyses, we focus on the following industries:

- Petroleum and coal products;
- Metals;
- Chemical rubber & plastic products;
- Paper products, publishing;
- Non-metallic minerals (for construction);
- Processed food.

The modelled geographical regions comprise of

- The Netherlands;
- Rest EU;
- USA;
- Rest of the OECD;
- China;
- Rest of the World (incl. India).

In the following, we summarise the main results of the analyses in the following steps:

- Summary of overarching results (section 5.1);
- Impact of the different CPFs on international competitiveness and carbon leakage (section 5.2);
- Impact on investments (section 5.3);
- Impact on employment (section 5.4); and
- Impact on macroeconomic indicators (section 5.5).

5.1 Overarching results

The introduction of a CPF in the Dutch industry market aims to provide more certainty regarding emission reductions. In KEV 2022, it is assumed that the ETS price will rise to ca. 110 EUR/tCO_2eq in 2030 for the main scenario. However, uncertainty around the actual development of the ETS price remains, which we reflect in a probability distribution for the development of the future ETS price. As an input to the stochastic modelling of the electricity sector there is a chance of ca. 5% that the ETS price will be around 63 EUR/tCO_2eq in 2030 (low EU ETS price case). In the sensibility analysis of the industrial sector we use this low EU ETS price case as an input to the deterministic modelling to identify potential risks and benefits from the CPF options. The following results are thus based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

If the **CPF -10%** is chosen, which means a floor price of 10% below the central assumption of KEV (96 EUR/tCO_2eq), the CPF will induce a 28% emission reduction by the industry. However, the cost price difference between Dutch production and similar sectors in countries where less climate policy is pursued would increase, which would put the Dutch industry at a competitive disadvantage. This will lead to a loss on investment (8%), production (1.3%), and 1900 jobs in the industrial sector, and GDP (0.2%). It will have no impact on total labour supply, but it will lead to labour shifts in favour of non-industrial carbon-extensive sectors. It is important to realize that most of the emission reduction will occur by CO_2 Capture, transport, and Storage (CCS) in the chemical, and oil refinery sectors. Hence any labour losses in these sectors are more than compensated by the extra labour demand involved in CCS. Note that transitional costs of labour shifts ("werk-to-werk") are not taken into account.

Table 7 Summary "impact on industry" in the low EU ETS price scenario in 2030

	CPF -10%	CPF -25%	CPF -40%	Notes
Carbon leakage rate*	20%	20%	12%	Emissions increase in developing countries not just restrict to highly carbon-intensive industrial goods, but also indirect leakage of demand for fossil-based electricity and gasoline-based transport services.
Carbon emission reduction**	28% (0.4%)	17% (0.2%)	2% (0.0%)	Binding impact of CPF -10%, CPF -25%, CPF -40% is equal to33, 19, and 2 EUR/tCO_2eq, respectively. Abatement curve (marginal cost of emissions reductions vs abatement) is strongly convex.
GDP-loss	0.2%	0.1%	0.0%	GDP losses from costly emission reductions, losses in production are partly compensated by production gains in service sectors and a terms-of-trade gain
Production loss industry	1.3%	0.8%	0.0%	Energy bill is only part of production processes, and costs from carbon pricing can be significantly avoided by emission reduction (abatement curve is convex as they include CCS as low-merit order options)
Employment loss Industry ('000)	1.9	1.1	0.0	At macro-level there is zero impact on labour supply. Reason: non-labour supply policies never have proven to have an impact on labour supply
Investment loss Industry	8%	4%	0%	Investment by industry drops more than production. The reason is that production drops especially in highly capital-intensive sectors (chemical, rubber and plastics and the metal sector). Investment increases in non-industry sectors, and at the macro-level the increase is more than the losses in industry.

Source: CE Delft

*Note: * Carbon leakage rate is the % emission increase outside NL divided by emission reduction inside NL.*

*** Emission reduction is reported for the Netherlands and the EU (between brackets).*

The limited production losses will also lead to limited investment losses, but these are largely offset by additional investments in lower-carbon production processes. The production advantage for Dutch competitors in China and countries in the rest of the world leads to extra carbon emissions in these regions, also because the extra energy-intensive production goes hand in hand with extra demand for electricity (including fossil) and transport services (gasoline). The carbon leakage rate is a relative measure, which is equal to the emission increase in the rest of the world divided by the emission reduction of the Netherlands. The leakage rate is approximately 20% in the CPF -10% case. Please note that in this analysis, just like in KEV 2022, the CBAM has not yet been included. However, that means that this Dutch leakage will be additional to the European leakage rate of 45% of the EU achieving its climate goals of the EU's Fit for 55 package (see Annex E.4). Bear in mind that the EU plans are significantly more stringent than those in the rest of the world.

If **CPF -25%** is chosen, i.e. the CPF is 25% below the central assumption of the ETS price of the KEV, this will lead to fewer emission reductions (17%) by the industry than in CPF -10% (285), resulting in a reduction of 19% emission reduction by the industry. This also means that the incremental costs of the CPF on production will be smaller than in CPF -10%, and production losses drop to 0,8%, and the GDP loss will be only 0.1%. The investment loss drops to 4%. There will be no impact on total labour supply, leading also to smaller shifts of labour in favour of more carbon-extensive sectors. Once again, the more limited production disadvantages will also limit investment in carbon intensive sectors, while these are largely offset by additional investment in lower-carbon production processes. The production advantage for Dutch competitors in China and the rest of the world leads to extra carbon emissions, although in absolute terms, it is significantly less than in CPF -10%. However, the relative carbon leakage of CPF -25% remains around 20%.

If **CPF -40%** is chosen, i.e. the CPF is 40% below the central assumption of the ETS price of the KEV, this will lead to even fewer emission reductions (only 2%) by the industry. This also means that the decline of production will be smaller than in CPF -10%, falling to 0.0%, and the GDP loss will be 0%. There will be no impact on labour supply leading to smaller shifts of labour in favour of more carbon-extensive sectors. Once again, the more limited production disadvantages will also limit investment, while these are largely offset by industry through additional investment in lower-carbon production processes. The production advantage for Dutch competitors in China and the rest of the world leads to extra carbon emissions, although in absolute terms, it is significantly less than in CPF -10% and CPF -25%. However, the relative carbon leakage of CPF -25% remains around 12%.

5.2 International competitiveness / leakage

In the analysed assumption set, if the ETS price drops below 63 EUR/tCO_2eq, then the CPF -10% is binding, i.e. the CPF effectively imposes a CO_2 levy of 33 EUR/tCO_2eq emissions.[29] It is important to

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[29] Next to the EU-ETS, there are also national climate policy instruments at work, i.e. CO_2 levy of 109 EUR/tCO_2eq on excess emissions over the EU-benchmark, combined with trade in emission allowances between and by Dutch companies, and an emission reduction subsidy to ensure that the CO_2 levy does not have to be imposed. In the baseline at this low 63 EUR/tCO_2eq reference ETS price, the emission reduction by the industry is expected to increase up to 12 MtCO_2eq reduction, which is in line with PBL (2022). The 550 million euros subsidizes the non-profitable part of the industrial' emission reductions. If the ETS price drops, then this subsidy becomes less effective.

realize the potential impacts that we are analysing of a binding CPF are conditional to this price level occurring (see section 3).

Having said that, a binding CPF leads to a cost price increase at a sectoral level, as a result of which inputs and/or outputs are substituted in production. This substitution takes place through the following channels by input or output substitution. Input substitution and/or extra expenditure on CO_2-reducing techniques (adjustments to the production process via so-called retrofit investments or CCS). Output substitution to industrial sectors or products for which the CO_2 intensity of production processes is lower or to non-industrial products. The former reduces the industry's average CO_2 intensity.[30] The latter reduces the CO_2 intensity of the whole economy. Such substitutions are costly (imperfect substitution) and lead to a fall in domestic production in favour of countries with less stringent climate policies. The tax revenue from the flat CPF is assumed to be channelled back to households in a lump sum way.[31]

Implementing a CPF -10% for industries would result in a market price increase of 0.2% for the industry as a whole (see Figure 36).[32] Roughly speaking, with a binding impact of a CPF -10% in 2030 at 33 EUR/tCO_2eq against residual emissions around 30 $MtCO_2$eq, the tax revenue can be estimated at approximately 1 bn EUR. The production value of the industry will grow in the baseline to approximately 300 bn EUR.[33] So the tax revenue amounts to approximately 0.3% of production value. Since industrial companies cannot fully pass on their extra costs to customers, a market price increase of almost 0.25%.[34] If a CPF -25% or CPF -40% is implemented, then the tax revenues will be lower. Hence, the market price for the industry will increase by only 0.1% or 0.0%, respectively.

The market price changes are sector-specific, depending on the tax payments (the residual emissions times 33 EUR/tCO_2eq) compared to the sectoral production value. We can see the highest market price increases for the metals sector (0.5%), followed by the chemical rubber and plastics sector (0.4%), non-metallic mineral sector (0.4%), and petroleum and oil products (0.25%). Note that a significant amount of emission reductions relies on CO_2 capture, transport, and storage under the sea especially for petroleum and oil products and the chemical sectors.

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[30] In the metal sector, one way to reduce carbon emissions is by producing thinner, but more expensive cans that have a lower CO_2 intensity. Another option is for a manufacturer of inexpensive cans with a CO_2-intensive production process to lose market share to a competitor who produces more expensive cans with a lower CO_2 intensity.

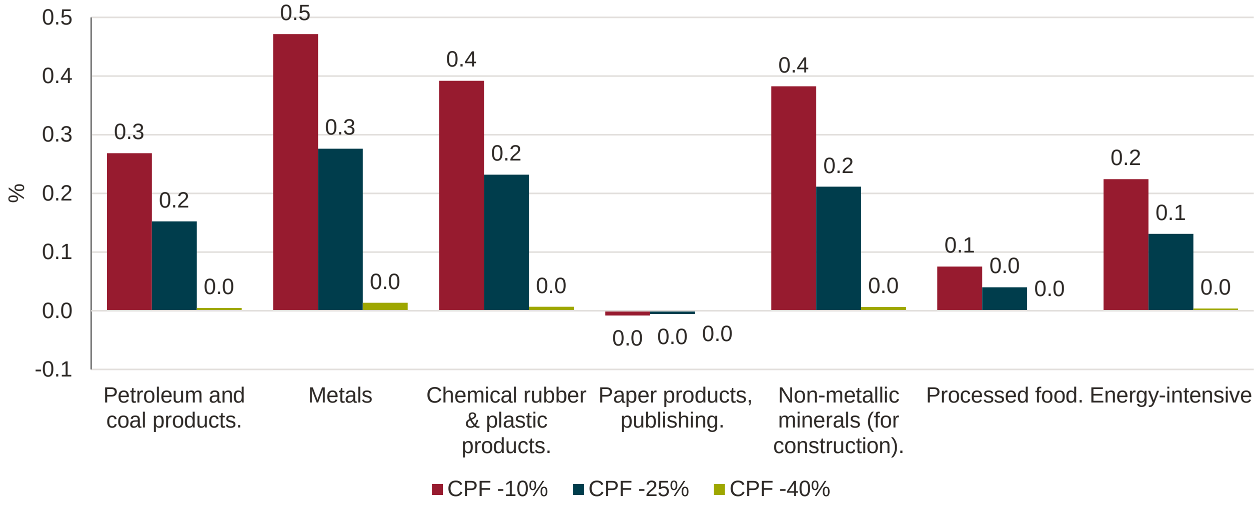
[31] Alternatively, the tax revenue could be returned as a targeted subsidy for industries in the Netherlands to reduce carbon emissions. This approach is expected to result in lower cost price increases and less production loss than implementing a flat CO_2 levy for industries, as the additional costs of the levy will be partially compensated through the subsidy.

[32] The market price is equal to the producer price, including all taxes (such as a flat CO_2 tax) and subsidies.

[33] Value Added (VA) restricts to the value of labour and capital (excluding other payments to intermediate consumption by industry) and will be 1/3 of the production value, i.e. around 100 bn€.

[34] This is in line with CPB and PBL (2019).

Figure 36 Market price impacts in 2030 at different CPFs



Source: *CE Delft*

Note: *The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.*

The expected 0.25% for the industry increase in the market price may cause a slight deterioration in the industry's competitive position, leading to a decline in exports. The extent to which exports react to the price change depends on the Armington elasticity, which is a measure of price substitution elasticity in this market. In the trade literature, the Armington elasticity for the industry is estimated to be around 6. Due to the relative increase in market price, the Dutch industry is experiencing a decline in market share at international markets, resulting in a 1.5% decrease in exports (6 times 0.25%). This, in turn, leads to a production loss of 1.3%.[35]

The “chemicals, rubber, and plastics” sector and “basic metals” sector are more significantly affected, with the percentage production losses roughly twice as high as the whole industry sector. This is due to the fact that these sectors are more CO_2 intensive and prone to international competition. However, with CPF -25% and CPF -40%, the overall production loss will be reduced, with a decrease in industrial production of 0.8% and 0.1%, respectively. Nevertheless, the chemical and base metal sectors are still expected to experience higher production losses than the industry as a whole.

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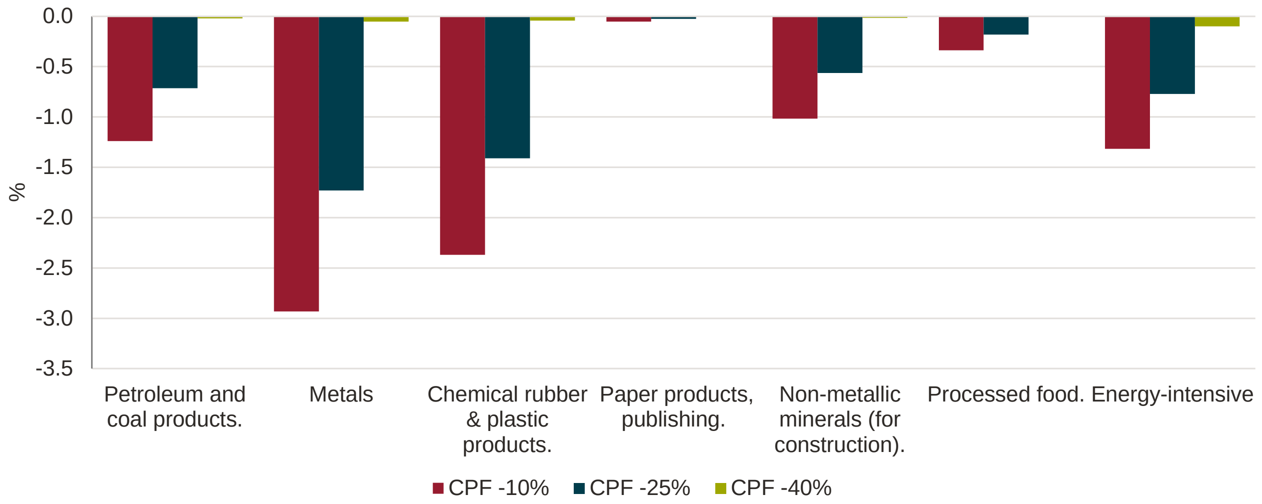
[35] Here some back-of-the-envelope calculus may be helpful. In 2030, production (305 billion euros) is equal to domestic demand (190 billion euros) plus exports (290 billion euros) minus imports (170 billion euros). Exports fell by 1.5% or 4 bn€. Production would then have to fall from 305 to 301 bn€, or 1.4%. The simulated outcome is close but 0,1% point lower, i.e. 1.3%.

Figure 37 Production impacts in 2030 at different CPFs



Source: CE Delft

Note: The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

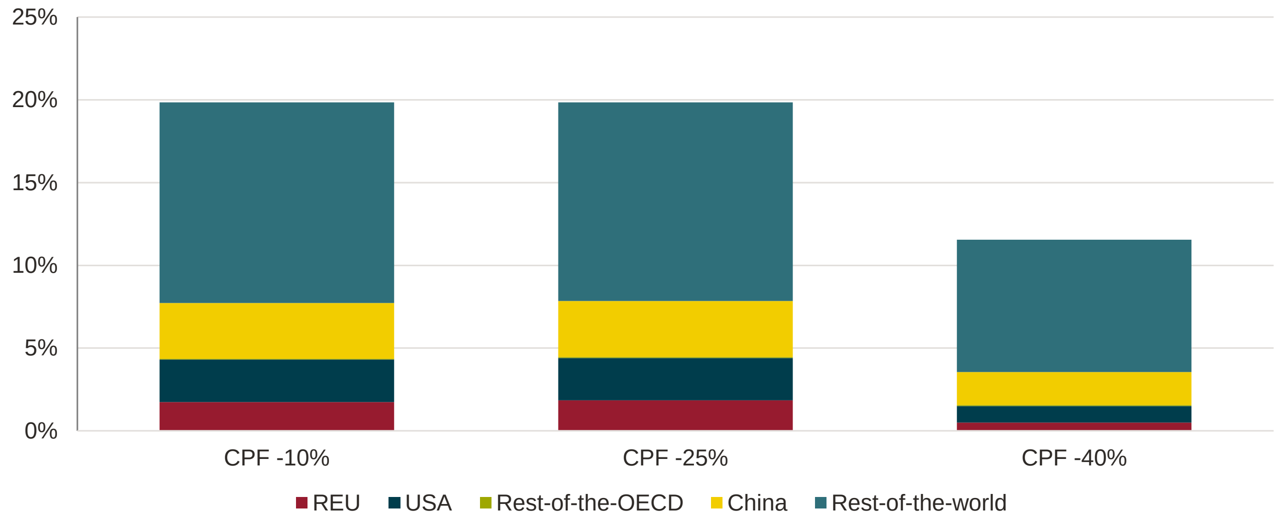
If the Dutch industry is faced with a binding CPF, then their direct carbon emission reduction efforts will be partially offset by an increase of emissions in other countries. Even in the CPF -10% scenario, carbon emissions will "leak" to more CO_2-intensive companies primarily located outside Europe. This happens despite the Netherlands' limited production losses.

When the cost price rate is relatively high compared to the production losses, carbon emissions leakage can be significant because of trade diversification in industrial activities and the corresponding demand for fossil energy. Here's how it works: as a result of the flat CO_2 levy, the Netherlands' export of products from CO_2-intensive production processes to Europe will decline. This will lead other European countries to produce these products themselves, thereby increasing their own emissions. It's important to note that only 10% of the leakage occurs within Europe.

The decline in exports from European countries to countries outside Europe is leading to an expansion of production activities in these non-European countries. To maintain their consumption levels, non-European countries are increasing their production of industrial products, resulting in additional carbon emissions. On average, the CO_2 intensity of industrial activities outside Europe is 2.5 times higher than in Europe. This relocation of production activities could lead to a fivefold increase in carbon emissions because the increased demand for industrial products will also drive up electricity consumption. Figure breaks down the leakage by regions/countries. While countries like China and the rest of the world are logical candidates for leakage, as they don't have binding CO_2 ceilings, our simulations show some leakage to the USA as well.[36,37] There's therefore a significant risk of a substantial increase in carbon emissions in countries outside Europe, which would negate the carbon emission reduction achieved by the Dutch industry by 20%. However, as emphasised before, the Dutch industry would only experience limited or moderate production losses.

In the CPF -25% case the relative leakage remains at the same level, although the absolute leakage will be much lower as the emission reduction by the Netherlands will be much lower in the CPF -25% and especially the CPF -40% scenarios. In the CPF -40% case the relative leakage declines to 10%, because the small increase in cost prices can more easily be passed on to foreign consumption.

Figure 38 Decomposition of carbon leakage to regions in 2030 at different CPFs



Source: CE Delft

Note: The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

Note also that this Dutch carbon leakage is on top of the European carbon leakage already occurring in the baseline simulation. This European leakage is measured as the emissions increase outside Europe divided by the emission reductions of the EU when intensifying EU's climate policy from the Energy Package to emissions of the Fit-for-55 package.[38] The estimated leakage rate is 45%. For

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[36] There is a non-binding intensity target in China (CO_2 / GDP reduction by 2030 of 65% compared to 2005), the Rest-of-the-World (dominated by e.g. India with a CO_2 / GDP reduction by 2030 of 45%), and no NDC in the USA as reported in WEO2021 (see IEA, 2021), while there is a binding pledge in the rest-of-the-OECD (Japan, Australia, and some OECD-South American countries).

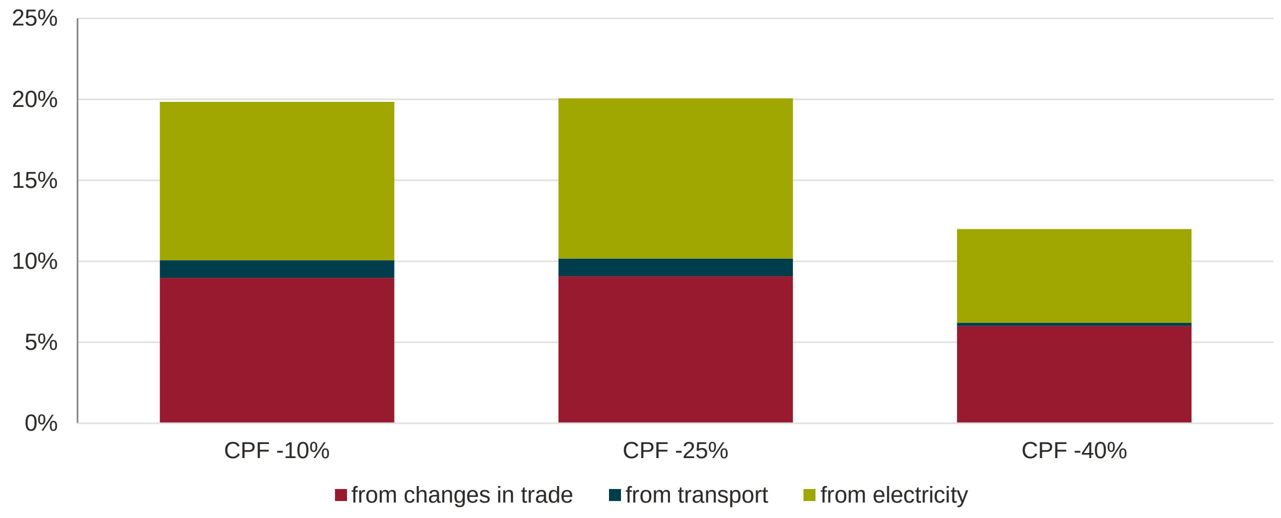
[37] Biden announced in mid-2021 their NDC with target emissions by 2030 – incl. LULUCF- to decline with 50%–52% below 2005 levels, which is actually a binding ceiling. Unfortunately, this is not included in this analysis. Nevertheless, this will have little impact on the simulated leakage results. If a binding USA target were assumed in the baseline, then there would be more leakage to the non-OECD region in the baseline simulation as production expands in the non-OECD. And while a relatively carbon-intensive non-OECD expands, then substitution at constant elasticities will yield a higher absolute leakage in those regions from a Dutch CPF.

[38] The CO_2eq emissions of the FF55 package are simulated by means of an efficient uniform carbon price over all sectors and yields a leakage rate of 45%. If the carbon budget is matched by more carbon pricing to the exposed industrial sectors, then leakage rate

more details, we refer to Appendix D4.[39] As a response, the EU has very recently also included a carbon Border Adjustment Mechanism (CBAM) as part of their FF55 package[40] to restore potential competitiveness losses and reduce leakage.[41]

Overall, extra production in non-OECD countries will also increase their GDP, leading to additional transport and demand for other services (also based on fossil fuels). Figure 5 decomposes the leakage by sectors. We can see that about half of the leakage will likely occur by trade-diversification, which comprises the most important emission-intensive sectors of the industry: the “chemical, rubber, and plastics” and the “basic metals” sector. But the other half of the leakage occurs indirectly. As production of energy intensive goods expand outside Europe, this production gain will be matched by extra demand for electricity (extra gas/coal) and oil (for transport purposes).

Figure 39 Decomposition of carbon leakage by sectors in 2030 at different CPFs



Source: CE Delft

Note: The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

Concluding, if the CPF ends up as a binding constraint on the Dutch carbon price, then leakage will be most likely around 20% due to production expanses in countries that have no binding ceilings on emissions or relatively low carbon intensity targets for the year 2030. If the CPF is less stringent. then the leakage rate remains at roughly 20%. Nevertheless, it is important to realize that in the CPF -25% case, the absolute leakage will be lower as the Dutch emission reduction declines compared to the

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will directly increase. If the carbon budget is matched by more carbon pricing outside industrial sectors, then the leakage by the industrial trade channel will decline, but it will increase by the energy price channel. In that case, the EU’s demand for gas for heating and oil for transport will decline, which will lower the international fossil energy prices for non-EU, see Boeters, S., and Bollen, J. (2012), Fossil fuel supply, leakage, and the effectiveness of border measures in climate policy, Energy Economics, Volume 34, Issue6, Available online 30 August 2012.

[39] There is no precedent in the literature analysing the leakage associated with EU’s ambitious FF55 package, i.e. compared to the non-binding pledges by some developing countries for the year 2030.

[40] https://climate.ec.europa.eu/eu-action/european-green-deal/delivering-european-green-deal_en

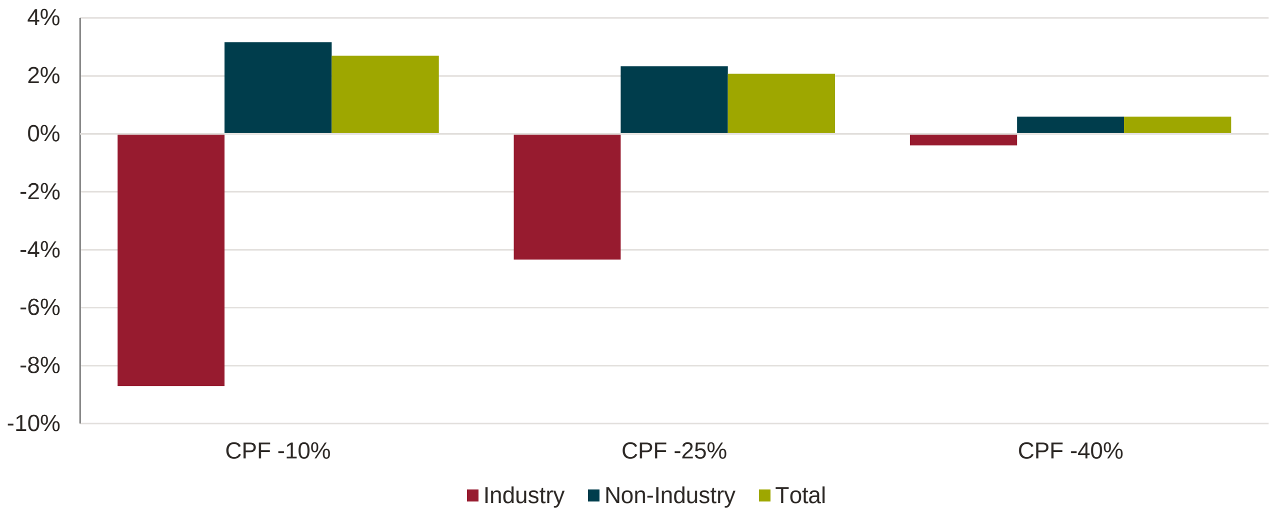
[41] CBAM is planned as an import tariff-wall covering some EU ETS sectors. If it successfully helps to improve the EU’s industrial competitiveness position and avoid leakage, it could stimulate industrial production in the EU.

CPF 10% case. Only for the CPF -40% scenario the relative leakage will also be lower, and decline to about 10%, which will hardly generate any absolute leakages as the reduction effort also declines.

5.3 Investment[42]

Here we present the effects of a binding CPF on investments. It is good to realize at forehand that investments in abatement only constitute a modest share of the overall investments, and hence the change in investment follows the changes in production rather than the extra investments from carbon abatement. Next to that, investment is one of the high-productive inputs to production next to all the other intermediate inputs producers need for production. So, the percentage changes on investment may be larger than the percentage changes on production as sectors seek to minimize on potential production losses. We can see in Figure 40 that the economy-wide investments even increase, so investments do not just reallocate, but expand as well (real interest rate slightly reduces).

Figure 40 Changes in investment in 2030 with different CPFs



Source: CE Delft

Note: The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

5.4 Employment

Next, we turn to the changes of employment from a binding CPF. The WorldScan model can assume two opposing strands in the literature, i.e. it allows for zero labour supply assumption versus endogenous labour supply responding to participation and the hours of work. As the Dutch labour market historically responded rather flexible with labour supply mostly insensitive to non-labour policies, we connect to the argument that long run labour supply is not likely to be affected by green

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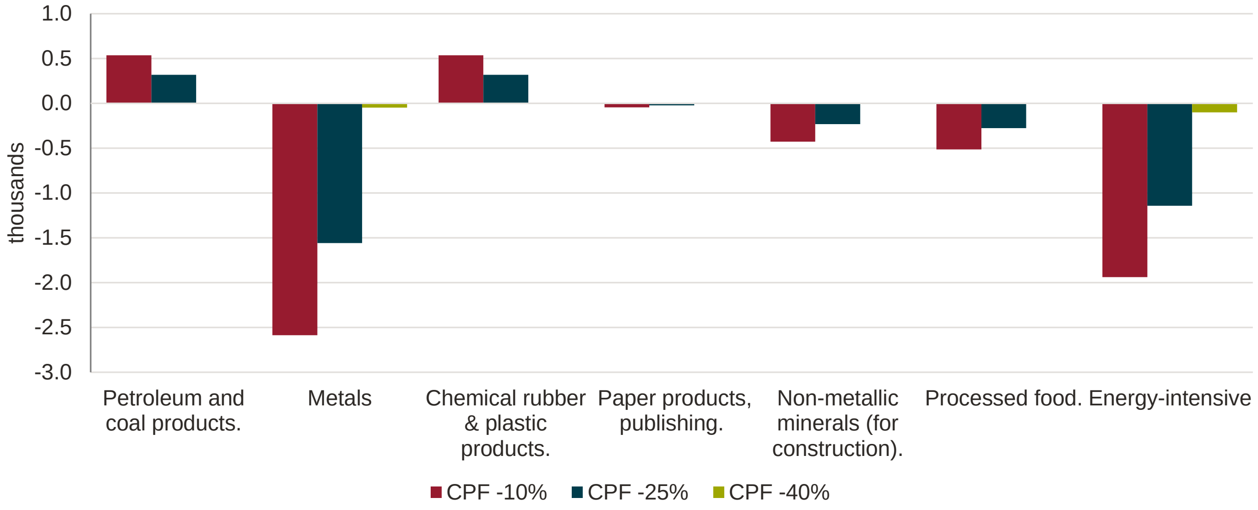
[42] As the model setup of WorldScan is deterministic, we cannot quantify the investments when the CPF is not binding. However, we believe that a non-binding CPF will have an insignificant impact on investments. This is because investments will anyway bias towards higher long-term Emission Trading Scheme (ETS) prices that align with the near-zero emission targets set for 2040. Moreover, subsidies in place up to 2030, as part of the Dutch Industrial Policy Package (see also KEV 2022), to finance industrial emission reductions further support this trend.

taxes (see also CPB/PBL, 2019). Also, it is important to realize that in this analysis only long-term changes in sectoral employment are simulated, so we refrain from potentially costly medium-term adjustments from employment shifts (for example on budgets to assist on so-called “werk-naar-werk”).

Figure 41 shows the impacts on the labour market in 2030, i.e. it illustrates the long-term changes in 2030 on employment at the sectoral level. We report here absolute changes in sectoral employment of a binding CPF. The general picture that emerges is a likely shift away from carbon intensive activities to carbon extensive sectors following the production patterns. So the industry employment will lower with approximately 2000 compared to the baseline without the CPF being offset by more employment outside the industry. Similarly to production losses, at CPF -25% and CPF -40% the losses in industrial employment (and gains in non-industrial employment) reduce considerably. We can see that the industrial employment losses from a CPF decline to roughly 1200 in the CPF -25% case, and almost to zero in the CPF -40% case.

Also at the subsector industrial level, Figure 41 presents changes in employment that follow the production pattern losses and yield a shift away from the most carbon intensive sectors. However, there is striking change not following this general pattern, i.e. the employment changes in the sectors “petroleum and coal products” and “chemical, rubber, and plastic products.” Whereas production drops in these highly energy-intensive sectors, we can observe actually employment increases. The reason is that in these sectors employment losses are more than compensated with the employment increases for the capture, transport, and storage of CO_2.

Figure 41 Changes in employment in 2030 at different CPFs



Source: *CE Delft*

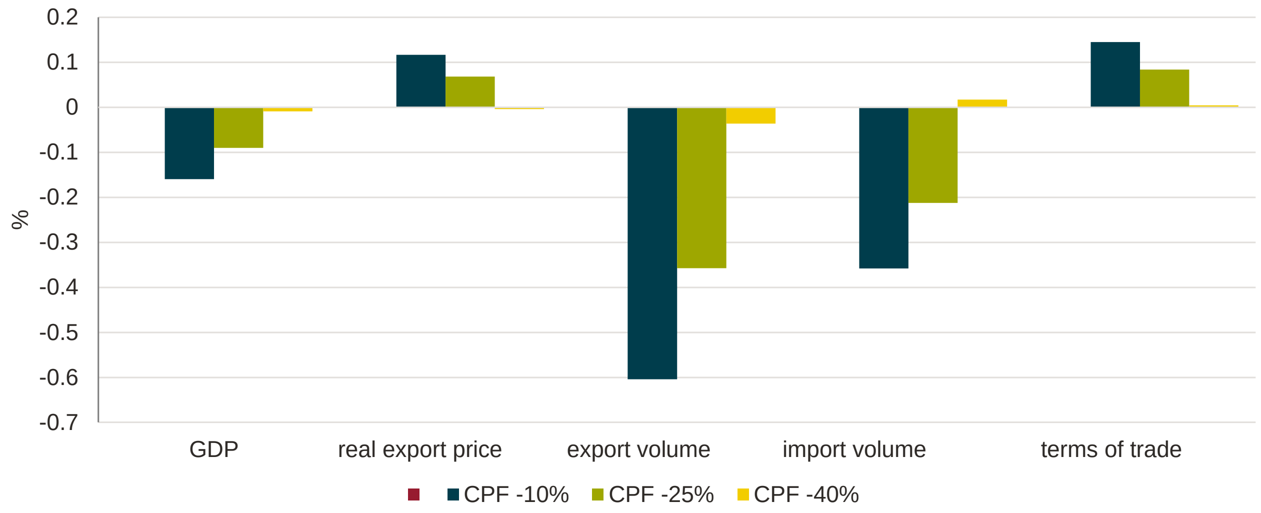
Note: *The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.*

5.5 Macro-economic Indicators

The average export price deviates slightly from the industry's market price because the industry is just a part of the Dutch economy, and there are slight adjustments in its structure. It can be observed that in the CPF -10% case, the export price increases by almost 0.1%. However, for the CPF -25% and CPF -40% cases, the export price increase drops back compared to the CPF -10% case, which follows a similar pattern as the market price increase. Additionally, the export volume now includes all sectors as compared to just the industry, meaning that the total export responds to a direct loss as described before. Here, a composite effect from structural shifts may also play a role. Imports adjust as well, but to a much lesser content as imports by the Netherlands are not directly taxed by a CPF but from adjustments of global trade flows. Moreover, the Dutch economy has less money to spend on imports while diversifying its portfolio of imports to more service-oriented activities, which are activities that are less subject to trade. A similar reasoning applies to the volume of exports and imports when switching to a less binding CPF, where the changes become smaller and almost reach zero in the CPF-45% case. It is also interesting to examine the average macro terms-of-trade changes, which are measured as the average export price divided by the average import price and resemble the purchasing power of the Dutch economy. In this context, higher prices are passed on to foreign consumers. We can observe that at the macro-level, there is a terms-of-trade gain of 0,1 implicating that mitigates the GDP losses by 0.05%. Moreover, the argument that a more relaxed CPF dampens these gains also applies here.

If we were to relax the zero labour supply assumption, a CPF could lead the Dutch government to increase expenses on social security and increase taxes to maintain budget neutrality. This, in turn, would result in higher GDP losses from green policies. Therefore, the long-term GDP estimates reported here serve as a lower-bound estimate. The GDP losses amount to 0.2%, 0.1%, and 0.0% in the different CPF cases, respectively.

Figure 42 Macro impacts in 2030 at different CPFs



Source: CE Delft

Note: The results are based on an assumption set, where the carbon prices are below the expected price level in 2030, so that the CPFs are binding.

6 Summary and conclusion

The Netherlands introduced a carbon price floor in 2022, during a time when the EU ETS price was significantly lower than today, to complement the EU-wide emission reduction mechanisms and provide additional economic certainty for investments in sustainable technologies.

Throughout 2022 and 2023, with EU ETS prices much higher than when the CPF was introduced, the floor price lost relevance. Currently, an update of the CPF level is considered. We were tasked to analyse at what level an updated CPF could provide benefits for sustainable technologies and what potential downsides might have to be taken into account.

To determine the potential effects of an updated CPF on the electricity and industry sectors, we undertook three analytical steps. First, we developed a probabilistic analysis of future carbon prices, which served as an input for the following steps. Second, we analysed the impact of different CPF options on the electricity sector by comparing market outcomes without and without a CPF. Third, we conducted a sensibility analysis on the impact of different CPFs on the industry sector. In the following we will summarise the main findings of the study.

The development of the Dutch electricity market can be characterised by a number of important trends. Next to a large increase in renewable generation capacities it is likely that additional storage capacity will be built to accommodate the intermittent electricity production. Coal plants will be phased out by 2030 so that renewable generation is in the medium to long term complemented by largely gas and storage capacities. The changes in the power plant park will lead to a strong decline in domestic emissions on the path towards climate neutrality. The modelling results indicate that these changes in the power plant park could lead to a stable reserve margin until 2030, which could decline in the period until 2040. The profits for renewable plants are likely going to decrease throughout the modelled period, with increasing renewable capacities and falling electricity prices.

CPFs constructed as a lower bound to EU ETS prices

The principle benefit of a CPF as constructed in this study is to provide a lower bound for carbon emission prices provided by the EU ETS: If EU ETS prices develop as expected (based on current assumptions regarding the future economic environment and current market indicators), the CPF should not be binding. Thus, it should not impose additional emissions costs on domestic market participants.

If the EU ETS price falls below a certain threshold, the CPF results in additional emissions costs which could potentially benefit the profitability of sustainable investments.

Our analysis shows that, contrary to the time of the first introduction of a CPF in the Netherlands, renewable technologies in the electricity sector, in particular utility scale solar PV and onshore as well as offshore wind, are significantly more competitive towards fossil fuel-based technologies than they used to be. Already at, compared to today, low carbon price levels, renewable energies appear profitable. This reduces the need for additional support in form of a CPF close to the current EU ETS price level.

CPFs likely to have no impact if EU ETS prices remain above the floor price

A CPF could impact the electricity and industry sectors even if it does not become binding. Actors in both sectors take into account potential future price and profitability developments when making decisions regarding for example new investments or the retirement of generation capacity. However, our results from the electricity market analysis show no significant impact of the analysed CPF scenarios for the case that EU ETS prices develop according to the reference scenario and CPFs do not become binding.

Also for the industry sector we believe that a non-binding CPF will have an insignificant impact on investments. This is because investments will anyway bias towards higher long-term Emission Trading Scheme (ETS) prices that align with the near-zero emission targets set for 2040. Moreover, subsidies in place up to 2030, as part of the Dutch Industrial Policy Package (see also KEV 2022), to finance industrial emission reductions further support this trend.

CPFs could have an impact on the power sector if EU ETS prices develop substantially lower than expected

In case of a substantially lower than expected EU ETS price, a CPF results in higher generation cost for fossil fuel plants. However, our analysis shows that this only partially supports the profitability of renewables. The impact of a binding domestic CPF is significantly diluted by the strong integration of the Netherlands into the European market. Higher domestic generation costs of fossil fuel plants translate only to a small extent into higher wholesale electricity prices - and therefore into only a slightly improved economic outlook for renewables. The effect on carbon emissions is likely to be very small on the European level as domestic fossil generation is replaced to a large extent by carbon intensive plants in other European countries.

On the other hand, a national CPF comes along with significant potential negative side effects. The magnitude of the effects depend heavily on the chosen CPF: While a lower CPF (e.g. at 40% below the expected EU ETS price) has a rather small impact on the Dutch electricity sector and the Dutch industry, an ambitious CPF (e.g. 10% below the expected EU ETS price) can have a considerable impact on the electricity sector and the industry if the EU ETS price decreases significantly. These include (compared with a situation without a CPF) reduced domestic production of electricity and goods from the industry, reduced electricity generation capacity and therefore potential adverse effect on security of supply, and carbon leakage.

Annex A – Methodological background on the probabilistic analysis of carbon prices

A.1 Model specification

A standard discrete time model of a mean reverting process can be expressed as

$$P_{t+1} = P_t + \delta + r(P_0 + \delta t - P_t) + \varepsilon_{t+1} \tag{1}$$

where P_t is the current carbon price (at date *t*), δ is the drift parameter along the long-term development of the price (between t and $t+1$), r is the reversion speed of the process and ε_{t+1} the error term, a normally distributed random shock with mean zero and a relative standard deviation $r\sigma$.

The sum of $P_t + \delta$ represents the expected price at time t, along a linear trajectory towards the expected future price. The term $r(P_0 + \delta t - P_t)$ is the “correcting factor” towards the expected future price at the rate *r,* acting as a reverting factor when the actual value of P_t deviates from the expected value $(P_0 + \delta t)$.

While the expected future drift is determined by the price expectations formulated in the KEV 2022 main scenario (110 EUR/tCO_2eq in 2030 and 179 EUR/tCO_2eq in 2040), we are estimating the reversion speed r and the relative standard deviation $r\sigma$ by running a regression analysis using historical data. Adapting (1) yields

$$P_{t+1} = rP_0 + \delta - r\delta + (1 - r)P_t + r\delta\, t + \varepsilon_{t+1} \tag{2}$$

with dependent variable P_{t+1}, independent variables P_t with slope $(1 - r)$ and t *with* slope $r\delta$ and intercept $rP_0 + \delta - r\delta$.

The expected future drift, inferred from long-term price expectations in the KEV 2022 main scenario, deviates from the one estimated on the basis of historical data. While acknowledging potential limitations of transferring the historic relative standard deviation and reversion speed into the future, we assume that the estimated relative price volatility and reversion speed will remain a fair approximation of future values. Measuring volatility in relative terms allows to account for differing price levels within the historical market data analysed, volatility of estimated future prices might therefore vary in absolute terms, according to price levels.

A.2 Results of an estimation using monthly (averaged) prices from 2018 to 2022

The choice of the time period (as in which past years to incorporate in the analysis) and time interval (as in whether to use daily changes in carbon prices or weekly/monthly averages) of the historical market data used to analyse volatility and reversion speed impacts the result. The chosen parameters should thus be suitable to the purpose of this exercise and goals of the subsequent electricity market analysis. We therefore suggest using

- **Monthly (averaged) prices** as a time interval, given the long-term nature of the modelling, and
- **A time period from 2018 to 2022**, as this time period allows to utilize a broad data basis across different price levels that incorporates the impacts of severe external shocks (e.g., Covid pandemic, war in Ukraine) as well as a period of steady price increase (in 2021).

We further conduct sensitivity analyses, testing different time periods and averaging of daily prices to contrast the choices and underlying assumptions made against possible alternatives.

Using 2018 to 2022 weekly (averaged) prices to estimate parameters through regression analysis yields a relative standard deviation of 0.118 or 11.8 % and reversion speed of 0.100. The reversion speed is obtained as 1 - slope of *price at t* (see equation 2), while the reversion speed translates to a time frame to revert (1/reversion speed) of around 10 month (see Table 8).

Table 8 Regression analysis results

Main specification	
Dependent variable	Price at t+1
Price at t	0.900*** (0.059)
t	0.0154* (0.008)
Constant	0.815 (1.232)
Adjusted R^2	0.964
Observations	59
RMSE	4.768
Mean of price	40.408
Relative standard deviation	0.118

Source: *Frontier Economics based on Energate Messenger*

Note: *The significance levels of the coefficients are indicated as follows: *** denotes a result that is significant at the 1% level, ** denotes a result that is significant at the 5% level, and * denotes a result that is significant at the 10% level. The relative standard deviation is obtained by dividing RMSE by the mean of price. The reversion speed is obtained as 1- slope of price (see equation 2).*

A.3 Sensitivity analysis

In order to contrast our parameter choices against possible alternatives we conducted several sensitivity analyses, using

- **Alternative time intervals:** Daily prices and weekly (average) prices instead of monthly (average prices) as a time interval, as well as
- **Alternative time periods:** Shortening, lengthening, and diverging the time period.

Table 9 Overview of reference and sensitivities

Time period	Time interval	Relative Standard Deviation	Reversion Speed	Time to revert (1/reversion speed)
Reference				
2018-2022	Monthly (avg.)	0.118	0.100	~ 10.0 months
Sensitivities				
2017-2022	Monthly (avg.)	0.125	0.090	~ 11.0 months
2019-2022	Monthly (avg.)	0.112	0.152	~ 6.5 months
2018-2022	Weekly (avg.)	0.066	0.030	~ 7.5 months
2018-2022	Daily	0.037	0.009	~ 3.5 months

Source: Frontier Economics, based on Energate Messenger.

Note: The Relative Standard Deviation as well as the reversion speed need to be interpreted considering the time interval chosen, therefore the time to revert (1/reversion speed) yields a more intuitive measure.

The values in Table 9 need to be interpreted while considering the impacts of the choice of time interval on the relative standard deviation and reversion speed. A much lower relative standard deviation is to be expected when choosing a daily time interval, in comparison to aggregating on a weekly/monthly basis. Furthermore, the results should also be interpreted against the implications of the choice of the time period and the interwoven implicit choices in terms of incorporating or leaving out the impacts of certain external shocks and other developments have on the results.

A.4 How to deal with increased uncertainty in the long term

An increasing uncertainty about future developments over time poses a demanding challenge when conducting long-term simulations. In order to adequately reflect those fundamental uncertainties in long-term projections:

- We decrease the reversion speed to the equivalent of a two-year time frame to revert to the long-term mean (reversion speed of 0.0096) from 2030 onwards, to allow for different price-developments to evolve lover a longer period of time.
- We cap the carbon price in our simulation at a maximum of 300 EUR, which reflects a potential upper bound of medium- to long-term CO_2 abatement cost through Direct Air Capture.[43]

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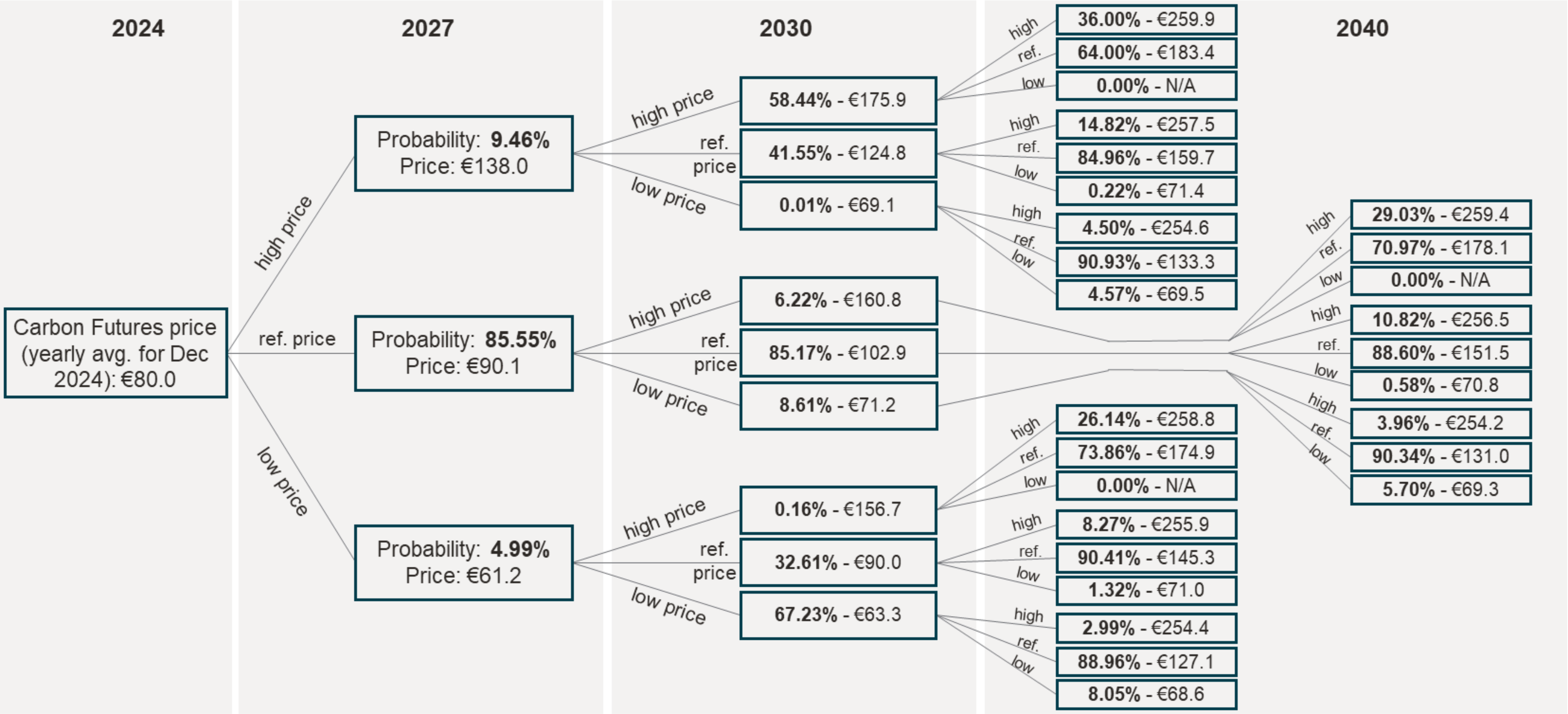
[43] S&P Global Commodity Insights: “Cost of capturing CO_2 from air to drop to \$250-\$300/mtCO_2e end-decade: Climeworks”, available at https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/042222-cost-of-capturing-CO_2-from-air-to-drop-to-250-300mtCO_2e-end-decade-climeworks

Annex B – Probability of future carbon price scenarios until 2040

Figure 43 Price path probability tree



Source: *Frontier Economics*

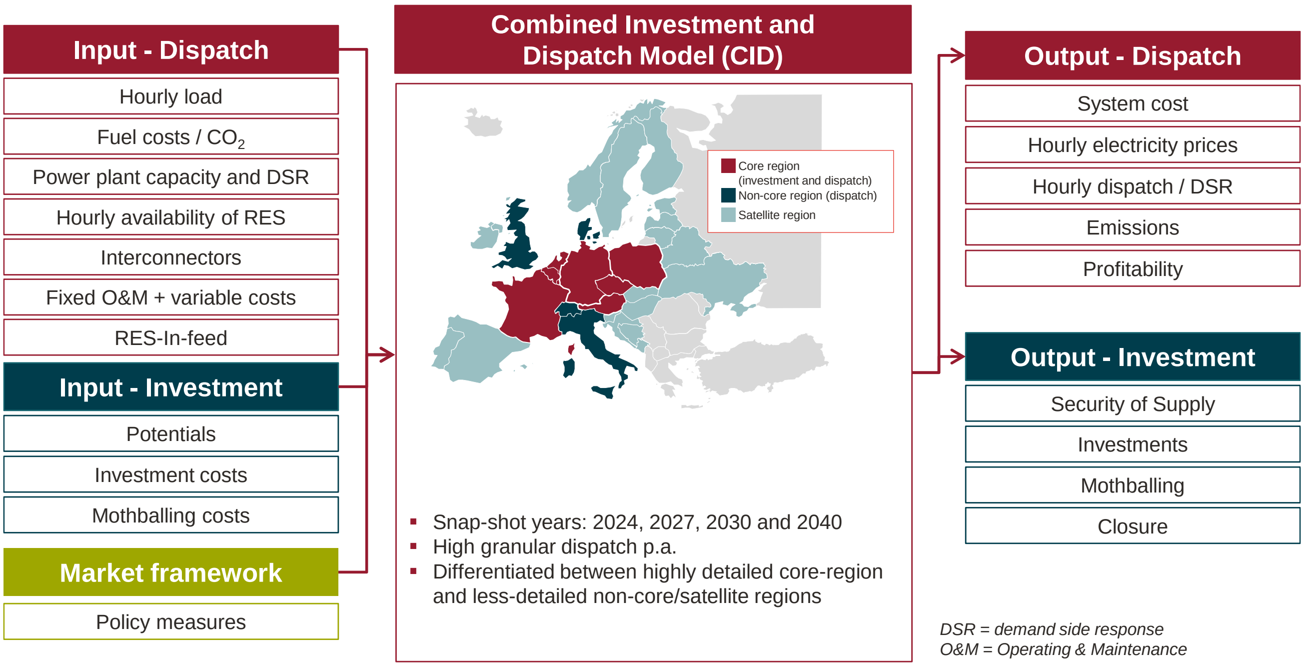
Note: *All prices in €2021/tCO₂eq, probabilities based on 10,000 Monte Carlo iterations*

Annex C – Combined Investment and Dispatch model

C.1 Model description

The Combined Investment and Dispatch model is used to evaluate long-term trends in the power market. It projects the development of generating capacities as well as their optimised dispatch. For this study, the power market model would be complemented by a stochastic component as described in section 2.3.

Figure 44 Frontier Investment and Dispatch Model



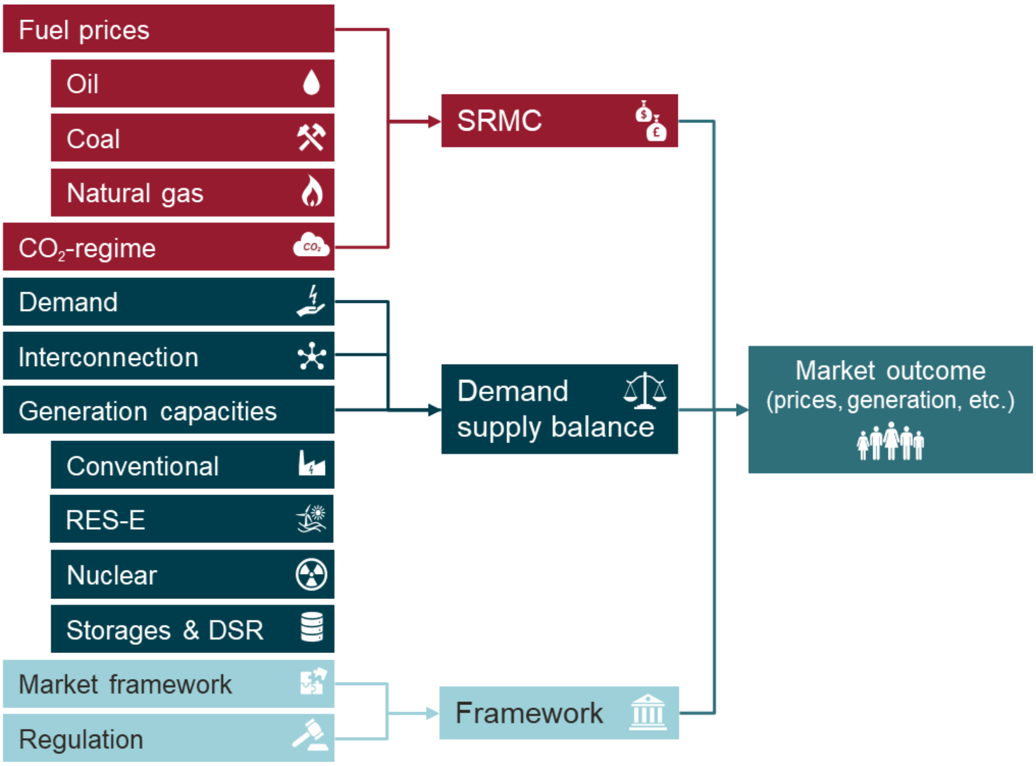
DSR = demand side response
O&M = Operating & Maintenance

Source: Frontier Economics

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. It 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).
  - Energy supply and consumption must be balanced in every hour in every region;
  - Power exchange between modelled regions is limited by interconnection capacity;
  - Technical and economic constraints for power plants, storages, demand-side management (DSM), as well as renewable energy sources.

Figure 45 Key input parameters



Source: *Frontier Economics*

- **Investment options** – In order to meet future demand at the least cost, the model optimises the power plant park in the so-called “core regions” of our model through either:
  - Investing in new capacities subject to technical and economic parameters and availability of different technological options;
  - Closing of existing power plants in the case of overcapacity; or
  - Mothballing plants and reactivation at a later point in time in order to save fixed operation and maintenance costs.
- **Geographical scope –** Our model focusses on Central-Western Europe as core region. Depending on the focus of the analysis, we differentiate between
  - **Core regions:** The power plant park is modelled on a very detailed (unit-based) level, the dispatch of power plants and demand-side management (DSM), as well as investment or divestment, are model outcomes.
  - **Non-core regions:** 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 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 model optimises representative days with an hourly resolution.

C.2 Input assumptions

Table 10 Summary of main power market model assumptions

Parameter	Source	Unit	2024	2027	2030	2040
Net electricity demand						
The Netherlands	KEV 2022 (main)	TWh	116.3	123.4	130.6	171.7
Modelled region	Frontier Economics	TWh	2,259	2,373	2,487	3,049
Peak load						
The Netherlands	Frontier Economics	GW	18.1	19.0	20.0	25.3
Fuel and carbon prices						
Natural gas	Futures 30.01.2023, KEV 2022 (main)	€/MWh_{th}	59.38	34.03	33.45	33.45
Hard coal (CIF ARA)	Futures 30.01.2023, KEV 2022 (main)	€/MWh_{th}	16.90	14.21	11.56	12.31
CO_2 (EU ETS)	Futures 30.01.2023, KEV 2022 (main)	€/tCO_2eq	80.0	93.3	109.8	178.9
Carbon price floor						
-10% scenario	-	€/tCO_2eq	72.0	83.9	98.8	98.8
-25% scenario	-	€/tCO_2eq	60.0	69.9	82.4	82.4
-40% scenario	-	€/tCO_2eq	48.0	56.0	65.9	65.9
Renewable capacity limits (NL)						
Wind offshore	KEV 2022 (main)	GW	4.63	5.96	15.76	21.18
Wind onshore	KEV 2022 (main)	GW	6.20	7.38	7.43	7.18
Solar PV	KEV 2022 (main)	GW	19.70	22.94	25.00	41.99

Note: Net electricity demand includes network losses, excludes own-consumption, storage demand, and DSM. The modelled region constitutes of AT, BE, CH, CZ, DE, DK, FR, IT, NL, PL, UK. Fuel prices calculated in terms of lower heating value and all prices are stated in real 2021 terms (as in the KEV 2022).

Annex D – Reference scenarios against which CPF impact is analysed

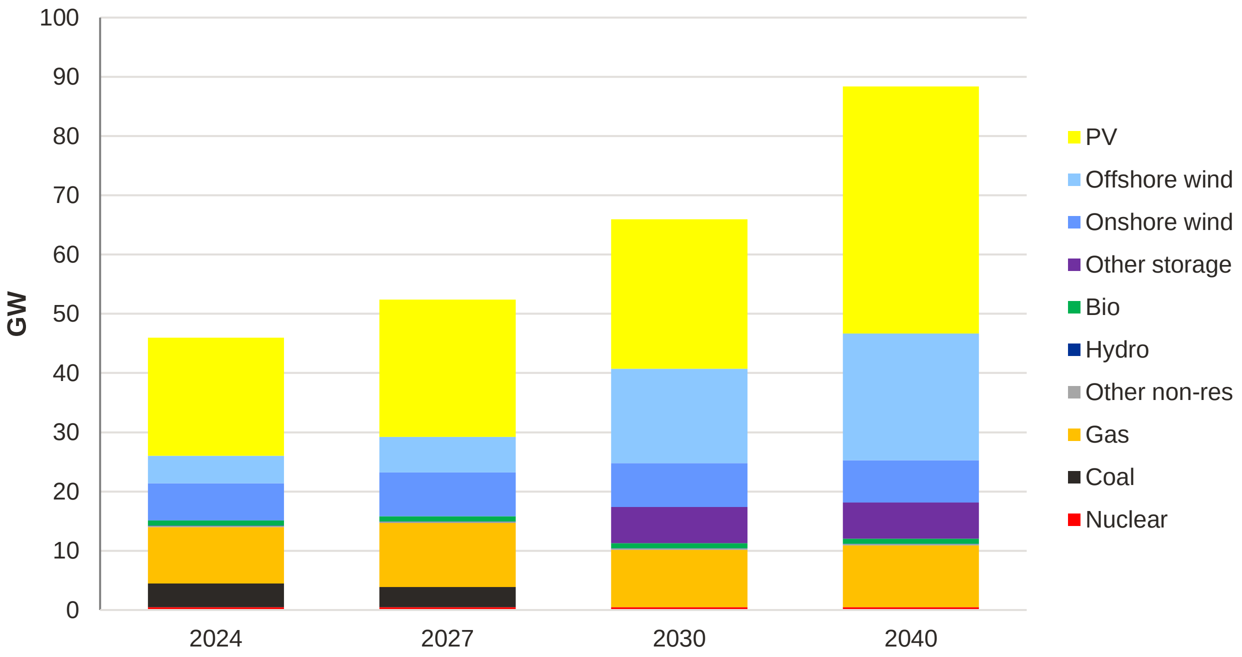
D.1 Low EU ETS price case

Table 11 Summary of key results of the low price case without a CPF

Key indicators	Development
Generation capacities	■ Large increase in **renewable** capacities ■ **Storage** capacity of ~6 GW built by 2030 ■ Installed **gas** gen. capacity of ~10 GW between 2024 and 2040
Domestic dispatch	■ Large increase in generation from **renewables**, which offset coal generation and cover increasing electricity demand ■ Fossil-based generation mostly by **CHP** plants ■ In 2030/40 **gas and storage** complement renewable generation
Emissions	■ Significant **decline** from ~36 $MtCO_2eq$ in 2024 to ~14 $MtCO_2eq$ in 2030, in particular due to coal phase out
Electricity price	■ **Declining** electricity prices from ~130 €/MWh in 2024 to ~85 €/MWh in 2030 ■ Further reduction to ~75 €/MWh by 2040
Reserve Margin	■ Increasing **reserve margin** until 2030, decreasing until 2040 ■ **Increasing peak load and coal phase-out** is met by contribution from largely storages, wind offshore and imports
Power plant profits	■ **CCGT** (mostly CHP) profits largely increasing between 2024 and 2027, but from 2030 onwards decreasing ■ **Renewables**: decreasing profits throughout the modelled period

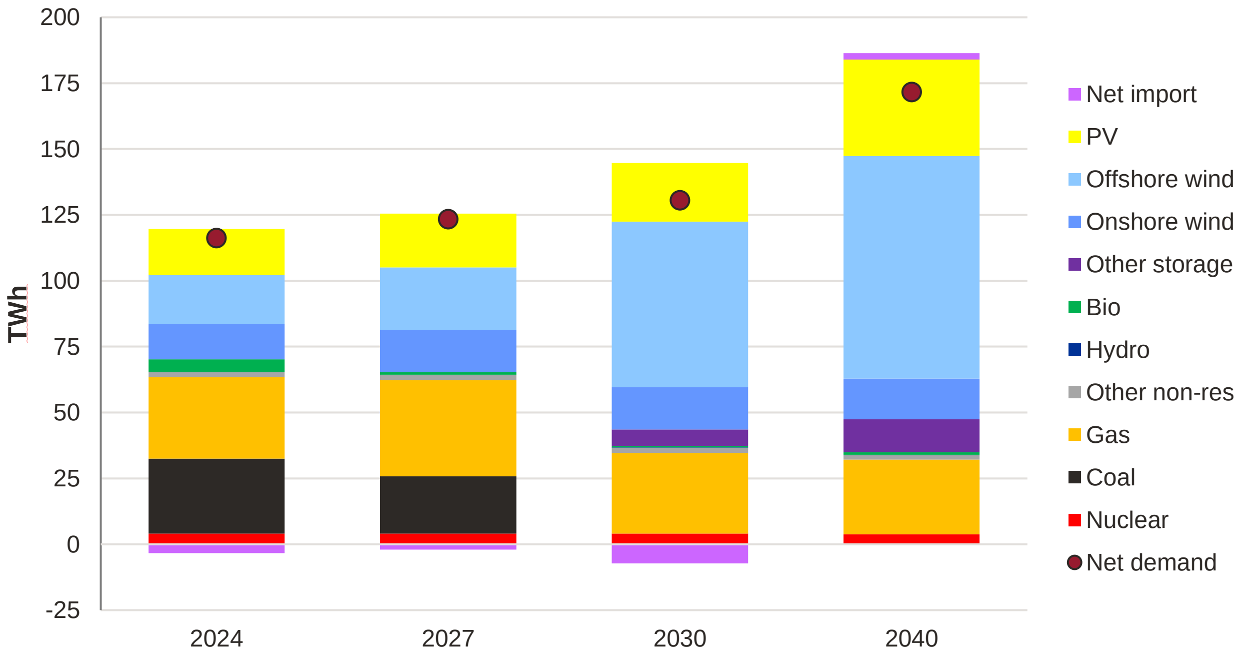
Source: Frontier Economics

Figure 46 Reference for low EU ETS price case: Installed generation capacity



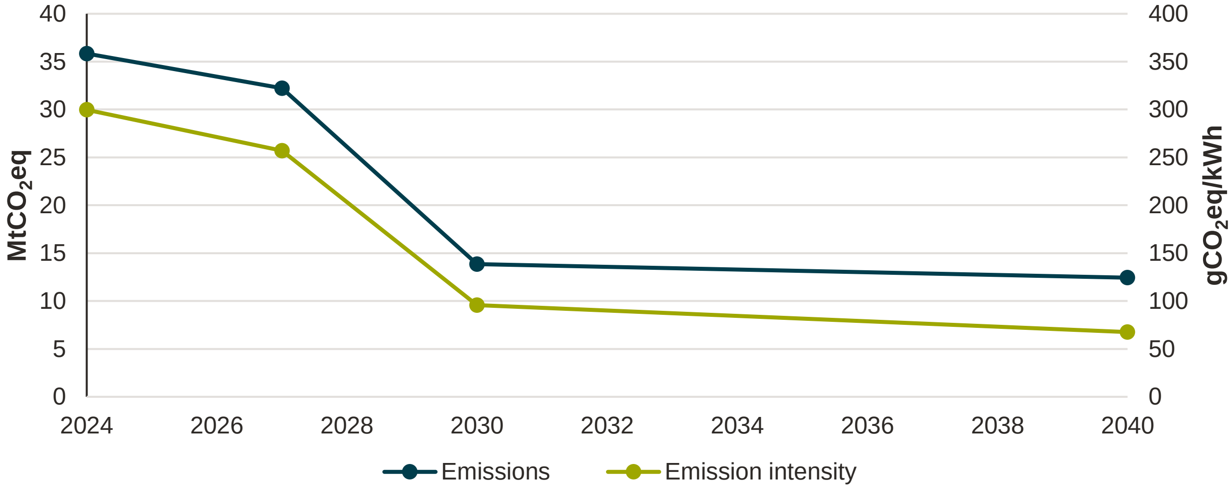
Source: *Frontier Economics*

Figure 18 Reference for low EU ETS price case: Annual dispatch and net imports



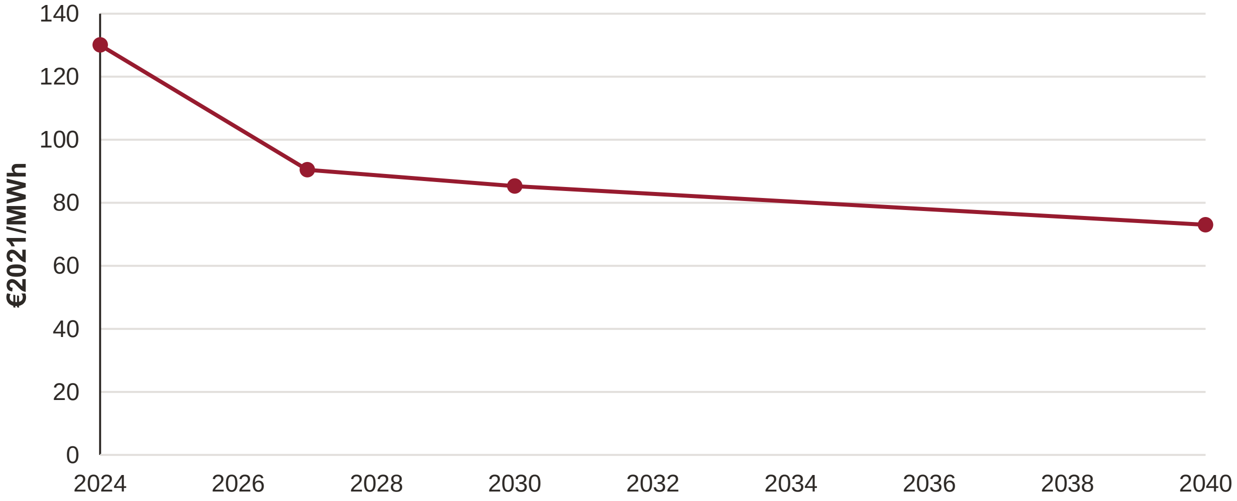
Source: *Frontier Economics*

Figure 47 Reference for low EU ETS price case: Emissions and emission intensity



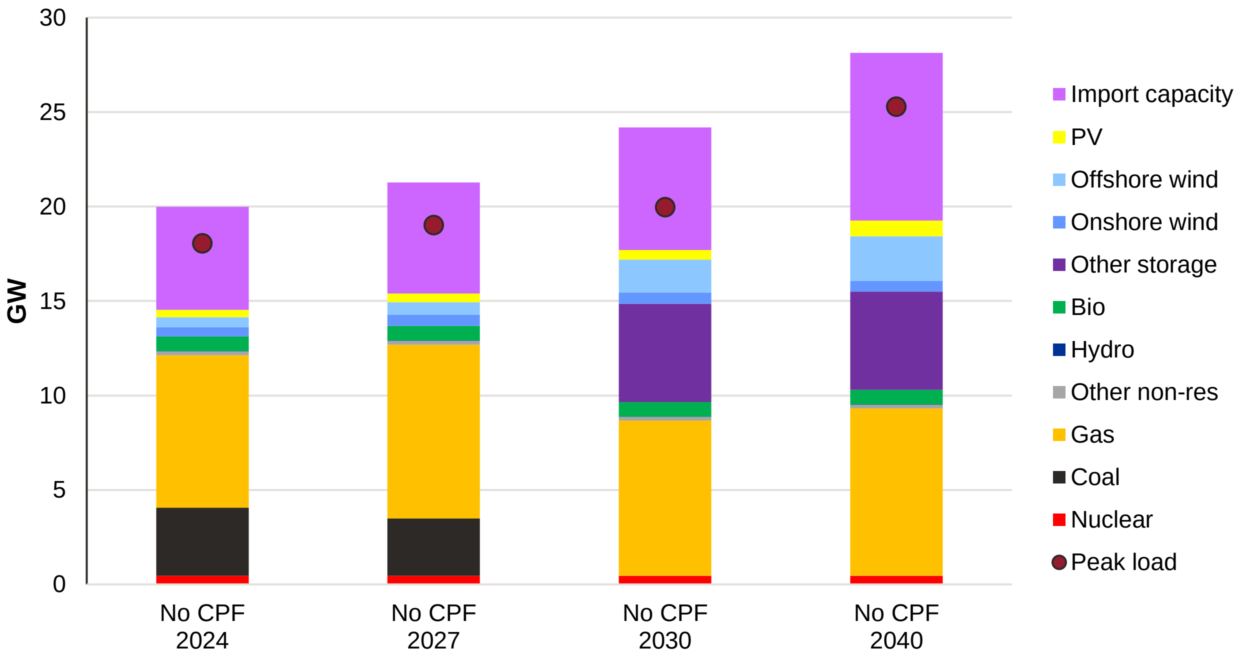
Source: Frontier Economics

Figure 48 Reference for low EU ETS price case: Average wholesale electricity prices



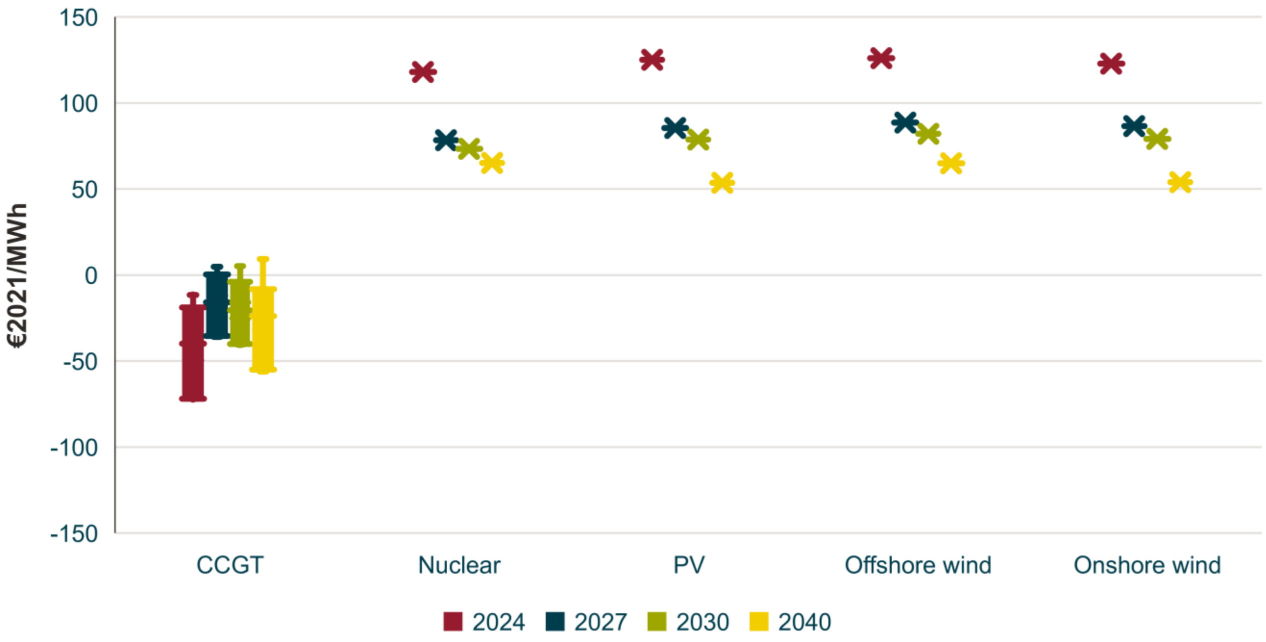
Source: Frontier Economics

Figure 49 Reference for low EU ETS price case: Adequacy reserve margins



Source: Frontier Economics

Figure 50 Reference for low EU ETS price case: Power plant profits



Source: Frontier Economics

Annex E – World Scan model description

E.1 Model description

Overview

A computational general equilibrium (CGE) model like WorldScan consists of three main elements. The underlying general equilibrium economic model, the multi-regional input-output data, and a set of exogenous parameters (being the most import the elasticities). The combination of these three elements yields a general equilibrium (calibrated) baseline in which all the accounting and market clearing conditions are met. Policy experiments consist of a shock to one or several exogenous variables (e.g. tariffs) that generate changes in the price and quantities of the endogenous variables such that a new general equilibrium is reached: the counterfactual scenario. The behavioural equations in the economic model determine how the endogenous variables react, while the underlying baseline data and the exogenous parameters (i.e. the various elasticities in the model) determine the size and scope of the adjustments.[44]

Economic model

General equilibrium models describe supply and demand relations in markets. In these models, prices and quantities of goods and factor inputs (i.e. labour and capital) adjust, such that demand and supply become equal at an equilibrium price and quantity level. These models also describe the interactions between several markets. For instance, firms must determine the factor inputs necessary to produce a final good, given the price and demand of that good. Firms' supply decisions, therefore, depend on the equilibrium product price and in turn they determine the demand for the necessary intermediate and factor inputs required. Consumers preferences and budget constrains will determine the demand for final goods and the supply of factor inputs (mainly labour). The interaction of the optimisation decisions by firms and consumers will ultimately determine the equilibrium prices and quantities of goods and factor inputs. Therefore, the core elements of all CGE models are the micro-economic founded neo-classical conditions: consumer and producer optimisation under budgetary constraints. Hence, economic behaviour drives the adjustment of quantities and prices given that consumers maximise utility given the price of goods and the consumers' budget constraints, while producers minimise costs, given input prices, the level of output and the production technology.[45]

These optimisation conditions are linked with market clearing conditions in the products markets (i.e. equating demand and supply for each production sector). The number of product markets is defined by the number of economic sectors in the database. For instance, the GTAP database identifies 57 sectors. In addition, there are market-clearing conditions for the factor markets. Following the example above, the supply of low- and high-skill labour by households must equal the demand of these factor

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[44] For a broader view of the CGE modelling framework, see Dixon, P. B. and D. W. Jorgenson, eds. (2012). Handbook of Computable General Equilibrium Modeling, vol. 1A, Amsterdam: Elsevier.

[45] A summary of the general equilibrium equations of WorldScan is provided in Appendix A in Lejour et al. (2006) and in the Supplementary Material from Rojas-Romagosa (2017).

inputs by firms. There are five different factor types in the GTAP database: unskilled and skilled labour, capital, land, and natural resources.[46] For instance, the demand of labour (determined from the profit maximisation conditions of firms) must equal the labour supply by households (which in turn is a function of economically active population and labour participation rates.) Consumption is modelled as non-homothetic demand system using the linear expenditure system (LES). All partial elasticities of substitution for composite commodities as well as price and income elasticities drive demand responses to economic shocks. Production is modelled as a nested structure of constant elasticities of substitution (CES) functions. The values of the substitution parameters reflect the substitution possibilities between intermediate inputs and production factors.

Monopolistic competition

WorldScan has the option of using an imperfect competition setting (described below) or a perfect competition setting with constant returns to scale where each sector has one representative price-taking firm that produces one variety (following the description of the supply and private demand equations above). Our main simulations, however, employ the WorldScan version with monopolistic competition and increasing returns to scale (see de Bruijn, 2006, for a detailed description). This version of the model is based on a Dixit-Stiglitz-Armington demand specification. In particular, it uses the love-of-variety –i.e. Dixit-Stiglitz (DS) – preferences for intermediate and final goods for non-agricultural sectors. Within a representative firm, individual varieties are symmetrical in terms of selling at the same price and quantity. However, increases in the number of varieties yield economic benefits because they are perceived to be different by intermediate and final demand agents. This DS approach is then nested within a basic CES demand system that includes both Armington- and DS-type demand systems for individual sectors using Ethier and Krugman-type monopolistic competition models –i.e. differentiated intermediate and differentiated consumer goods. [47]

This imperfect competition version of the model slightly modifies the demand and supply equations from the perfect competition setting, by including the number of varieties by sector and region in the demand and supply equations following Dixit-Stiglitz preferences. Economies of scales are introduced in the supply side as a technical scaling factor in combination with imposing a fixed set-up cost for in the production process. The specific modelling equations can be found in Section 2 in de Bruijn (2006).

International trade

Finally, the model provides an explicit and detailed treatment of international trade, international transport margins and other trade costs (e.g. tariffs, NTBs, export subsidies). Bilateral trade is handled via CES (constant elasticity of substitution) preferences for intermediate and final goods, using the so-called Armington assumption, where the substitution of domestics and imports –as well as product differentiation– is driven by the region of origin (i.e. by import source). This assumption is generic to

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[46] The GTAP-9 version identifies five different labour types, but these can be aggregated to the common two labour types used in most CGE models.

[47] This can be done because one can reduce Ethier-Krugman-models algebraically to Armington type demand systems with external scale economies linked to a variety of effects (Francois and Roland-Holst, 1997; Francois and Nelson, 2002).

most CGE models as it is a simple device to account for “cross-hauling” of trade (i.e. the empirical observation that countries often simultaneously import and export goods in the same product category).

Representation of energy technologies and abatement GHG

Emissions are introduced at different places of the nested production structure in the model. Emissions from energy use are calculated using a fixed emission coefficient (i.e. a fixed amount of emissions per unit of coal, oil, natural gas, or biomass used). The use of chemical fertilizer in agriculture is a significant source of emissions of CH4. Emissions related to the use of chemical fertilizer are calculated using the intermediary input from the energy-intensive (chemical) sector to the agricultural sector as a proxy for the amount of fertilizer used. Process emissions are linked to the sectoral output, the top of the production function nest. The production structure for the agricultural sector is similar for other sectors. The main difference with other sectors is that these sectors don’t have fertiliser as an input.

For CO_2, the emission factors link energy use differs per fuel type to emissions but is independent of the sector and region. Emission factors for other substances are sector and region specific. Emission factors up to 2030 for non-CO_2 GHGs are calculated such that emission levels by region, sector, and activity in the BAU reproduce the corresponding emission levels of WEO-2021 scenario.[48]

Applications

The WorldScan model is used in numerous papers to analyse the role of the industry in the EU ETS as part of climate policy and interactions between climate and air pollution policies in Europe. Further it is also used in other topics, such as estimating the EU’s structural changes and economic impacts of policies, for example on Türkiye’s entry to the EU, on Brexit, on trade conflicts, and on protective CBAM policies.[49]

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[48] The calibration of emission factors in WorldScan can be found in Bollen J. (2014), The Value of Air Pollution Co-benefits of Climate Policies: Analysis with a Global Sector-Trade CGE model called WorldScan, in Technological Forecasting and Social Change Volume 90, Part A, January 2015, Pages 178-191).

[49] See Boeters, S., and Bollen, J. (2012), Fossil fuel supply, leakage, and the effectiveness of border measures in climate policy, Energy Economics, Volume 34, Issue6, Available online 30 August 2012. Bollen (2015), The value of air pollution co-benefits of climate policies: Analysis with a global sector-trade CGE model called WorldScan, Technological Forecasting and Social Change, Volume 90, Part A, 2015, Pages 178-191. Bollen J., and Brink C.J. (2014), Air Pollution Policy in Europe: Quantifying the Interaction with Greenhouse Gases and Climate Change Policies, CPB Discussion Paper 220, CPB, the Hague, the Netherlands. Lejour A., and De Mooij, RA (2004), Turkish Delight – Does Turkey’s accession to the EU bring economic benefits? CESifo Working Paper Series 1183, CESifo. Bollen, J., G. Meijerink, and H. Rojas-Romagosa (2016). “Brexit Costs for the Netherlands Arise from Reduced Trade,” CPB Policy Brief 2016/07, CPB Netherlands Bureau for Economic Policy Analysis. Bollen, J., and Rojas-Romagosa, H. (2018), Trade Wars: Economic impacts of US tariff increases and retaliations, an international perspective, CPB Background Document, 6 July 2018. Bollen, J., Koutstaal, P., Veenendaal, P. (2011), Trade and Climate Change, EU Commission, DGtrade, Brussels, Belgium.

E.2 Baseline scenario assumptions and characteristics for reference EU ETS price path

Assumed trends

In this report, the baseline scenarios are based on the 2021 World Energy Outlook (WEO-2021, IEA, 2021), and for energy prices we rely on the values reported in the KEV 2022.The BAU calibration employs trends for population and GDP by region, energy use by region and energy carrier, and world fossil fuel prices by energy carrier. Population is exogenous, but the other time series are reproduced by adjusting the model parameters. GDP is targeted by Total Factor Productivity (TFP, differentiated by sector), energy quantities are targeted by energy efficiency, and fuel prices are targeted by the amount of natural resources available as input to fossil fuel production.

In policy variants, TFP, energy efficiency, and natural sources are fixed, and GDP, energy use and prices are endogenous.

Assumed Policies

NDC's follow the assumptions of the STEPS scenario of IEA's 2021 outlook. In this report uniform carbon prices over sectors are simulated for each region to match the carbon budgets of the NDC's of the different regions. For the ROW, we assume no binding targets as this region includes too many countries without a binding carbon budget or intensity target (for example, India), or a non-binding intensity target (for example, China has a non-binding intensity target, i.e. CO_2 / GDP reduction of 65% by 2030 compared to 2005).

For the EU28, we assume the GHG emissions of the fit-for-55 package to hold. In this report uniform carbon prices over sectors are simulated for the EU28 to match the 55% emission reduction by 2030. As to align the simulated carbon prices with the KEV, we ad-hoc lowered the marginal carbon abatement functions of the industry with a uniform factor (13%) in the REU region to simulate the reference path of the carbon price of the KEV.

For the Netherlands, we implemented also a direct subsidy of 550 mn Euro to carbon abatement by the industry with the assumption that government finances with this budget the emission reductions of the "non-profitable" part ("onrendabele top") at the ETS price of reference path of the KEV.[50]

Parameters

All other parameters of WorldScan are the same as used in Bollen et al. (2020).[51]

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[50] This means that the subsidy becomes less effective if the ETS price drops compared to the

[51] Bollen J, Delen, A., Hoogendoorn, S, and Trinks, A. (2020), CO_2-heffing en verplaatsing, CPB Achtergronddocument November 2020, CPB, Den Haag.

E.3 Regions and Sectors in WorldScan

Table 12 Regions

Code	Country / region
NLD	Netherlands
REU	EU-28
USA	USA
ROE	Rest of the OECD
ROW	Rest of the World

Source: CE Delft

Table 13 Sectors

Code	Sector	GTAP Sector
HOR	Horticulture	Vegetables, fruit, nuts; Other crops;
OAG	Other Agricultural Activities	Paddy rice; Wheat; Other cereal grains; Oil seeds; Sugar cane; Plant-based fibres; Bovine cattle; Other animal products; Raw milk; Wool; Forestry; Fishing
OIL	Winning of Oil	oil
COL	Winning of Coal	Coal
GAD	Winning and distribution of Gas	Gas; Gas manufacture and distribution
MIN	Other Minerals	Other mining
P_C	Oil Refineries	Petroleum and coal products
BME	Basic Metals	Ferrous metals; Non-ferrous metals
CRP	Chemical, Rubber, and Plastics	Chemical, rubber, plastic products
PPP	Paper prod.& publish.	Paper products, publishing
NMM	Other mineral prod.	Non-metallic minerals

Code	Sector	GTAP Sector
COF	Processed foods	Bovine meat products; Other meat; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Other food; Beverages and tobacco
CPI	Capital Goods	Metal products; Motor vehicles and parts; Other transport equipment; Electronic equipment; Other machinery and equipment
CON	Consumer Goods	Textiles; Wearing apparel; Leather products; Wood products; Other manufacturing
ELY	Electricity Production	Electricity
OTP	Transport over land	Other transport
TRR	Other Transport	Water transport; Air transport
OSE	Other Services	Water, Construction; Trade; Communication; Other financial services; Insurance; Other business services; Recreational and other services; Public administration, defence, education, health; wellings

Source: *CE Delft*

Note: *Aguiar, Narayanan en McDougall, 2016, an Overview of GTAP9 Data Base, Journal of Global Economic Analysis, vol, 1(1): 181-208.*

E.4 Excursus: Carbon leakage through Fit For 55

Here we compare the Fit for 55 scenario (55% emission reduction) with the Energy Package scenario (40% emission reduction), however without reflecting the latest plans for an introduction of a carbon Border Adjustment Mechanism (CBAM). For 2030, this means that Europe’s GHG emissions will be reduced with another 6%. We assumed for the Energy Package scenario a reduction of carbon prices with almost 55 EUR/tCO_2eq in all sectors compared to the Fit-for-55 scenario, which simulates a 40% emission reduction of GHGs by 2030.

Figure 51 breaks down the leakage by regions/countries by comparing the FF55 scenario with the Energy Package scenario. While countries like China and the rest of the world are logical candidates for leakage, as they don't have binding CO_2 ceilings, our simulations show some leakage to the USA as well.[52] There is therefore a significant risk of a substantial increase in carbon emissions in countries outside Europe, which would negate the carbon emission reduction achieved by the EU by almost 45% (carbon leakage). However, as emphasised before, the Dutch industry would only experience limited or moderate production losses.

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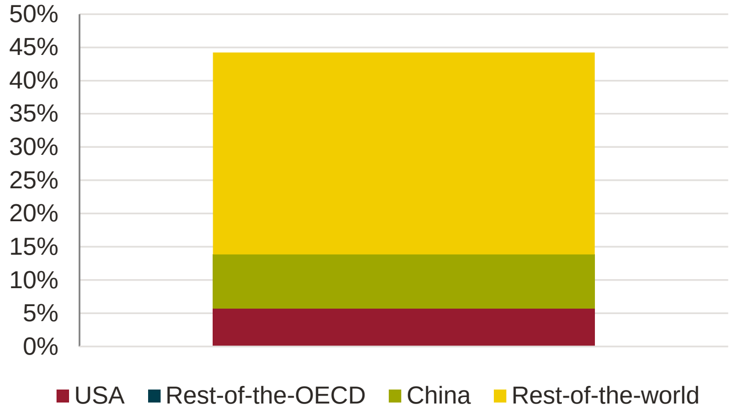
[52] The updated NDC of the USA aiming to reduce GHG emissions by 50-52% by 2030 is not included in this analysis. Nevertheless, this will have little impact on the simulated leakage results. If the updated NDC of the USA was assumed in the baseline, then there would be leakage from the USA to the non-OECD region. So EU’s carbon policies would no longer yield leakage to the USA, but as carbon-intensive non-OECD expands from USA implanting policies to meet their NDC, then substitution at constant elasticities will yield also more absolute leakage from EU’s carbon policies to those regions.

Figure 51 Decomposition of carbon leakage to regions of Fit-for-55 Package (2030)



Source: CE Delft

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