RESEARCH OF SCENARIOS FOR COAL-FIRED POWER PLANTS IN THE NETHERLANDS

Addendum for MinEZ

26 August 2016

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SUMMARY

Background

The Netherlands has committed itself to reaching a low-carbon energy system that is reliable, affordable and safe in 2050. Within this context, the Dutch Energy Agreement represents an irreversible step towards achieving this goal. As part of the Energy Agreement, two of seven remaining coal-fired power stations that are currently operational in The Netherlands will be closed mid-2017. On 26 November 2015, the second chamber of the Dutch Parliament has accepted a motion that asks the minister of Economic Affairs to develop a plan to phase-out coal-fired electricity generation in The Netherlands. In response to this request, the Ministry of Economic Affairs (MinEZ) has asked Frontier to model several scenarios with our European power market simulation model and to evaluate these scenarios based on the given set of indicators. The final report was submitted to MinEZ on 1st July 2016.

Additional scenarios

After submission of the final report, discussions with stakeholders and within the government revealed the need to analyse additional scenarios, beside the ones already included in the Study. Therefore, MinEZ has asked Frontier to model additional policy scenarios and evaluate these scenarios based on the framework developed in the original study.

These scenarios are an addition to the study “Research of scenarios for coal-fired power Plants in The Netherlands” (hereafter “the Study”):

- **Addendum 1: Additional CO_2 abatement measures at the coal plants in 2020 –** In this scenario, the coal plants apply possible measures to reduce the CO_2 emission per unit of delivered electricity to such a level that the emissions are at least equal to the average CO_2 emissions of a modern gas-fired power plant (350 gCO_2/kWh_{el}). *Scenario 1* of the main Study assumed that these measures would be implemented in 2025. *Addendum 1* now assumes implementation already in 2020. The measures include increased co-firing of biomass, implementation of CCS or increased residual heat utilisation.
- **Addendum 2: Additional scenarios with fixed closure dates and optimised abatement measures at the plants based on economic viability –** In the second Addendum, coal-fired power plants in The Netherlands are required to shut-down at specific dates. The main study assumed that with closure dates in 2030 and 2040, the coal-fired plants apply the same abatement measures as listed in *Scenario 1*. In this Addendum, we assume that abatement measures additional to the ones already included in the *Reference Case* will only be implemented based on their economic viability (and not mandatorily as assumed in the Study). Co-firing of biomass becomes economically viable as of 2040, while existing CCS becomes economically viable by 2035.

- **Addendum 3: Additional scenarios with early closure of old plants and fixed closure dates for newer plants -** In the third Addendum, the two oldest coal-fired power plants in The Netherlands built in the 1990s are required to shut-down until 2020. The remaining three coal-fired plants remain online until 2030 or 2040. In the Study, we assumed that with closure dates in 2030 and 2040, the coal-fired plants apply the same abatement measures as listed in *Scenario 1*. In this Addendum, as in Addendum 2, we assume that abatement measures will only be implemented based on their economic viability (and not mandatorily as assumed in the Study).

- **Addendum 4: Ambitious European climate action leading to significantly higher CO_2 price –** This Addendum assumes that, in response to the Paris Agreement on Climate Change, the EU implements ambitious climate action that results in a significantly higher CO_2 price in the medium and long-term. No assumptions have been made on the specific policy actions that might be taken, since this is not known or in preparation at the moment. We have just assumed that, whatever form the policy takes, it results in a higher CO_2 price in the whole EU.

Based on the analysis framework developed in the Study, the results of the additional scenarios can be summarised as follows.

Reduction of CO_2 emissions

The additional policy measures assessed in this report show different degrees of emission reductions in The Netherlands and in Europe (compared to the Reference Case):

- **Addendum 1:** The implementation of additional abatement measures in 2020 lowers emissions by up to 13 mn. tCO_2 per year and by 235 mn. tCO_2 (-22%) aggregated from 2018 until 2049, if the costs of the additional measures are borne by the companies (*Addendum 1a*). If the costs are not borne by the companies, but compensated by the state (*Addendum 1b*), the operation of coal plants is affected to a limited extent and aggregated emission reduction is slightly lower (-18% / 190 mn. tCO_2 2018-2049). At the same time, a lower amount of emissions is “exported” to neighbouring countries in this Addendum as less generation in the Netherlands needs to be substituted.

  Consequently, the net-reduction in all modelled countries is higher in *Addendum 1b (*182 mn. tCO_2) than in *Addendum 1a* (134 mn. tCO_2).

  As expected, the aggregated emission reduction is higher compared to *Scenario 1a* and *Scenario 1b* of the Study, in which additional abatement measures are taken in 2025. In *Scenario 1a* (costs of measures are borne by the companies) the domestic emission reduction amounts to 180 mn. tCO_2 and net-reduction 121 mn. tCO_2, while in Scenario 1b (costs are compensated by the state) domestic emission reduction is 162 mn. tCO_2 and net-reduction is -152 mn. tCO_2. The relative amount of emissions that are “exported” are also higher in this Addendum than in Scenario 1 of the Study.

- **Addendum 2**: In *Addendum 2a* (closure of all plants until 2030), the domestic emission reduction amounts to 191 mn. tCO_2 while the net-reduction taking into account increasing emissions abroad amounts to less than half of this (87 mn. tCO_2). This means that a very large share (55%) of the emission reduction achieved in The Netherlands is compensated by higher emissions in neighbouring countries ("waterbed effect").

Compared to the scenario in the Study with fixed closure dates until 2030 (*Scenario 3c*) in combination with additional abatement measures, this Addendum shows that the additional abatement measures did result in significantly higher domestic reduction (44 mn. tCO_2 more than *Addendum 2a*), but only slightly higher net-reduction of 114 mn. tCO_2 (20 mn. tCO_2 more than *Addendum 2a*).

Closure of all plants until 2040 (*Addendum 2b*) lowers domestic emissions by 44 mn. tCO_2 and emissions in all modelled countries by 36 mn. tCO_2. The emission reduction in Addendum 2b is significantly lower than in Scenario 3d of the Study where all plants are forced to close until 2040 but also have to implement abatement measures as off 2025. In *Scenario 3d*, the aggregated domestic emission reduction amounts to 194 mn. tCO_2.

- **Addendum 3:** If the oldest plants close in 2020 and the remaining ones remain operational in 2030 (*Addendum 3a*), the aggregated domestic emission reduction amounts to 230 mn. tCO_2. Due increasing emissions abroad, net-reduction only amounts to 88 mn. tCO_2.

  If the remaining plants stay operational until 2040 (*Addendum 3b*), the reduction in The Netherlands only amounts to 106 mn. tCO_2 and in all modelled regions to 47 mn. tCO_2 (aggregated from 2018-2049).

- **Addendum 4:** Assuming significantly higher CO_2 prices brings domestic emissions in the Netherlands down by as much as 55% per year compared to the *Reference Case* (in 2040). Aggregated across all modelled years, the emission reduction amounts to 26% (276 mn. tCO_2). This is more than the domestic emission reduction that is achieved in any of the Scenarios in the Study, except closure of all plants in 2020 (Scenario 3a). As other countries are affected by the CO_2 price increase to a greater extent, coal and lignite-fired power supply drops by 70% compared to the Reference Case after 2030. Therefore, net-emission reduction in all modelled countries is even higher (4.8 bn. tCO_2; -35% aggregated from 2018-2049).

  The reduction of coal-fired generation, more co-firing of biomass, more CCS and higher in-feed from wind and solar PV increase the reduction over time: Emission from 2015 until 2040 decrease by 79% in The Netherlands (53% in the Reference Case). The decrease over time observed in Central-Western-Europe (PLEF + GB) even amounts to 85% (from 2015 until 2040).

System costs and distributional effects

The impact of the additional policy measures on the affordability of electricity supply is reflected in two ways: the costs of the electricity system and the payments of final consumers:

- **Addendum 1:** The implementation of additional abatement measures in 2020 increases system costs by up to 4.5 bn. EUR (NPV 2018-2049) (*Addendum 1b*). From a Dutch perspective, the specific abatement costs of the additional measures range between 14 €/tCO_2 (if costs are borne by the companies, *Addendum 1a*) and 24 €/tCO_2 (if costs are not borne by the companies, *Addendum 1b*). The difference between the two sub-scenarios arises from the lower emission reduction in *Addendum 1b* (no impact on operation of plants if costs are not borne by the companies) paired with higher system costs. These costs are significantly higher compared to Scenario 1 that is included in the Study, in which additional abatement measures are taken in 2025 (1.4 bn. EU when costs are borne by the companies (Scenario 1a) and 2.1 bn EUR if costs are compensated by the state (Scenario 1b)).

From an EU-wide perspective, taking into account the net-emission reduction and system costs in all modelled countries, the net-abatement costs amount to ca. 25 €/tCO_2.

As power prices are not affected to a great extent by the additional measures, consumer payments do not change significantly compared to the *Reference Case.*

- **Addendum 2:** Closure of all plants until 2030 (*Addendum 2a*) increases system costs by 4.2 bn. EUR (NPV 2018-2049). Specific abatement costs amount to 22 EUR/tCO_2 from a Dutch perspective and to 45 EUR/tCO_2 if effects in other regions are taken into account (net-EU abatement costs). The closure of all coal plants until 2040 leads to an increase of system cost of 1.9 bn. EUR (NPV 2018-2049) and yields domestic abatement costs of around 41 €/tCO_2 (*Addendum 2b*).

  As expected, *Addendum 2a* and *Addendum 2b* result in lower system costs than the scenarios in the Study with fixed closure dates until 2030/2040 (*Scenario 3c:* 4.5 bn. EUR / *Scenario 3d:* 3.1 bn EUR). The difference is due to the fact that in *Addendum 2a* and *Addendum 2b*, no abatement measures are taken form 2025.

- **Addendum 3:** If the two oldest plants close in 2020 and the remaining ones in 2030, the increase of the systems costs amounts to 4.9 bn. EUR (NPV 2018-2049) (*Addendum 3a*). This case leads to domestic abatement costs of ca. 21 €/CO_2. If the remaining plants stay operational until 2040 (*Addendum 3b*), system costs increase by only 3 bn. EUR (NPV 2018-2049). However, due the lower emission reduction achieved in this case, domestic abatement costs are higher than in *Addendum 3a* (28 EUR/tCO_2).

  Closure of the two oldest plants until 2020 combined with closure of the remaining plants in 2030 or 2040 results in higher system costs compared to *Scenario 3e* and *Scenario 3f*, in which abatement measures are taken from 2025 at the remaining plants (+ 2.1 bn. EUR) or no actions are taken at all at these plants (+1.1 bn. EUR).

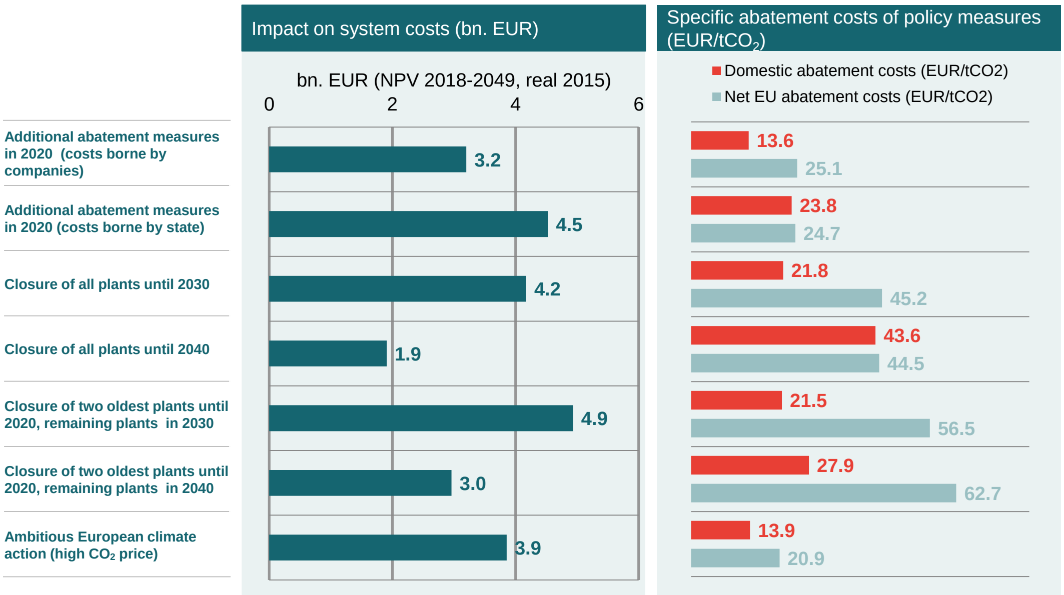
  As mentioned above, a large share of the emission reduction achieved in The Netherlands is offset by higher emission in other countries. Therefore, specific abatement costs from a European perspective are much higher than from a domestic perspective, e.g. 56 €/tCO_2 in *Addendum 3a* and 63€ /tCO_2 for *Addendum 3b*.

Consumers are affected the most if the two oldest power plants close in 2020 and the remaining ones in 2030 (+ 2 bn. EUR NPV 2018-2049). If closure of the remaining plants is postponed to 2040, consumer payments increase by 0.9 bn. EUR (NPV 2018-2049).

- **Addendum 4:** Assuming that the Paris Agreement will lead to a significant increase in CO_2 prices increases system costs in The Netherlands by 3.9 bn EUR (NPV 2018-2049). The increase is driven by earlier investment in generation capacities (gas and RES-E) as well as higher variable costs of conventional plants due to higher emission costs.[1] Relating this increase in system costs to the domestic emission reduction yields specific abatement costs of around 14 EUR/tCO_2. Taking into account the emission reduction and the increase in system costs across Europe, specific abatement costs increase to 21 EUR/tCO_2.

  The assumed increase of CO_2 prices leads to significantly higher power prices in all modelled countries compared to the *Reference Case*. Dutch prices increase by up to 18 €/MWh compared to the *Reference Case*. This increases the costs to final consumers by 10-12% and increases revenues of low-carbon technologies compared to carbon-intensive technologies.

Figure 1. Impact on system costs and specific abatement costs



Source: Frontier

Security of Supply and import dependency

The Dutch electricity system is characterised by a high degree of Security of Supply. The introduction of the policy measures assessed in this study does have an impact on the level of operational capacities in The Netherlands. However, due to high levels of import capacities available and the amount of mothballed

[1] This scenario can be compared to the other scenarios only to a limited extent due to the structural differences in power supply across Europe arising from the assumed significant increase in CO_2 prices. Furthermore, increasing variable costs are mainly driven by this higher CO_2 price assumption.

capacity in the short-term, the measures do not lead to a risk to Security of Supply:

- **Addendum 1:** The additional abatement measures at the plants do not influence the availability of generation capacities to a large extent. Consequently, Security of Supply and import dependency are not affected.
- **Addendum 2:** The closure of coal-fired power plants directly decreases generation capacity in The Netherlands. However, investment in gas-fired capacities and higher imports due to vast power generation capacities around Europe compensate this decrease.
- **Addendum 3:** As in Addendum 2, closure of the coal-plants decreases generation capacity in The Netherlands. However, this decrease is compensated by earlier reactivation of mothballed gas-fired power plants and higher imports due to vast power generation capacity around Europe in the short and medium term. However, it has to be noted that the reactivation of the mothballed gas-fired power plants depends on the view the owners take on the future energy market. Early closure of the two plants built in the 1990's has a limited negative effect on the reserve margin and import dependency.
- **Addendum 4:** The assumption of a significantly higher CO_2 price increases domestic power supply in The Netherlands in the short- to medium term. Dutch gas-plants substitute fossil fuelled generation in other countries that are affected to a greater extent by the higher CO_2 price. Therefore, exports increase.

Impact on RES-E

The different policy measures can have an impact on the development of renewable energy sources in The Netherlands either directly through a changing framework for biomass co-firing (e.g. further subsidies for co-firing) or indirectly through a changing market environment (e.g. higher wholesale power prices leading to earlier market driven investment in RES-E):

- **Addendum 1:** The additional emission reduction achieved in *Addendum 1* is largely based on increased co-firing of biomass in the coal plants. This measure also increases the absolute amount of RES-E in the system (on average between 4 and 5 %-points increase of the RES-E share of net-demand).
- **Addendum 2:** Closure of the coal plants in Addendum 2 reduces the amount of biomass co-firing and consequently lowers the share of RES-E in The Netherlands (-1%-point average RES-E share of net-demand).
- **Addendum 3:** The closure of the coal plants in Addendum 3 reduces the amount of biomass co-firing and consequently lowers the share of RES-E in The Netherlands. The decrease is higher than in Addendum 2 as the two older plants close already in 2020 (-1.4%-point average RES-E share of net-demand).
- **Addendum 4:** Given that the CO_2 price increases significantly compared to the Reference Case in this Addendum, renewable energy sources become economically viable without any subsidies earlier and additional investment

takes place already in 2030. Consequently, the share of renewable electricity of net-demand increases by up to 20%-points in 2030 and by 6 %-points in 2040.

1 INTRODUCTION

1.1 Background

The Netherlands has committed itself to reaching a low-carbon energy system that is reliable, affordable and safe in 2050. Within this context, the Dutch Energy Agreement represents an irreversible step towards achieving this goal. As part of the Energy Agreement, two of seven remaining coal-fired power stations that are currently operational in The Netherlands will be closed mid-2017. On 26 November 2015, the second chamber of the Dutch Parliament has accepted a motion to phase-out coal-fired electricity generation in The Netherlands. In its proposal, the Parliament

- has taken the view that **no permissions to build new coal-fired power station** in The Netherlands will be granted; and
- has asked the government and the electricity sector to develop a plan to **phase-out existing coal-fired power generation**.

Frontier has conducted a study on behalf of MinEZ to model several scenarios of different policy measures around the phasing-out of coal-fired generation in The Netherlands and the introduction of additional CO_2 abatement measures in The Netherlands and the EU. The final report was submitted to MinEZ on 1st July 2016. After submission of the final report, discussions with stakeholders and within the government revealed the need to analyse additional scenarios, beside the ones already included in the study. Therefore, MinEZ has asked Frontier to model additional policy scenarios and evaluate these scenarios based on the framework developed in the original study.

These scenarios are an addition to the study “Research of scenarios for coal-fired power Plants in The Netherlands” (hereafter “the Study”):

- **Addendum 1:** Additional CO_2 abatement measures at the coal plants in 2020 (2 scenarios);
- **Addendum 2**: Additional scenarios with fixed closure dates and additional abatement measures at the plants based on economic viability (2 scenarios); and
- **Addendum 3:** Additional scenarios with earlier closure of old plants and fixed closure dates for the newer plants (additional abatement measures at the plants based on economic viability*)* (2 scenarios); and
- **Addendum 4:** Ambitious Europe climate action as a result of the Paris Agreement leads to European policy initiatives that result in a significantly higher CO_2 price in the whole EU.

Section 2 contains a more detailed description of the additional scenarios.

1.2 Approach of our analysis

The analysis in this Addendum follows the approach taken in the Study *"Research of scenarios for coal-fired power Plants in The Netherlands".* We have used the *Reference Case* of the Study to analyse the impact of the additional policy scenarios on the indicators defined in the Study.

For more detailed information on the approach, methodology and results of the main analysis please refer to the main publication *"Research of scenarios for coal-fired power Plants in The Netherlands".*

1.3 Structure of the report

The report is structured as follows:

- Definition of additional policy scenarios (**Section 2**);
- Indicator based assessment of the additional policy (**Section 3**); and

Detailed information on the model, the modelling assumptions as well as on the results can be found in the Annexes of the main Study.

2 ADDITIONAL SCENARIOS

MinEZ has developed the outline for four additional scenarios (and a number of sub-scenarios), each representing different policy measures or policy frameworks addressing the future of coal-fired power generation in The Netherlands:

- **Addendum 1: Additional CO_2 abatement measures at the coal plants in 2020 –** In this scenario the coal plants apply possible measures to reduce the CO_2 emission per unit of delivered electricity to such a level that the emissions are at least equal to the average CO_2 emissions of a modern gas-fired power plant (350 gCO_2/kWh_{el}). *Scenario 1* of the main Study assumed that these measures should be implemented in 2025. *Addendum 1* now assumes implementation already in 2020. The measures include increase co-firing of biomass, implementation of CCS or increase of residual heat utilisation.
- **Addendum 2: Additional scenarios with fixed closure dates and optimised abatement measures at the plants based on economic viability –** In the second Addendum, coal-fired power plants in The Netherlands are required to shut-down at specific dates. These dates have been set prior to the expected technical lifetime of the coal plants. The main study assumed that with closure dates in 2030 and 2040, the coal-fired plants apply the same abatement measures as listed in *Scenario 1*. In this Addendum, we assume that abatement measures additional to the ones already included in the *Reference Case* will only be implemented based on their economic viability (and not mandatorily as assumed in the main study).
- **Addendum 3: Additional scenarios with early closure of old plants and fixed closure dates for newer plants -** In the third Addendum, the two oldest coal-fired power plants in The Netherlands built in the 1990s are required to shut-down until 2020. The remaining three coal-fired plants remain online until 2030/2040. In the Study, we assumed that with closure dates in 2030 and 2040, the coal-fired plants apply the same abatement measures as listed in *Scenario 1*. In this Addendum, as in Addendum 2, we assume that abatement measures will only be implemented based on their economic viability (and not mandatorily as assumed in the Study).
- **Addendum 4: Ambitious European climate action leading to significantly higher CO_2 price –** In this fourth Addendum, we assume that the EU takes ambitious collective action in response to the Paris Agreement on Climate Change (COP21). Although it is not know which policy actions might be implemented, it is assumed this leads to a significantly higher CO_2 price in the whole EU in the medium and long term than assumed in the Reference Case.

In the following, we describe the assumptions of these scenarios in more detail.

2.1 Addendum 1: Additional abatement measures at the plants in 2020

In this Addendum, it is assumed that plant operators implement additional measures at the coal plants to reduce the CO_2 emission per unit of delivered electricity to such a level that the emissions are at least equal to the average CO_2 emissions of a modern gas-fired power plant (350 gCO2/kWh_{el}). It is assumed that these measures are effective in the model period 2020, which means implementation of the measures has to happen before 31 December 2019.

In the *Reference Case*, a number of abatement measures are already included, such as 25 PJ/a co-firing (for modelling purposes, this is split evenly over the five plants), heat decoupling and the ROAD CCS-project. In the context of the Study, for Scenario 1, the operators of the Dutch coal plants have been asked to provide information on possible additional abatement measures that could be implemented by 2025 at their power plants to lower their emission to the threshold of 350 gram/kWh_{el}[2] , which is comparable to a highly efficient gas-fired power plant. In this Addendum, we assume that the same measures as in Scenario 1 of the Study are implemented in 2020.

In the following, we describe which measures have been included and how they are implemented in the context of the power market model.

2.1.1 Emission abatement measures

Measures that could be implemented by the plant operators are identical to the ones analysed in the Study and include:

- **Co-firing of biomass** - Co-firing up to 25 PJ/a across all Dutch coal plants is included in the Reference Case. This subsidised co-firing takes place from 2020 until 2028. In addition to this amount, plant operators could use higher shares of co-firing compared to the Reference Case. Biomass co-firing is regarded as CO_2-neutral and reduces the specific emissions of the plant accordingly. Based on the information received from the operators, all coal plants would implement additional biomass co-firing as a measure to reduce the specific carbon emissions to the level of a modern gas plant.
- **Increase utilisation of residual heat output** - Two of the power plants in focus already dispose of combined-heat and power production (CHP) in the Reference Case. In this Addendum, additional utilisation of heat decoupling could be implemented in order to lower specific emissions of the power plant. For each additional MWh_th heat output, a heat credit for CO_2 emission reduction is granted that equals the avoided amount of carbon dioxide emissions in the heat sector. Based on the information received from the operators, one power plant would increase its heat output to lower its specific emissions per unit of electricity produced. Other plant operators indicated that additional heat decoupling is theoretically possible, but not included in this context.

2 Based on 58% electrical efficiency and 203g CO_2/kWh.

- **Implementation of Carbon Capture and Storage (CCS)**: The ROAD CCS-facility at the Maasvlakte is the only CCS installation included in the Reference Case. In addition to this, plant operators could implement CCS to lower their emission. One plant operator indicated that additional CCS would be used in order to lower specific emissions of the power plant in this scenario. Furthermore, one additional plant operator indicated that the implementation of CCS at its plant is theoretically possible, but not necessary to achieve the target emission-intensity in this context.

2.1.2 Modelling framework

The abatement measures described above are not economically viable by themselves in 2020. Because of that, the question who bears the costs of the measures impacts the outcomes of this Addendum. Similarly to Scenario 1 of the Study, this Addendum consists of two sub-scenarios which are differentiated by the treatment of the costs associated with the implementation of the additional emission reduction:

- **Addendum 1a**: **Emission reduction measures at the plants (no compensation) –** Plant operators have to bear the costs associated with the additional emission reduction themselves. This includes investment costs to achieve the required emission reduction, increased variable and fixed operating and investment costs as well as efficiency losses. In this scenario, abatement measures and associated costs are included as off 2020. Based on the parameters included, the model optimises whether the plants stay operational until the end of their lifetime or cease operation earlier.
- **Addendum 1b**: **Emission reduction measures at the plants (compensation) –** This sub-scenario includes the same abatement measures as Addendum 1a. The costs associated with the emission reduction measures, however, are not included in the firm’s cost base. Therefore, this scenario can be interpreted as a framework in which plant operators are compensated for additional costs arising from the implementation of additional abatement measures at their plants.

2.2 Addendum 2: Fixed closure of coal plants and optimised abatement measures based on their economic viability

Similarly to four of the different sub-scenarios in Scenario 3 of the Study, we have analysed additional scenarios with fixed closure dates for all coal-fired power plants.

2.2.1 Background

In the Study, we analysed the impact of the closure of coal-plants at a given date:

- Scenario 3a and 3b modelled the closure of all plants until 2020 / 2025. In these scenarios, no additional abatement measures at the coal plants have been assumed.
- Scenario 3c and 3d modelled the closure of all plants until 2030 / 2040. In these scenarios, mandatory additional abatement measures at the plants were included in 2025 (the same measures as in Scenario 1).

As Addendum to the Study, we analyse the two following scenarios:

- **Addendum 2a**: Closure of all plants until 2030. Additional abatement measures (based on Scenario 1 of the Study) are implemented by the companies only if economically viable (in the original *Scenario 3c* the implementation of these measures was mandatory); and
- **Addendum 2b**: Closure of all plants until 2040. Additional abatement measures (based on Scenario 1 of the Study) are implemented by the companies only if economically viable (in the original *Scenario 3d* the implementation of these measures was mandatory).

2.2.2 Modelling framework

In this Addendum, we analyse if additional abatement measures at the plants are economically viable on a market driven basis. Only these measures are taken into account in the simulation.

The potential additional measures analysed are based on the most important options the companies provided for the Study, i.e.

- Potential additional co-firing of biomass (see Addendum 1; we would assume a limit of ca. 55 PJ per year according to the biomass use in the other scenarios with abatement measures at the coal plants; this reflects e.g. potential medium and long term limitations on the availability of sustainable biomass on the world markets);
- Potential additional CCS at two of the coal fired power plants.

As in the Reference Case of the Study and based on the assumed fuel and CO_2 prices as well as the information provided by the plant operators, we conclude that co-firing of biomass becomes economically viable in 2040. Therefore, additional co-firing on top of the 25 PJ/a subsidised co-firing between 2020 and 2028 does not apply to Addendum 2a and 2b as all coal plants are required to shut-down before market based co-firing becomes economically viable.

As in the Reference Case, the CCS demonstration plant “ROAD” is economically viable after 2035, and is therefore included in Addendum 2b but not 2a. Implementation of CCS at the second plant is not viable before 2040.

2.3 Addendum 3: Early closure of old plants and fixed closure dates for the newer plants

Similar to Scenario 3e and 3f in the Study, we have analysed additional scenarios with fixed closure dates for all coal-fired power plants, differentiating between older plants built in the 1990 and newer plants that have come into operation in 2015.

2.3.1 Background

In the Study, we analysed the impact of the closure of two of the oldest coal-plants in 2020:

- Scenario 3e: closure of the two oldest plants until 2020, no enforced closure of the newer plants, additional abatement measures at the remaining plants in 2025 (the same measures as in Scenario 1).
- Scenario 3f: closure of the two oldest plants until 2020, no enforced closure of the newer plants, no additional abatement measures at the remaining plants.

As Addendum to the Study, we analyse the two following scenarios:

- **Addendum 3a**: Closure of the two oldest plants in 2020 and closure of the remaining plants until 2030. Additional abatement measures (based on Scenario 1 of the Study) are implemented by the companies only if economically viable (in the original *Scenario 3e* the implementation of these measures was mandatory); and
- **Addendum 3b**: Closure of the two oldest plants in 2020, closure of the remaining plants until 2040. Additional abatement measures (based on Scenario 1 of the Study) are implemented by the companies only if economically viable (in the original *Scenario 3e,* the implementation of these measures was mandatory).

2.3.2 Modelling framework

In this Addendum, we analyse if additional abatement measures at the plants are economically viable on a market driven basis. Only these measures are taken into account in the simulation.

The potential additional measures analysed are based on the most important options the companies provided for the Study, i.e.

- Potential additional co-firing of biomass (see Addendum 1; we would assume a limit of ca. 55 PJ per year according to the biomass use in the other scenarios with abatement measures at the coal plants; this reflects e.g. potential medium and long term limitations on the availability of sustainable biomass on the world markets);
- Potential additional CCS at two of the coal fired power plants.

As in the Reference Case of the Study and based on the assumed fuel and CO_2 prices as well as the information provided by the plant operators, we conclude that co-firing of biomass becomes economically viable in 2040. Therefore, additional co-firing on top of the 25 PJ/a subsidised co-firing between 2020 and 2028 does not apply to Addendum 3a and 3b as all coal plants are required to shut-down before market based co-firing becomes economically viable.

As in the Reference Case, the CCS demonstration plant “ROAD” is economically viable after 2035, and is therefore included in Addendum 3b but not 3a. Implementation of CCS at the second plant is not viable before 2040.

2.4 Addendum 4: Effective European climate action leading to significantly higher CO_2 price

This Addendum assumes that the EU takes ambitious collective action in response to the Paris Agreement on Climate Change (COP21). Although it is not know which policy actions might be implemented, it is assumed this leads to a significantly higher CO_2 price in the whole EU in the medium and long term than assumed in the Reference Case.

2.4.1 Definition of alternative CO_2 price assumption

The Paris Agreement and the outcomes of the UN climate conference (COP21) aim at reducing the global temperature rise to well below 2 degrees Celsius and strive for 1.5 degrees Celsius. Additional efforts should be taken to limit the emission of greenhouse gases further. While it is unclear which measures and legally binding EU initiatives might arise from the agreement, we assume that the European climate policy will be impacted by the implementation of the agreement. The long-term goal of the EU to achieve an emission reduction of 80-95% by 2050 compared to 1990 may be strengthened and/or the CO_2 emission caps in the EU ETS may be strengthened. For the purpose of this Addendum, it is not relevant what specific form the policy initiative(s) would take, but we assume this will result in a significant increase, *compared to the Reference Case,* of the CO_2 price in the medium and long term (assuming that additional abatement takes place in the EU ETS).

2.4.2 Modelling framework

Since it is unknown how the Paris Agreement might be implemented in the EU and what specific effects this might have on the CO_2 price in Europe, for the purpose of this Addendum we have based the alternative CO_2 price development on the World Energy Outlook 2015 “450 Scenario”. The 450 Scenario assumes that significant additional climate policy measures are implemented globally.[3]

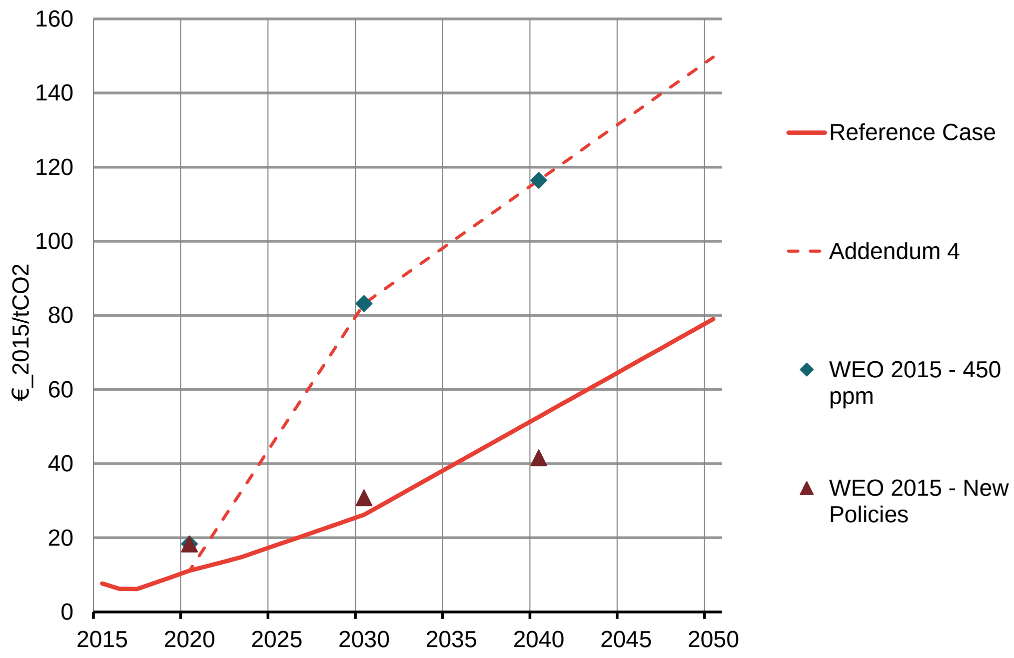
Figure 2 compares different projections of the price of EU allowances to the *Reference Case* assumption:

- **Short-term (until 2020)** – We assume that the short-term development follows the *Reference Case*, i.e. additional policies that lead to an increase of the CO_2 price will take effect after 2020.
- **Medium- and long-term (until 2040) –** After 2020, we assume that the CO_2 price will rise to the level of the WEO 450 Scenario of ca. 80 €(real, 2015) / tCO_2. In the long-run, the price is assumed to follow the path of the WEO (ca.

[3] IEA WEO (2015), p. 35.

116 €/tCO_2 in 2040) and is extrapolated linearly until 2050. In the long-run, the CO_2 price approximately doubles compared to the Reference Case.

Figure 2. Comparison of CO_2 price assumptions (Addendum 4)



Source: Frontier

In order to reflect the increased efforts to lower emissions of CO_2 in the EU, we have also adjusted the following assumptions:

- **Existing coal-fired power plants in the Netherlands –** Increased efforts to lower emissions of CO_2 with respect to the operation of Dutch coal-fired power plants could lead to additional co-firing of biomass, above the 25 PJ limit assumed in the *Reference Case*. Consistent with our previous calculations in Scenarios 1a / 1b and Addendum 1a / 1b (assuming higher biomass usage than in the *Reference Case*), we assume that at maximum the amount of co-firing per plant indicated by the power companies as additional measure to reduce CO_2 emissions can be pursued.[4] At maximum, this amounts to ca. 55 PJ of co-firing in 2030 in all coal-fired power plants.

  In addition, two of the five coal-fired power plants have indicated that the implementation of CCS could be pursued based on their economic viability. Given the increased CO_2 price, the operation of CCS becomes economically viable at the existing power plants as off 2025 / 2030.[5]

- **New built power plants and RES-E in The Netherlands** – We have maintained the assumption that new-built CCS plants (gas or coal) can in theory come online after 2025. We have also increased the potential to build additional RES-E (endogenous investment) slightly compared to the Reference Case: We assume that endogenous investment in RES-E can take

[4] The total amount of co-firing is limited in order to account for the availability of sustainable biomass.

[5] There is only one CCS installation included in the *Reference Case*. However, one plant operator mentioned that the implementation of CCS would be possible at their plant. Based on the information provided, we have assessed the economic viability of this installation.

place already in 2030 due to early “grid parity” of wind onshore, offshore or solar PV. We have also doubled the possibilities to invest in RES-E in The Netherlands in 2035.

- **Generation capacities in other model regions –** We have adjusted the generation capacities in other modelled regions slightly to reflect the changing market environment:
  - Core-regions (with endogenous investment): Higher potential for endogenous investment in RES-E in core-regions (i.e. more possibilities for the model to investment in RES-E in Central Western Europe). We assume that endogenous investment in RES-E can take place already in 2030 due to early “grid parity” of wind onshore, offshore or solar PV. We increase the possibilities to invest in RES-E in 2035 across Central Western Europe by 250%.

    It has to be noted that this increase provides further options for the model to invest in renewable capacities and therefore, the increase in capacity and therefore increase of RES-E in-feed is an outcome of the model.

    The assumptions for (optimised) new built CCS plants remain unchanged.
  - Non-core regions (no endogenous investment): Higher RES-E (40% more RES-E capacities in 2035 and 50% in 2040 compared to the Reference Case) and a decrease in coal- or lignite-fired capacities (-40% in 2035 compared to the Reference Case) in other model regions without endogenous/optimised capacity development.

3 INDICATOR BASED ASSESSMENT

In this chapter, we summarise the results of the indicator-based assessment of the additional scenarios..

The section is structured as follows:

- Summary of the main findings (**Section 3.1**);
- Impact on carbon-dioxide emissions in The Netherlands and Europe (**Section 3.2)**
- Impact on the affordability of the power system (**Section 0**);
- Impact on power prices (**Section 3.4**) and consumer payments (**Section 3.5**);
- Impact on Security of Supply and import dependency (**Section 3.6**);
- Impact on the development of RES-E (**Section 3.7**); and
- Impact on other indicators (**Section 3.8**).

3.1 Summary

Table 1 summarises the indicator based assessment of the Addendums. The definition of the different indicators in the table is the same as in the Study and is specified as follows (more detailed description can be found in the following chapters):

- **Impact on CO_2 emissions** - Accumulated difference of CO_2 emissions compared to the Reference Case (2018-2049) in The Netherlands (domestic emission reduction); total CO_2 emission reduction in all modelled countries, including The Netherlands (net emission reduction).
- **Impact on wholesale prices for electricity in The Netherlands** - Difference of the yearly average wholesale power price compared to the Reference Case.
- **System costs and specific abatement costs -** Impact on the system costs of the electricity supply in The Netherlands and in all modelled countries, expressed as net present value from 2018-2049, compared to the Reference Case. Specific abatement cost have been calculated by dividing additional system costs by additional CO_2 emission reduction - from a Dutch perspective (Domestic abatement costs) and a European perspective (Net-EU abatement costs).
- **Impact on consumer payments** - Difference to the Reference Case of consumer payments for electricity supply and RES-E support, expressed as net present value from 2018-2049.
- **Impact on Security of Supply and import dependency** - Impact on the average reserve margin (based on peak load and de-rated generation capacities) from 2018-2049 and impact on average level of net-imports from 2018-2049, compared to the Reference Case.

Impact on RES-E - Impact on the average share of renewable energy sources of net-demand (%-points), compared to the Reference Case.

Table 1. Indicator based assessment of the Addendum – Summary

Scenario	Add. 1a	Add. 1b	Add. 2a	Add. 2b	Add. 3a	Add. 3b	Add. 4
Impact on emissions							
Domestic emission reduction (mn.tCO_2, sum 2018-2049)	-235 (-22 %)	-190 (-18 %)	-191 (-18 %)	-44 (-4 %)	-230 (-21 %)	-106 (-10 %)	-276 (-26 %)
Net emission reduction all countries (mn.tCO_2, sum 2018-2049)	-134 (-1.0 %)	-182 (-1.3 %)	-87 (-0.6 %)	-36 (-0.3 %)	-88 (-0.6 %)	-47 (-0.3 %)	-4,814 (-35.1 %)
Impact on wholesale prices for electricity in the Netherlands							
Price increase in 2020 EUR/MWh	1.7	0.0	-	-	0.9	0.9	0.4
Price increase in 2030 EUR/MWh	0.8	0.0	3.7	-	3.7	0.7	18.1
System Costs and specific abatement costs							
Impact on system costs in the Netherlands (bn. EUR)	3.2 (4.0 %)	4.5 (5.6 %)	4.2 (5.2 %)	1.9 (2.4 %)	4.9 (6.1 %)	3.0 (3.7 %)	3.9 (4.8 %)
Impact on system costs in EU (bn. EUR)	3.4 (0.4 %)	4.5 (0.6 %)	3.9 (0.5 %)	1.6 (0.2 %)	5.0 (0.7 %)	2.9 (0.4 %)	100.7 (13.2 %)
Domestic abatement costs (EUR/tCO_2)	13.6	23.8	21.8	43.6	21.5	27.9	13.9
Net-EU abatement costs (EUR/tCO_2)	25.1	24.7	45.2	44.5	56.5	62.7	20.9
Impact on consumer payments							
Impact on household payments (bn. EUR/%)	0.2 (0.9 %)	0.0 (0.0 %)	0.3 (1.6 %)	0.1 (0.4 %)	0.5 (2.2 %)	0.2 (1.1 %)	2.7 (12.4 %)
Impact on other consumer payments (bn. EUR/%)	0.6 (0.7 %)	0.0 (0.0 %)	1.0 (1.2 %)	0.2 (0.3 %)	1.4 (1.7 %)	0.7 (0.9 %)	8.0 (10.0 %)
Security of Supply and import dependency							
Impact on average Reserve Margin (GW)	0.0	0.1	-0.5	0.0	-0.6	-0.3	0.3
Impact on average net-imports (TWh)	4.3	1.1	7.4	1.3	9.4	4.1	-6.3
Impact on Renewable Energy Production							
Impact on average RES-E %-points	3.8%	5.3%	-0.9%	-0.9%	-1.4%	-1.4%	8.4%

Source: Frontier

Note: Values shown in table above represent differences compared to the Reference Case

The results are described and explained in more detail in the following chapters.

To provide a comprehensive overview of the findings in this report and in the Study and to make comparisons between the Addendums in this study and the

Scenarios in the Study possible, we have included **Table 2**, which contains all indicator-based outcomes in the Study.

Table 2. Indicator based assessment of the Study - Summary

Scenario	Scen. 1a	Scen. 1b	Scen. 2	Scen. 3a	Scen. 3b	Scen. 3c	Scen. 3d	Scen. 3e	Scen. 3f
Impact on emissions									
Domestic emission reduction (mn.tCO_2, sum 2018-2049)	-180 (-17 %)	-162 (-15 %)	-58 (-5 %)	-322 (-30 %)	-258 (-24 %)	-242 (-23 %)	-194 (-18 %)	-209 (-19 %)	-63 (-6 %)
Net emission reduction all countries (2018-2049)	-121 (-0.9 %)	-152 (-1.1 %)	-401 (-2.9 %)	-87 (-0.6 %)	-82 (-0.6 %)	-114 (-0.8 %)	-132 (-1.0 %)	-113 (-0.8 %)	-11 (-0.1 %)
Impact on wholesale prices for electricity in the Netherlands									
Price increase in 2020 EUR/MWh	-	-	10.5	4.1	-	-	-	0.9	0.9
Price increase in 2030 EUR/MWh	0.8	0.0	3.6	3.7	3.7	3.7	0.8	1.1	0.7
System Costs and specific abatement costs									
Impact on system costs in the Netherlands (bn. EUR)	1.4 (1.7 %)	2.1 (2.6 %)	0.3 * (0.4 %)	7.1 (8.8 %)	4.2 (5.2 %)	4.5 (5.6 %)	3.1 (3.9 %)	2.1 (2.7 %)	1.1 (1.3 %)
Impact on system costs in EU (bn. EUR)	2.3 (0.3 %)	2.8 (0.4 %)	9.4 * (1.2 %)	7.9 (1.0 %)	6.0 (0.8 %)	5.1 (0.7 %)	3.6 (0.5 %)	3.1 (0.4 %)	1.4 (0.2 %)
Domestic abatement costs (EUR/tCO_2)	7.5	12.8	5.1*	21.9	16.2	18.7	16.0	10.3	27.5
Net-EU abatement costs (EUR/tCO_2)	18.6	18.7	22.7*	90.9	73.5	45.1	27.7	27.7	119.2

Scenario	Scen. 1a	Scen. 1b	Scen. 2	Scen. 3a	Scen. 3b	Scen. 3c	Scen. 3d	Scen. 3e	Scen. 3f
Impact on consumer payments									
Impact on household payments (bn. EUR/%)	0.1 (0.3 %)	0.0 (0.0 %)	2.1 (9.6 %)	0.9 (4.2 %)	0.5 (2.4 %)	0.4 (1.6 %)	0.2 (0.9 %)	0.2 (0.9 %)	0.2 (0.7 %)
Impact on other consumer payments (bn. EUR/%)	0.2 (0.2 %)	0.0 (0.0 %)	6.4 (8.0 %)	2.6 (3.3 %)	1.5 (1.9 %)	1.0 (1.3 %)	0.6 (0.8 %)	0.6 (0.7 %)	0.5 (0.6 %)
Security of Supply and import dependency									
Impact on average Reserve Margin (GW)	0.0	0.1	1.0	-1.2	-1.0	-0.5	-0.1	-0.2	-0.3
Impact on average net-imports (TWh)	2.6	1.2	1.2	14.3	11.5	8.4	3.7	4.6	2.8
Impact on Renewable Energy Production									
Impact on average RES-E %-points	3.6%	4.8%	0.7%	-2.1%	-1.8%	-0.2%	2.0%	2.7%	-0.5%

Source: Frontier

Note: Values shown in table above represent differences compared to the Reference Case
* Not including the increase of variable costs related to the carbon price floor

3.2 Impact on carbon-dioxide emissions

The policy scenarios defined in **Section 2** aim to reduce the carbon-dioxide emissions from Dutch coal plants through different policy measures. In this chapter, we describe the impact of the different measures on the CO_2 balance in The Netherlands and the other modelled-countries.

3.2.1 Methodology

The carbon dioxide emissions from power production are calculated as all power related emissions, based on net-electricity production and plant or technology specific CO_2 emission intensities. Emissions from CHP-production are taken into account on the basis of plant-specific emission intensity. If the policy measures include an improvement of the plant specific emission intensity based on an increase of heat utilisation, a credit for this increase in the form of lower emission intensity is granted.[6]

CO_2 emissions are reported as differences to the Reference Case and defined as:

[6] Based on the emission intensity of an alternative heat source.

- **Domestic emission reduction** in the Netherlands, that takes into account lower emissions from Dutch coal plants and an increase of emissions from other Dutch power plants; and
- **Net emission reduction** taking into account changes of emissions in all modelled European countries, including the Netherlands.

In addition, we analyse to what extent the development path of emissions from 2015 until 2040 is affected by the implementation of the policy measures.

3.2.2 Results

The policy measures have the following impact on carbon dioxide emissions in The Netherlands:

Domestic emission reduction differ significantly between scenarios

- **Addendum 1: Additional abatement measures at the plants from 2020 –** Implementing additional abatement measures at the Dutch coal plants reduces the CO_2 emission intensity to the level of a modern gas-fired plant as off 2020.
  - In **Addendum 1a**, the costs of the emission reduction are borne by the plant operators. This leads to an earlier decommissioning of one of the coal plants built in the 1990s: for this plant, operation with an increased (unsubsidised) share of biomass co-firing becomes no longer economical viable after 2028 and the plant closes before 2030 instead of until 2035. In total, the implementation of additional abatement measures in *Addendum 1a* reduces the CO_2 emissions in The Netherlands by ca. 235 mn. tCO_2 (-22%, aggregated emission reduction from 2018-2049).[7] The highest yearly emission reduction is achieved in 2030 with 13 mn. tCO_2 less emissions than in the Reference Case.
  - In **Addendum 1b**, the abatement costs are not fully incorporated into the firm's cost base (increased fuel and fixed costs are assumed to be compensated by the state)[8]. This leads to lower variable costs of generation in the medium term and therefore higher utilisation of coal plants compared to *Addendum 1a*.[9] Because of this, earlier decommissioning of coal plants does not take place. Therefore, aggregate emission reduction in The Netherlands in *Addendum 1b* is (moderately) lower than in *Addendum 1a* (-190 mn. tCO_2, -18% aggregated from 2018-2049).

  In both additional scenarios, the emission reduction is higher than in the comparable *Scenario 1a* (+50 mn. tCO_2) and *1b* (+28 mn. tCO_2) of the main study, as the additional abatement measures are implemented already in 2020 instead of 2025.

[7] Emission reduction from 2018 until 2049 have been calculated based on the representative modelled years.

[8] Calculated costs of the additional measures (excl. efficiency losses) amount to 4.5 bn EUR (NPV 2018-2049).

[9] Emission reduction measures are implemented to achieve a reduction of the specific emission factor to at least 350 gCO_2/kWh_el .

- **Addendum 2: Fixed closure of coal plants and optimised abatement measures based on their economic viability –** In this Addendum, we assume that additional abatement measures, on top of those already implemented in the Reference Case of the Study, will only be implemented if economically viable without any subsidies. The analysis has shown that biomass co-firing is the pre-dominant form of CO_2 abatement at the coal-plants. As co-firing becomes economically viable only in 2040, the emission reduction achieved in these additional scenarios is solely based on the closure of the coal-plants:
  - **Addendum 2a**: The closure of all plants until 2030 without implementing any additional abatement measures reduces the emission of CO_2 in The Netherlands by 191 mn. tCO_2 (-18%, aggregated from 2018-2049); and
  - **Addendum 2b**: The closure of all plants until 2040 (the two older plants are assumed to cease operation already until 2035 due to the end of their assumed lifetime) reduces emission of CO_2 in The Netherlands by 44 mn. tCO_2 (- 4% aggregated from 2018-2049).

  This domestic emission reduction is lower than the reduction achieved in the *Scenarios 3c* (-242 mn.tCO_2) and *3d* (-194 mn.tCO_2) of the main Study. The difference is due to the mandatory abatement measures implemented at the plants as off 2025 in these scenarios.
- **Addendum 3: Early closure of old plants and fixed closure dates for the newer plants –** It is assumed that the two older coal-fired power plants (built in the 1990s) will cease operation until 2020. The newer plants will remain operational until 2030 (*Addendum 3a*) or 2040 (*Addendum 3b*). As in *Addendum 2*, we assume that additional abatement measures, on top of those already included in the Reference Case of the Study, will only be implemented if economically viable without any subsidies. Given that the same market framework applies as in *Addendum 2*, the emission reduction compared to the Reference Case is solely based on the closure of the coal-plants:
  - **Addendum 3a:** The closure of the older plants until 2020 and of the remaining plants until 2030 (without implementing any additional abatement measures) reduces the emission of carbon dioxide by 2030 mn. tCO_2 (-21 %, aggregated from 2018-2049). Closure of the two oldest plants results in around 4 mn. tCO2 reduction in 2020 in The Netherlands ; and
  - **Addendum 3b:** If the older plants ceased operation in 2020 but the newer plants remain online until 2040, emissions decrease by 106 mn. tCO_2 (-10%, 2018-2049).
- **Addendum 4:** Higher prices for CO_2 emission lead to a cost advantage of the Dutch plant park compared to neighbouring supply systems. This leads to higher exports to e.g. Germany and the carbon dioxide emissions in The Netherlands increase moderately by 1-2 mn. tCO_2 in 2020 / 2025. In the medium- to long-term (after 2030), the high CO_2 prices lead to a significant drop in coal-fired power generation (ca. - 20 TWh in 2030), while co-firing of biomass and generation from other renewable technologies such as wind or

solar PV increases. This leads to a structural change in the supply structure and as a result, annual emissions decrease by 50% in the long-run compared to the *Reference Case* (-14 mn. tCO_2/a in 2040). Over the modelling period, the domestic emission reduction amounts to 275 mn. tCO_2 (aggregated 2018-2049).[10]

Table 3 summarises the domestic reduction of emissions in The Netherlands compared to the Reference Case.

Table 3. Domestic emission reduction (NL)

mn.t CO_2	Sum 2018-2049	2018	2020	2025	2030	2035	2040
Addendum 1a	-235 (-22 %)	0 (0 %)	-11 (-30 %)	-10 (-24 %)	-13 (-33 %)	-6 (-22 %)	-3 (-12 %)
Addendum 1b	-190 (-18 %)	0 (0 %)	-7 (-20 %)	-8 (-19 %)	-11 (-27 %)	-6 (-20 %)	-3 (-12 %)
Addendum 2a	-191 (-18 %)	0 (0 %)	0 (0 %)	0 (0 %)	-18 (-44 %)	-11 (-37 %)	-5 (-19 %)
Addendum 2b	-44 (-4 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	-4 (-18 %)
Addendum 3a	-230 (-21 %)	0 (0 %)	-4 (-10 %)	-4 (-9 %)	-18 (-44 %)	-11 (-37 %)	-5 (-19 %)
Addendum 3b	-106 (-10 %)	0 (0 %)	-4 (-10 %)	-4 (-9 %)	-5 (-12 %)	0 (0 %)	-4 (-18 %)
Addendum 4	-276 (-26 %)	0 (0 %)	1 (2 %)	2 (5 %)	-15 (-38 %)	-16 (-52 %)	-14 (-56 %)

Source: Frontier

Note: Reduction of emission compared to the Reference Case.

Increase in emissions abroad partially offsets domestic emission reduction

National measures that affect the operation of power plants in one country can have an impact on the operation of plants in interconnected countries. The Netherlands can be described as a relatively small power system with a high level of interconnections. Therefore, interactions with other countries have to be taken into account when assessing the CO_2 reduction effects of national measures in The Netherlands.[11] It has to be noted that the second order effect in the EU ETS due to national climate policy measures in The Netherlands is not taken into account in this analysis (for detailed explanation of this effect, see the textbox on page 39 of the Study).

[10] Emissions from de-central CHP production are assumed to decrease at the same rate as the power sector due to higher utilisation of low-carbon heat sources (e.g. biogas / biomass).

[11] It has to be noted that the optimisation of interconnector flows in the model is subject to simplifying assumptions. In reality, interconnector flows are also influenced for example by transit or loop flows that could limit the extent to which other countries are affected by national measures.

- **Addendum 1: Domestic emission reduction is partially offset by increased emissions abroad** – The implementation of the additional abatement measures in The Netherlands in 2020 affects the electricity supply in other countries significantly only if the costs for these measures are included in the firm's cost base (*Addendum 1a*).
  - **Addendum 1a:** Due to lower utilisation and earlier decommissioning of coal-fired plants in The Netherlands, power generation and CO_2 emissions in neighbouring countries increase. The net emission reduction in all modelled countries amounts to 134 mn. tCO_2 from 2018 to 2049 (aggregated over the period), i.e. ca. 100 mn. tCO_2 emissions (approximately 40%) are "exported" to neighbouring countries.
  - **Addendum 1b:** If additional abatement costs are compensated by the state, the operation of the coal plants is only affected to a limited extent. Therefore, emissions in neighbouring countries do not change significantly. The net-reduction of CO_2 emissions from 2018 until 2049 in all modelled countries amounts to 182 mn.t CO_2 as compared to 190 mn. tCO_2 of domestic reduction (aggregated). This means 8 mn.tCO_2 are "exported" to other countries over the period from 2018 until 2049.

  In the Scenarios 1a and 1b of the main study, the net-emission reduction was slightly lower (121 mn. tCO_2 in Scen.1a and 152 mn.tCO_2 in Scen. 1b) as the additional abatement measure were implemented in 2025 instead of 2020.

- **Addendum 2: Closure of Dutch coal plants significantly increases emissions abroad** – The closure of Dutch coal plants leads to increase of emissions in neighbouring countries:
  - **Addendum 2a:** Closing the Dutch coal plants until 2030 reduces net emissions in The Netherlands by ca. 18%. Lower emissions from closing coal plants are partly offset by more emissions from other power plants in the Netherlands: Around 30% of omitted power generation from Dutch coal plants is substituted by domestic electricity supply, especially gas-fired power generation.[12] The larger share, around 70%, is substituted by higher net-imports of power and, consequently, CO_2 emissions in neighbouring countries increase. The domestic emission reduction of 198 mn t.CO_2 in corresponds to net-reduction in the modelled countries of only 87 mn. tCO_2 in the period 2018 until 2049 (aggregated). For example, German power generation from hard coal and lignite-fired generation increases by 2.1 TWh and gas-fired generation increases by 1.5 TWh in 2030.[13]
  - **Addendum 2b:** If power plants have to cease operation in 2040, the net-reduction in all modelled countries amounts to 36 mn. tCO_2. As this measure takes effect only in the very long-run, a time period in which utilisation of coal-plants has already decreased due to higher CO_2 prices, less generation is substituted by coal-plants in other countries and the "export" of emissions only amounts to 8 mn. tCO_2 (2018-2049). The

[12] %-share of domestic substitution varies between 17% in 2030 and 80% in 2040 (see A.3)

[13] See A.3.

majority of generation from coal-plants in 2040 is substituted by domestic gas-fired plants (70%).

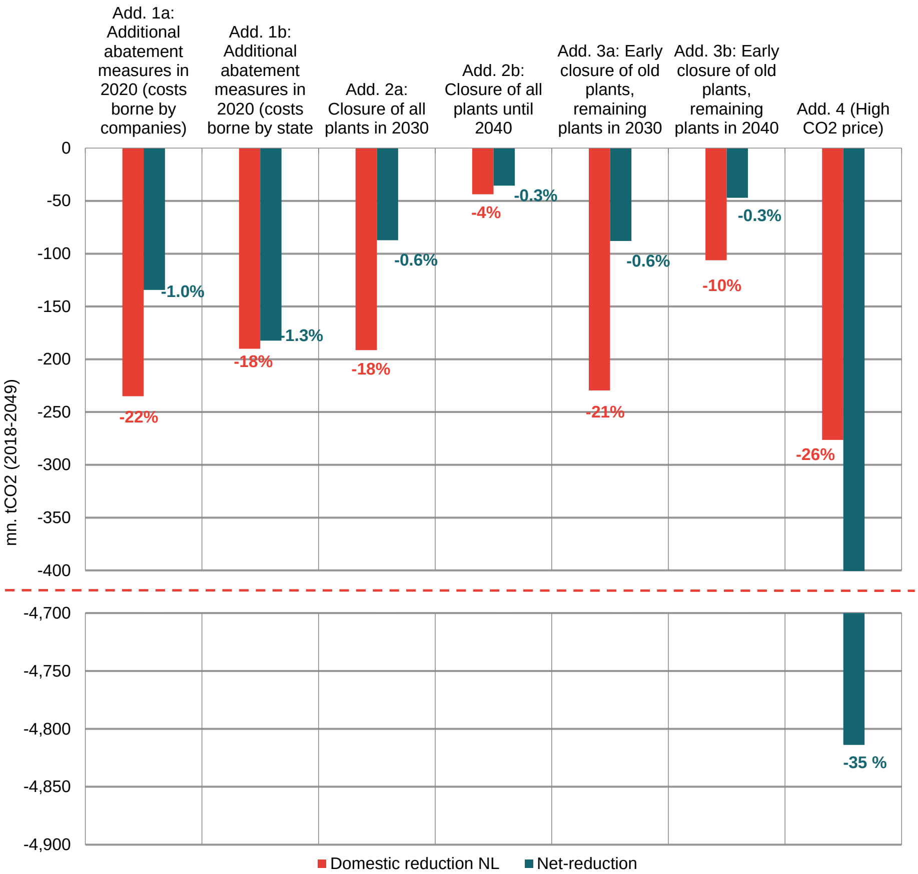
The net-emission reduction achieved in the *Scenario 3c* (-114 mn. tCO_2, closure in 2030) and *3d* (-132 mn. tCO_2, closure in 2040) of the main study is higher than what is achieved in these additional scenarios. This is due to the fact that, in *Scenarios 3c* and *3d*, the coal plants were forced to implement additional abatement measures as off 2025.

- **Addendum 3: Early closure of older plants increases emission abroad –** If, compared to Addendum 2, the older plants close in 2020, the share of emissions "exported" to neighbouring countries increases:
  - **Addendum 3a:** If the two oldest coal-fired plants close before 2020, while the other plants remain operational until 2030, net emission reduction would amount to 88 mn. tCO_2 (aggregated from 2018 to 2049). Compared to emission reduction in The Netherlands of 235 mn. tCO_2, emissions in neighbouring countries increase by 142 mn. tCO_2, meaning that around 60% of domestic reduction is offset in other countries.
  - **Addendum 3b:** If the two oldest coal-fired plants close before 2020, while the other plants remain operational until 2040, net emission reduction would amount to 47 mn. tCO_2 (aggregated from 2018 to 2049). Emissions in neighbouring countries increase by 59 mn. tCO_2.
- **Addendum 4: Significant emission reduction across Europe –** The ambitious EU climate policy and the resulting high CO_2 prices lower CO_2 emissions in Europe significantly as power supply moves toward carbon-neutrality in the long-run (see text box at the end of this chapter). Aggregated from 2018 until 2049, the emission reduction in all countries amounts to as much as 35% or 4.8 bn. tCO_2.

  In the long-run, annual emission reduction over time in 2040 compared to 2015 amounts to 85% compared to 55% reduction in the Reference Case.

Figure 3 and **Table 4** summarise net-reduction of CO_2 emissions in all modelled countries compared to the Reference Case.

Figure 3. Domestic and net-reduction of CO_2 emissions



Source: Frontier

Note: Domestic emission reduction in The Netherlands and net-reduction in all modelled countries

Table 4 Net-emission reduction (model region)

mn.t CO_2	Sum 2018-2049	2018	2020	2025	2030	2035	2040
Addendum 1a	-134 (-1.0 %)	0.0 (0 %)	-2.8 (0 %)	-5.2 (-1 %)	-8.4 (-2 %)	-5.5 (-1 %)	-2.5 (-1 %)
Addendum 1b	-182 (-1.3 %)	0.0 (0 %)	-7.9 (-1 %)	-7.2 (-1 %)	-10.6 (-2 %)	-5.8 (-2 %)	-2.5 (-1 %)
Addendum 2a	-87 (-0.6 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	-6.7 (-2 %)	-3.6 (-1 %)	-3.5 (-1 %)
Addendum 2b	-36 (-0.3 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	0.0 (0 %)	-3.6 (-1 %)
Addendum 3a	-88 (-0.6 %)	0.0 (0 %)	0.1 (0 %)	-0.3 (0 %)	-6.7 (-2 %)	-3.6 (-1 %)	-3.5 (-1 %)
Addendum 3b	-47 (-0.3 %)	0.0 (0 %)	0.1 (0 %)	-0.3 (0 %)	-2.1 (0 %)	0.0 (0 %)	-3.6 (-1 %)
Addendum 4	-4,814 (-35.1 %)	12.6 (2 %)	-4.4 (-1 %)	-115.9 (-23 %)	-231.3 (-53 %)	-246.4 (-65 %)	-184.9 (-64 %)

Source: Frontier

Note: Reduction of emission compared to the Reference Case

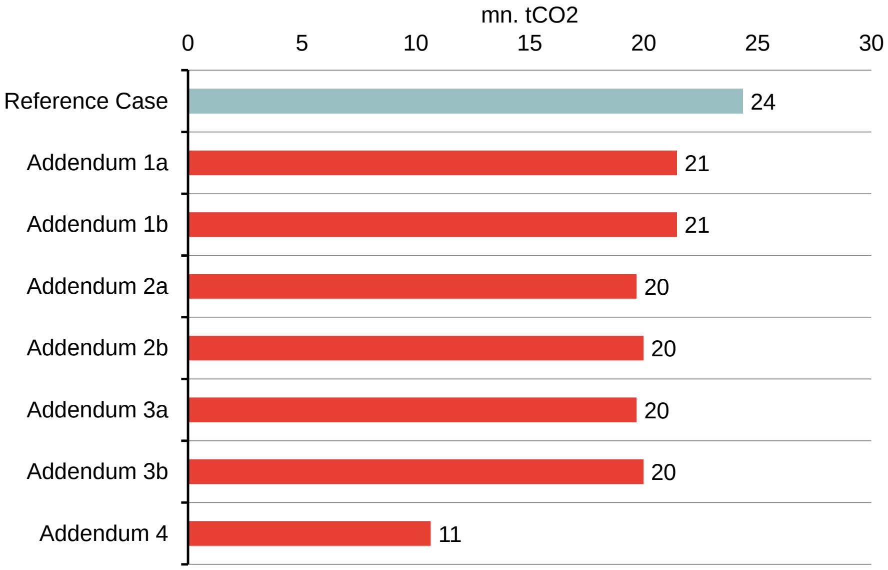
Reduction of annual CO_2 emission in The Netherlands (2040)

The impact on the long-term CO_2 emission reduction path depends on the long-term structural change induced by the policy measure. **Table 3** shows the absolute impact of power-related CO_2 emissions in The Netherlands in 2040 and the relative change compared to 2040 emission in the Reference Case:

- **Addendum 1: Additional abatement measures induce 12% reduction of CO_2 emissions in 2040 –** If additional abatement measures are implemented at the Dutch coal-fired plants after 2020, domestic power-related CO_2 emissions in 2040 are 12% lower than in the Reference Case.
- **Addendum 2: Closure of coal plants reduces long-term emissions by up to 20% –** Closing all coal-fired power until 2030 (*Addendum 2a*) or 2040 (*Addendum 2b*) lowers the annual emissions in 2040 by ca. 5 mn. tCO_2 (ca. 20%) compared to the Reference Case in 2040.
- **Addendum 3: Closure of coal plants reduces long-term emissions by up to 20% –** Closing the oldest plants in 2020 and the remaining ones until 2030 (*Addendum* 3*a*) or 2040 (*Addendum 3b*) lowers the annual emissions in 2040 by ca. 5 mn. tCO_2 (ca. 20%) compared to the Reference Case in 2040.
- **Addendum 4: High CO_2 price lowers annual emission in 2040 by 50%** - Assuming a CO_2 price that is significantly higher than in the other scenarios leads to a structural change in the power supply with less conventional power supply and more RES-E in the medium-to long-term. This lowers annual emissions in 2040 by ca. 14 mn. tCO_2 (-56%)

Figure 4 and **Table 3** illustrate the impact of the policy scenarios on the level of CO_2 emissions in 2040.

Figure 4. CO_2 emissions (NL) in 2040



Source: Frontier

Table 3. Differences of annual CO_2 emissions in 2040 (NL)

mn.t CO_2	Add. 1a	Add. 1b	Add. 2a	Add. 2b	Add. 3a	Add. 3b	Add. 4
Difference in CO_2 emissions in 2040	-2.9	-2.9	-4.7	-4.4	-4.7	-4.4	-13.7
%-reduction compared to Reference Case	-12%	-12%	-19%	-18%	-19%	-18%	-56%

Source: Frontier

Note: Reduction of annual emission compared to the Reference Case

EXCURSUS: Impact of the high CO_2 price on power supply in The Netherlands and an Europe (Addendum 4)

This Addendum assumes that the EU takes ambitious collective action in response to the Paris Agreement on Climate Change (COP21). As described above, it is not know which policy actions might be implemented, it is assumed this leads to a significantly higher CO_2 price in the whole EU in the medium and long term than assumed in the Reference Case.

In this scenario, the power supply structure across Europe changes fundamentally. Therefore, it differs significantly from the other policy scenarios assessed in this study and we explain the impact of the higher CO_2 price on the electricity supply in The Netherlands and in Europe in more detail in this excursus. The assumptions of this scenario are described in **Section 2.4.**

The Netherlands: More RES-E, less coal-fired generation

The higher CO_2 price has the following impact on electricity supply in The Netherlands:

- **Short-term increase of gas-fired generation and exports** – In the short-run (2020-2025), the price of CO_2 is assumed to increase by 30 EUR/tCO_2 compared to the *Reference Case*. Higher costs of carbon dioxide emissions lead to a comparative cost advantage of Dutch gas-fired plants compared to other conventional thermal plants. Therefore, generation from Dutch gas-fired plants increases by ca. 14 TWh in 2025 (+ 40%), and the majority of this generation is exported to neighbouring countries, esp. Germany which is affected by the higher CO_2 price to a larger extent.

- **Medium- to long-term increase of RES-E** – Co-firing of biomass in coal-plants becomes more economical than coal-fired generation already in 2030 as compared to 2040 in the Reference Case and increases by 12 TWh in 2030. As described in **Section 2.4**, the amount of biomass co-firing per plant is limited to the amount of co-firing indicated by the companies for Scenario 1 of the Study (i.e. ca. 55 PJ across all plants per year at maximum), i.e. the coal-plants cannot run on 100% biomass.[14]

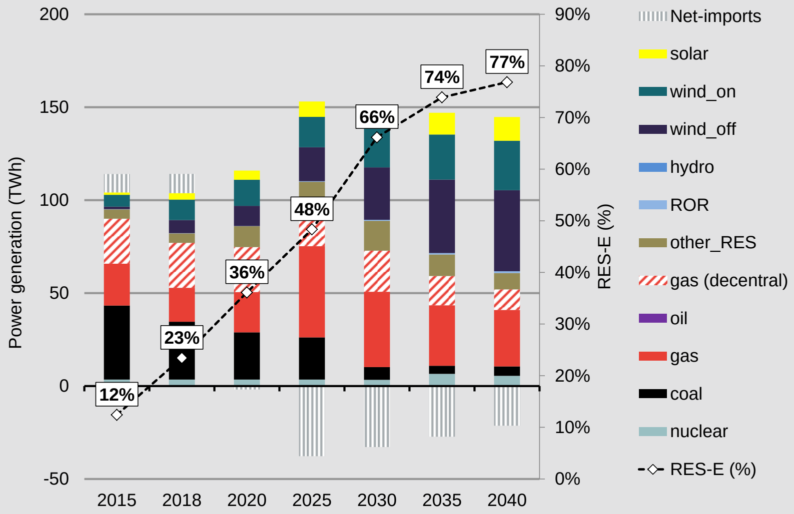
  Apart from biomass co-firing, other renewable technologies increase compared to the *Reference Case*: Investment in wind power and in solar PV increases after 2030 and electricity supply from these technologies grows by ca. 14 TWh compared to the *Reference Case*. The long-term renewable share in electricity supply increases by 6%-points to 77% in 2040.

- **Conventional coal-fired generation not economical in the long-run** – With CO_2 prices increasing to more than 100 EUR(real, 2015)/tCO2 after 2035, conventional coal-fired generation becomes no longer economical in the Netherlands Overall coal-fired power generation decreases by more than 60% in 2040 compared to the Reference Case. Coal fired power generation is maintained by existing power plants with CCS installations. In addition, new

[14] Total amount of biomass co-firing is limited in order to account for the limited availability of sustainable biomass. However, some plant operators indicated that their plant could run on up to 100% biomass in the future.

investment in coal-fired power plants with CCS becomes economical in the very long-run (2040).

Figure 5. Net-electricity supply (NL)



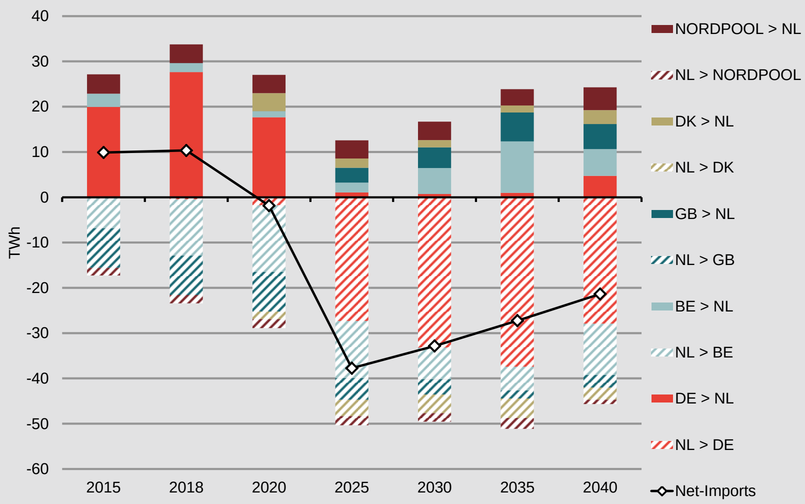
Source: Frontier

Note: Co-firing of biomass is included in fuel type (other-RES)

High net-exports of power in the medium-term

Exports of power from The Netherlands to neighbouring countries increase with higher CO_2 prices. As described above, especially Germany is affected to a greater extent than The Netherlands by the increase in CO_2 prices. Therefore, net-exports to Germany grow by more than 25 TWh in 2030 / 2035 compared to the Reference Case. Given the comparative advantage of the Dutch plant park, net-exports to all countries grow significantly from ca. 25 TWh (2025) in the *Reference Case* to ca. 38 TWh (2025) in *Addendum 4* (Figure 6).

Figure 6. Imports/Exports of power (NL, Addendum 4)



Source: Frontier

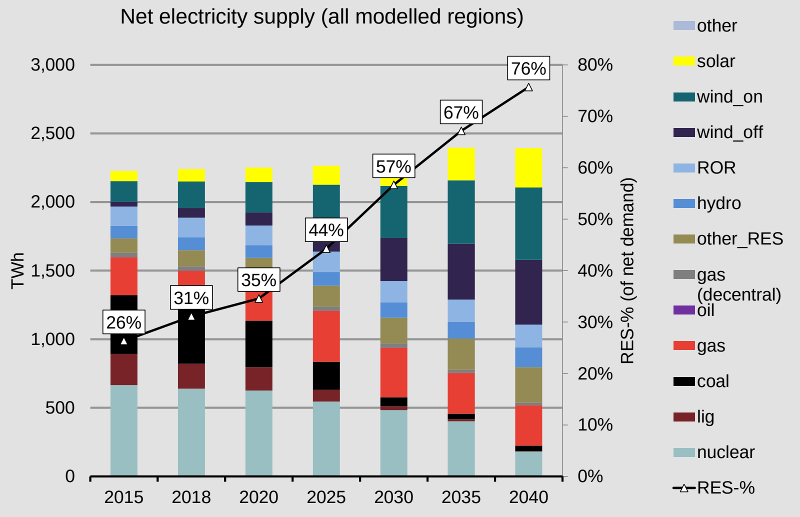
Note: negative values represent exports / positive values represent imports

Central Western Europe: High CO_2 prices lead to drop in coal and lignite-fired generation

Across all modelled countries, the higher CO_2 prices lead to less generation from carbon-intensive electricity sources, while power generation from low-carbon or carbon-neutral technologies increases:

- **70% drop in coal-fired generation after 2030 –** With a CO_2 price well above 80 €/tCO_2, power generation from conventional coal or lignite-fire power plants becomes no longer economical. Consequently, electricity supply from these sources drops by more than 70% in 2030 compared to the *Reference Case*. In Germany for example, coal and lignite-fired power supply decreases by 60 % compared to the *Reference Case*.
- **Medium-term increase of gas-fired generation** – In the medium-term (2030), higher CO_2 prices increase the utilisation of gas-fired power plants in Europe (+40% in 2030). In the long-run, however, the steady increase of carbon prices also affects the profitability of these gas-fired plants as compared to carbon-neutral energy sources and electricity supply from gas plants decreases in 2040 by 7% compared to the Reference Case.
- **Medium- to long-term increase of low-carbon power supply** – Electricity supply from wind onshore, offshore and solar PV increases significantly by ca. 20% in 2040. In addition, investment in CCS technologies (coal IGCC and gas CCGT) becomes economical in those countries, in which CCS is politically feasible. In total, 16 GW of CCS installations are built across Europe until 2040.

Figure 7. Net electricity supply (all model regions)



Source: Frontier

3.3 System costs and specific abatement costs

In this section, we analyse the impact of the different policy measures / scenarios on the affordability of the electricity system. For each of the policy scenarios, we calculate two indicators that inform about the cost impact:

- Impact on the system costs of electricity supply in The Netherlands; and
- Specific abatement costs.

For a more detailed definition of the system costs, please refer to **Section 4.3** of the Study.

3.3.1 Impact on system costs of electricity supply

The calculation of the impact on system costs of The Netherlands is based on the methodology described in Frontier (2015) and consistent with the methodology of the main Study.[15] For a detailed description of the methodology underlying the following calculations, please refer to the Study.

System costs in the Netherlands

The policy measures analysed have the following impact on the costs of the Dutch electricity supply:

- **Addendum 1: Additional abatement measures at the plants from 2020** - If additional abatement measures are implemented at the Dutch coal plants, system costs in The Netherlands (NPV, 2018-2049) increase by 3.2 to 4.5 bn EUR. In particular:
  - In **Addendum 1a,** where the costs are borne by the companies, the total system cost increase by 3.2 bn. EUR. As the implemented abatement measures increase the firms' operating costs, utilisation of coal plants and exports to neighbouring countries decrease. Therefore, decreasing power exchange credits are the largest contributor (3.7 bn. EUR). These are in part offset by variable generation cost savings (0.9 bn EUR). Fixed costs are less material and only amount to 0.5 bn. EUR.
  - In **Addendum 1b** where the costs are borne by the state, the total system costs increase by 4.5 bn. EUR. In this scenario the impact from power exchange credits are immaterial as domestic power production is not affected to a great extent. The costs of the implemented measures however, are incurred nonetheless: Variable cost make up most of the increase (4.1 bn. EUR) while fixed cost increases amount to 0.5 bn. EUR.

  Compared to the sub-scenarios of *Scenario 1*, in which the additional abatement measures are taken by 2025, the system costs are substantially higher in this Addendum with implementation of the additional abatement measures in 2020 (Scenario 1a: 1.4 bn. EUR / Scenario 1b: 2.1 bn. EUR). This is caused on the one hand by the earlier implementation of the abatement measures which leads to an absolute increase in the duration of

[15] Frontier (2015): *Scenarios for the Dutch electricity supply system.*

the measures and on the other hand a relative increase of the subsidies required due to the higher cost advantage of coal-fired generation over biomass given the low CO_2 prices in the short-term.[16]

- **Addendum 2: Closure of Dutch coal plants increases costs in the Netherlands** – Closing the Dutch coal plants before 2030 or 2040 influences the supply structure of the Dutch power system. Domestic generation decreases in total and more electricity needs to be imported from neighbouring countries in hours when the price is high. Therefore, debits for higher imports more than offset the decrease in variable generation costs. Saved fixed costs by closing the coal plants are almost completely offset by higher fixed costs incurred from earlier reactivation and investment in gas-plants.
  - In **Addendum 2a,** when all coal plants are closed in 2030, the increase in total system cost amounts to 4.2 bn. EUR (5.2%). The cost of lost power exchange credits amounts to 6.7 bn. EUR. Fixed costs increase amounts to 0.7 bn. EUR and additional 0.3 bn. EUR are incurred by higher RES-E related grid investments. 3.6 bn. EUR are saved on variable generation. The increase in system costs is slightly less in this Addendum than in *Scenario 3c* of the Study (+ 4.5 bn. EUR), because no additional abatement measures need to be taken by 2025.
  - In **Addendum 2b,** in which coal plants stay open until 2040 the increase in total system cost amounts to 1.9 bn. EUR (2.4%). In this scenario, power exchange debits play a smaller role in the cost increase (0.8 bn. EUR) and variable cost savings also less material (0.1 bn. EUR). The increase in system costs is substantially less in this Addendum than in *Scenario 3d* of the Study (+3.1 bn. EUR), because no additional abatement measures need to be taken by 2025.

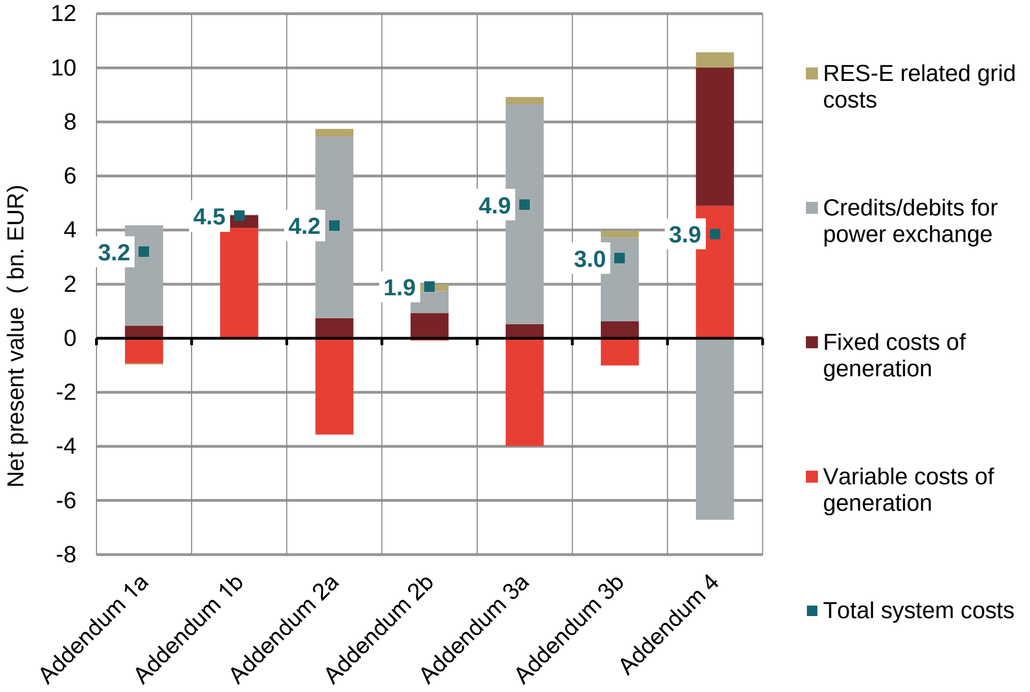
    The difference in the two scenarios is largely driven by the higher amount of generation that needs to be replaced in The Netherlands after closure of the plants in 2030. In addition, in 2039, the two oldest coal plants have already been closed in the *Reference Case*.
- **Addendum 3: Early closure of older plants increases system costs further –** This scenario is identical to *Addendum 2* with the only exception that two older plants are closed in 2020. The impact is that the total system cost (relative to the Reference Case) in both cases increases by approximately 1%-point more than in *Addendum 2*. As before, the loss of generation in The Netherlands is offset by higher imports of power:
  - **Addendum 3a:** Relative to the *Reference Case*, total system cost increase by 4.9 bn. EUR (6.1%). Most of the additional costs are due to an increase in power exchanges debits (relative to *Reference Case*, power exchange cost increase by 8.1 bn. EUR).
  - **Addendum 3b:** Relative to the *Reference Case,* total system cost increase by 3 bn. EUR (3.7%). Most of the additional costs are due to

[16] In addition, the impact of discounting is also lower as the measures take effect already in 2020 instead of 2018 and discounting happens to 2018.

increase in power exchanges debits (relative to *Reference Case*, power exchange cost increase by 3.1 bn. EUR).

- **Addendum 4:** The increase in CO_2 prices increases variable costs of generation by 4.9 bn. EUR. At the same time, more investment in RES-E incurs higher fixed costs of additional 5.6 bn. EUR. These increasing effects are partially offset by higher credits for power exports (6.7 bn. EUR). In sum, system costs increase by 3.9 bn. EUR (+4.8 %, NPV 2018-2049).[17]

Figure 8. Impact on system costs (NL)



Source: Frontier

Note: Difference of system costs to the Reference Case (NPV, 2018-2049)
Subsidies for co-firing that are saved due to early closure are assumed not to be spent elsewhere

[17] This scenario can be compared to the other scenarios only to a limited extent due to the structural differences in power supply across Europe arising from the assumed significant increase in CO_2 prices. Furthermore, increasing variable costs are mainly driven by this higher CO_2 price assumption.

Table 4. Impact on system costs in The Netherlands

bn. EUR (NPV 2018-2049)	Total system costs	Variable costs of generation	Fixed costs of generation	RES-E related grid costs	Credits/debits for power exchange
Addendum 1a	3.2 (4.0 %)	-0.9	0.5	0.0	3.7
Addendum 1b	4.5 (5.6 %)	4.1	0.5	0.0	0.0
Addendum 2a	4.2 (5.2 %)	-3.6	0.7	0.3	6.7
Addendum 2b	1.9 (2.4 %)	-0.1	0.9	0.3	0.8
Addendum 3a	4.9 (6.1 %)	-4.0	0.5	0.3	8.1
Addendum 3b	3.0 (3.7 %)	-1.0	0.6	0.3	3.1
Addendum 4	3.9 (4.8 %)	4.9	5.1	0.6	-6.7

Source: Frontier

Policy measures in The Netherlands also affect system costs in neighbouring countries

The effects on system costs[18] in the modelled region can be summarised as follows (**Table 5)**.

- **Addendum 1**: **Additional abatement measures at the plants from 2020 marginally increases EU wide system costs –** Regardless of whether the costs of the additional abatement measures are borne by the state or the companies, the impact on EU wide costs is relatively low and mostly born by The Netherlands. At the upper end (*Addendum 1b*), relative to the *Reference Case*, the system wide costs would increase by 0.6% (4.5 bn. EUR) whereas if the companies bare the cost of the additional abatement measures (*Addendum 1a*) the system cost would increase by 0.4% (3.2 bn EUR).
- **Addendum 2: Closure of Dutch power plants does not materially the EU system cost –** The closure of all coal plants in 2030 in the Netherlands increases the system cost in the region by up to 4 bn. EUR (NPV, 2018-2049).
- **Addendum 3:** Early closure of older plants increases system costs further in the Netherlands, but has no additional effect on neighbouring regions – As in *Addendum 2*, closing coal plants in the Netherlands has limited impact on system costs in the neighbouring countries. This remains the case when the two older plants are closed at an earlier date. The region-wide impact is around +0.4 - 0.7% (+3 – 5 bn. EUR) all being absorbed in the Netherlands.
- **Addendum 4:** System costs in all modelled countries increase significantly given the higher CO_2 price: On the one hand, new investment in RES-E capacities increase fixed costs; on the other hand, variable costs of the

[18] EU system costs include fixed and variable costs of operation, CAPEX for new investment and costs of power exchange with other modelled regions. Grid costs are not part of the definition. NL, DE, BE, FR, AT, CH, DK, CZ, PL, IT

remaining fossil-fuelled plants rise. In total, system costs increase by ca. 100 bn. EUR (13%).[19]

Table 5. Impact of policy measures on EU system costs*

	Add. 1a	Add. 1b	Add. 2a	Add. 2b	Add. 3a	Add.3b	Add. 4
Difference in system costs (NPV 2018-2049)	3.4	4.5	3.9	1.6	5.0	2.9	101
%-difference compared to Reference Case	0.4%	0.6%	0.5%	0.2%	0.7%	0.4%	13.2%

Source: Frontier

*Note: * EU system costs include fixed and variable costs of generation (incl. Capex for investment) as well as costs of power exchange with satellite regions.*

3.3.2 Specific abatement costs

Specific CO_2 abatement costs can be calculated by relating the difference in system costs to the achieved additional CO_2 emission reduction. In effect, the specific abatement costs thereby provide a measure for the average costs incurred for the abatement of one ton ofCO_2, and thereby provide insight into the cost-effectiveness of a specific policy scenario. In the following, we differentiate between:

- **Domestic abatement costs –** Additional system costs in The Netherlands (NPV) are divided by the domestic additional CO_2 reduction (aggregated from 2018 to 2049). The increase of emissions from other Dutch plants is included in this calculation.
- **Net EU abatement costs in the region –** Additional system costs in modelled regions (NPV) are divided by the additional CO_2 reduction in all modelled countries (aggregated from 2018 to 2049).

The specific CO_2 abatement costs calculated cannot be compared to actual CO_2 prices in the EU ETS. In our calculation discounted system cost are divided by accumulated emissions (from 2018-2049). Furthermore, the calculated specific abatement costs are average costs per abated tonne of CO_2, while prices in the EU ETS can be interpreted as marginal abatement costs.

The policy measures result in specific abatement costs as shown in **Figure 9:**

- **Addendum 1: Additional abatement measures at the plants amount to 14 – 25 EUR/tCO2 –** In *Addendum 1a*, the domestic abatement costs amount to 14 EUR/tCO2. If costs and the impact on emissions in neighbouring countries are taken into account, the net EU abatement costs increase to 25 EUR/tCO_2, especially due to the "export" of emissions abroad. If the costs of emission abatement measures are not included in the firm's cost base (*Addendum 1b*),

[19] This scenario can be compared to the other scenarios only to a limited extent due to the structural differences in power supply across Europe arising from the assumed significant increase in CO_2 prices. Furthermore, increasing variable costs are mainly driven by this higher CO_2 price assumption

the domestic abatement costs are 23.8 EUR/tCO_2, while net EU abatement costs increase moderately to 24.7 EUR/tCO_2, as less emissions are “exported” abroad.

As expected, specific abatement costs are higher if the additional abatement measure need to be taken in 2020 compared to 2025, as in *Scenario 1* of the Study (*Scenario 1a*: domestic abatement costs 8 EUR/tCO_2 & net abatement costs 19 EUR/tCO_2 / *Scenario 1b*: domestic abatement costs 13 EUR/tCO_2 & net abatement costs 19 EUR/tCO_2).

- **Addendum 2: Closure of coal plants with higher net abatement costs –** Closing the Dutch coal plants in 2030 reduces domestic emissions at the costs of ca. 22 EUR/tCO_2. From a European perspective, the specific abatement costs increase significantly to 45 EUR/tCO_2 due to the lower net-reduction achieved as compared to the domestic emission reduction in The Netherlands. If closure is postponed to 2040, fewer emissions are abated and the specific abatement costs from a Dutch perspective amount to 43.6 EUR/tCO_2. As only a very small share of the missing coal-fired generation is subsisted by imports in *Addendum 2b*, the net EU abatement costs do not deviate significantly from the domestic costs (44.5 €/tCO_2).

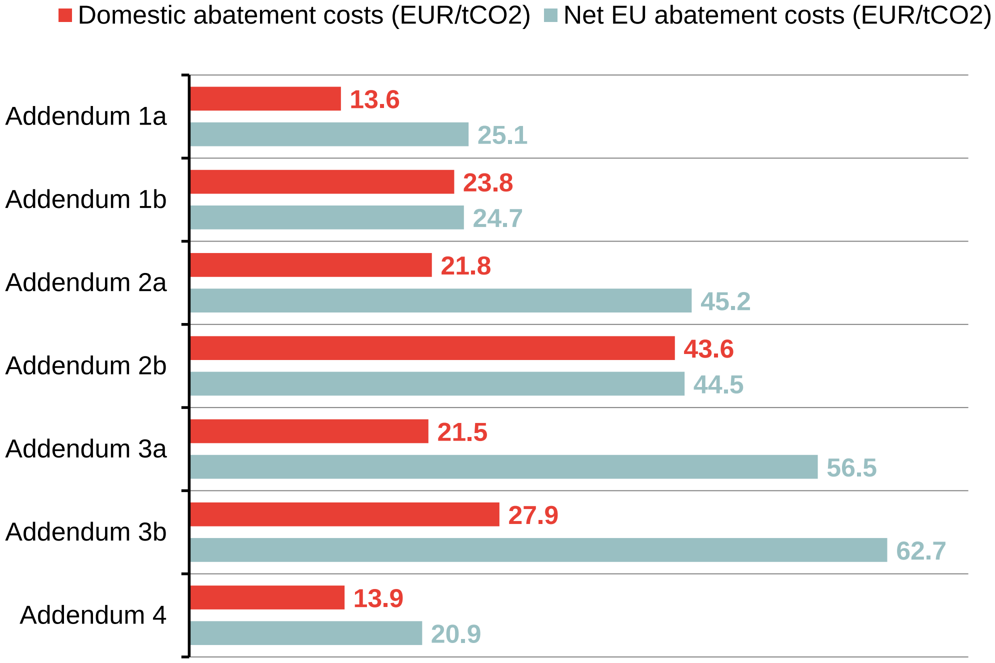
  Due to the lower emission reduction achieved in these additional scenarios, the specific abatement costs in the Netherlands are slightly higher compared to the *Scenario 3c* and *3d* of the Study (3c: 19 EUR/tCO_2; 3d: 16 EUR/tCO_2).

- **Addendum 3: Closing the oldest plants until 2020 increases net EU abatement costs –** In Addendum 3, the two oldest plants close until 2020 and the remaining plants remain operational until 2030 (*Addendum 3a*) or 2040 (*Addendum 3b*). Closing the oldest plants early yields higher emission reductions, but also comes at higher costs. The specific abatement costs from a Dutch perspective amount to 20.7 EUR/tCO_2 in *Addendum 3a* and to 26.7 EUR/tCO_2 in *Addendum 3b.*

  From a European perspective, the specific abatement costs increase as some of the abated emissions from closing the Dutch coal plants are exported to neighbouring countries: Net EU abatement costs amount to 51.6 EUR/tCO_2 in *Addendum 3a* and to 56.3 EUR/tCO_2 in *Addendum 3b*.

- **Addendum 4:** The domestic abatement costs in the Netherlands amount to 14 EUR/tCO_2. From a European perspective, the net-abatement costs amount to 21 EUR /tCO_2. These results are comparable to the other scenarios only to a limited extent since the implementation and targets of EU climate policy differ significantly from the other scenarios. Consequently, the power supply structure across Europe is fundamentally different from the *Reference Case*.

Figure 9. Specific emission abatement costs EUR(real, 2015)/tCO_2



Source: Frontier

Note: Specific abatement costs have been calculated based on NPV of system costs differences and the accumulated sum of emission reduction (2018-2049).

3.4 Impact on power prices

In this sub-section, we analyse the changes in power prices in the different policy scenarios compared to the Reference Case. In the following, we describe the impact of the policy measures on:

- Wholesale prices for electricity in The Netherlands; and
- Electricity prices in Central-Western Europe.

Impact on wholesale price of electricity in The Netherlands

The impact of the modelled policy measures on the power prices in The Netherlands can be summarised as follows:

- **Addendum 1: Short-term impact on power prices** – Implementing additional abatement measures at the Dutch coal plants affect the power prices in The Netherlands in the short-term. Power prices in 2020 increase by 1.7 EUR (real, 2015)/MWh if the costs are borne by the companies as utilisation of coal-plants decreases and more power is imported from neighbouring countries. If the costs of the emission reduction are not taken into account in the operation of the plants (*Addendum 1b*), there is almost no impact on power prices.

  This moderate impact on power prices is higher than in *Scenario 1a* of the Study, as the abatement measures are implemented already in 2020. The price difference to the Reference Case in 2025 amounts to 0.8 EUR(real, 2015)/MWh in both cases (*Scenario 1a* and *Addendum 1a*).

- **Addendum 2: Closure of coal plants increases wholesale power prices by up to 4 EUR(real, 2015)/MWh** – The decommissioning of all Dutch coal plants before 2030 leads to an increase of power prices by 3.7 EUR(real, 2015)/MWh in 2030. If plants close at a later stage (2040, Addendum 2b) the price increase only amounts to 0.5 EUR(real, 2015)/MWh.

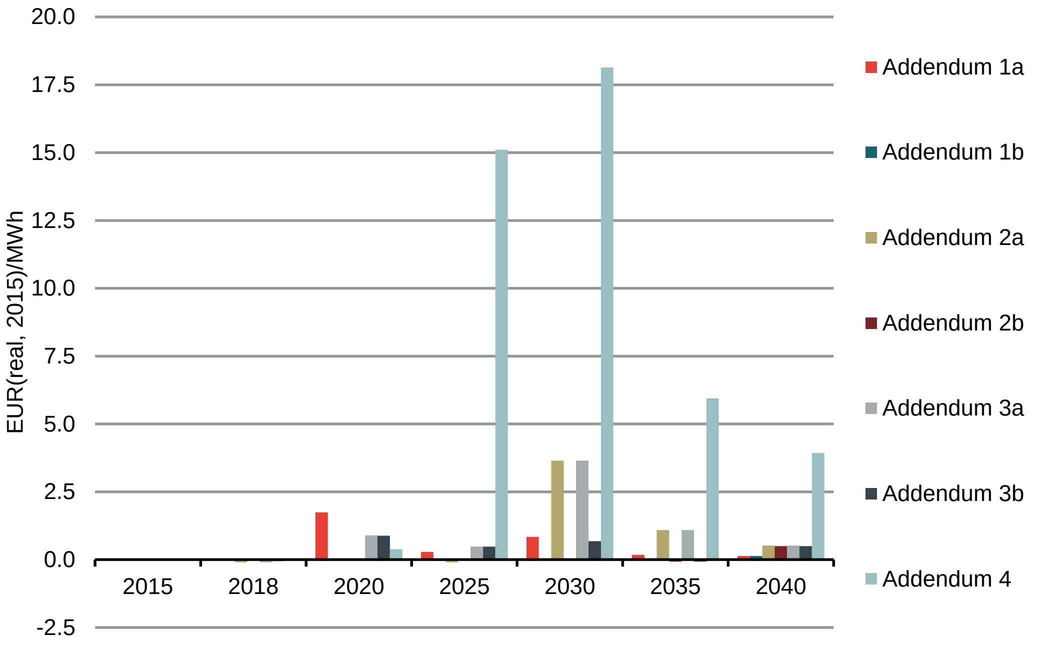
  This increase in price is comparable to the results of *Scenario 3c* and *3d* of the Study.

- **Addendum 3: Closure of oldest plants in 2020 increases price by 1 EUR/MWh –** If the two oldest power plants have to cease operation in 2020, the power price in The Netherlands increases by ca 0.9 EUR(real, 2015)/MWh in the same year. With closure of the remaining plants in 2030 (Addendum 3a), the price increases by 3.7 EUR in the same year. If the remaining plants close in 2040, the price increase in that year amounts to 0.5 EUR (see *Addendum 2*).

- **Addendum 4: Significant increase in power prices** – If European climate policy leads to significantly higher CO_2 prices, it can be expected that this increase translates in significantly higher power prices in all countries. In this Addendum, power prices in The Netherlands increase by up to 18 EUR (real, 2015)/MWh in 2030.

Figure 10 and **Table 6** summarise the impact of the different policy scenarios on Dutch electricity prices.

Figure 10. Impact on power prices (NL)



Source: Frontier

Note: Difference of the power price to the Reference Case

Table 6. Wholesale prices of electricity in The Netherlands

EUR(real, 2015)/MWh	2018	2020	2025	2030	2035	2040
Reference Case	35.3	39.3	54.6	61.3	70.0	66.7
Addendum 1a	35.3	41.0	54.9	62.1	70.2	66.9
Addendum 1b	35.3	39.3	54.6	61.2	70.1	66.9
Addendum 2a	35.2	39.3	54.5	64.9	71.1	67.3
Addendum 2b	35.3	39.3	54.6	61.3	70.0	67.2
Addendum 3a	35.2	40.2	55.1	64.9	71.1	67.3
Addendum 3b	35.3	40.2	55.1	61.9	70.0	67.2
Addendum 4	35.4	39.7	69.7	79.4	76.0	70.7

Source: Frontier

Impact on wholesale price of electricity in neighbouring countries (example: Germany)

Power prices in neighbouring countries are also affected by the introduction of national climate policy measures in The Netherlands. As an example, **Table 7** shows the impact of the different policy measures on power prices in Germany.

- **Addendum 1: Small increase of power prices in Germany** – Power prices in Germany increase moderately due to the implementation of abatement measures at Dutch coal plants. The maximum increase of wholesale prices amounts to 0.7 EUR(real, 2015)/MWh in 2030. Prices in Germany increase due to lower utilisation of Dutch coal plants and consequently lower imports from The Netherlands.
- **Addendum 2: Dutch coal phase-out increases German power prices by up to 3 EUR/MWh –** The closure of coal-fired power plants has the most significant impact on German power prices in the period of 2030 when the supply demand balance is becoming tighter. The German power prices increase by 3.2 EUR(real, 2015)/MWh in 2030 following the closure of the Dutch coal plants in 2030 (Addendum 2a). If the Dutch coal plant remain operational until 2040, the price increase in Germany only amounts to 0.4 EUR.
- **Addendum 3: Closure of oldest plants in 2040 increases German price 0.4 EUR/MWh –** Closing the two oldest coal-fired plants increases production of power in Germany. Consequently, the price increases but only moderately by 0.4 EUR/MWh. The long-term price impact of closing the remaining plants in 2030 (*Addendum 3a*) or 2040 (*Addendum 3b*) correspond to Addendum 2.
- **Addendum 4: CO_2 price increase with higher impact on German power prices –** Power prices in Germany increase by up to 22.5 EUR (real, 2015)/MWh following the increase in CO_2 prices in this scenario.

Table 7. Impact on wholesale power prices in Germany

EUR(real, 2015)/MWh	2018	2020	2025	2030	2035	2040
Addendum 1a	0.0	0.4	0.3	0.7	0.2	0.1
Addendum 1b	0.0	0.0	0.0	0.0	0.1	0.1
Addendum 2a	0.0	0.0	-0.1	3.2	1.0	0.4
Addendum 2b	0.0	0.0	0.0	0.0	-0.1	0.4
Addendum 3a	0.0	0.4	0.5	3.2	1.0	0.4
Addendum 3b	0.0	0.4	0.5	0.5	-0.1	0.4
Addendum 4	0.1	0.7	15.8	22.5	12.0	5.5

Source: Frontier

Note: Increase of the yearly average (base price) in Germany compared to the Reference Case

3.5 Impact on consumers

The increase of power prices in The Netherlands described in **Section 3.4** increases costs for final consumers. In the following, we describe the impact of the policy scenarios on consumer payments for households and business customers. For a description of the underlying methodology, please refer to the main Study (see description in **Section 4.5** of the Study).

As described in **Section 3.4**, the policy measures affect the wholesale power prices in the Netherlands to a varying extent. As a consequence, the costs to consumers are affected differently in the individual scenarios:

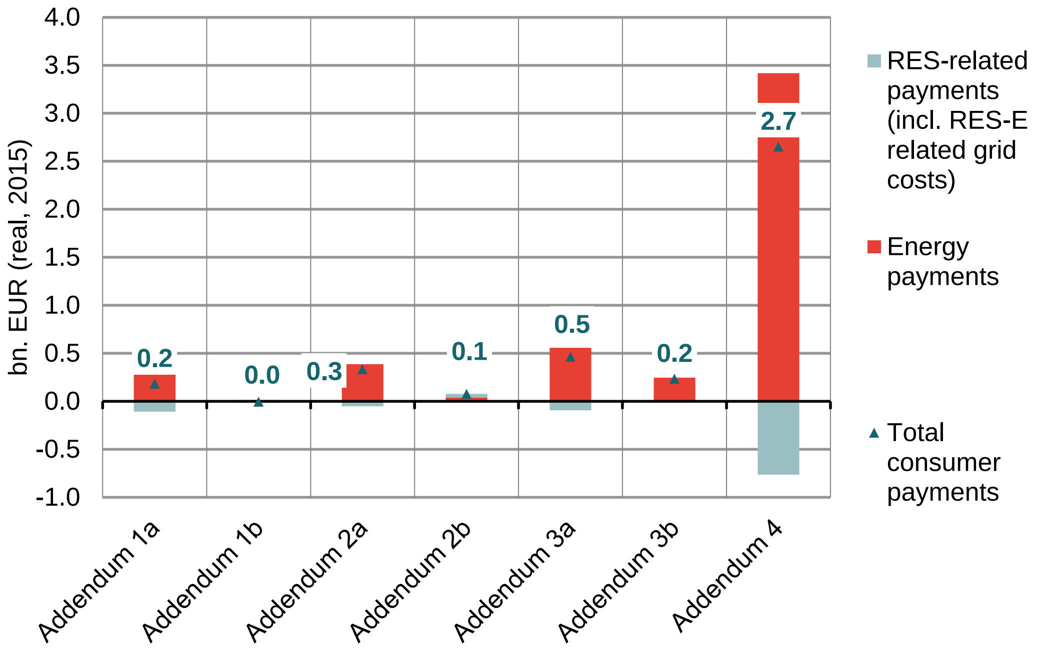
- **Addendum 1: Comparably low impact of additional abatement measures on consumers** – The implementation of additional abatement measures increases costs for households by 0.15 bn. EUR (+ 0.7%) (NPV 2018-2049) and for other customers by 0.6 bn. EUR (+0.7%), assuming that no compensation for the implementation of additional measures is granted to the plant operators. The financing of state payments to the coal plant operators is not taken into account in the calculation since it is unclear where the financing would come from.
- **Addendum 2: Closure of coal plants until 2030 increases consumer payments by ca. 1% –** Closing all plants until 2030 increases prices by up to 4 €/MWh and consequently the costs for households in The Netherlands increase by ca. 0.33 bn. EUR (1.6%). Costs for other consumers increase by 1 bn. EUR (1.2%). Closure in 2040 lowers the cost increases for households and other consumers to 0.5 bn. EUR (2.4%) and 1.5 bn. EUR (1.9%), respectively (*Scenario 3b*).
- **Addendum 3: Early closure of older plants increases consumer payments by up to 2 % –** Closing the two oldest coal-fired plants until 2020 and the remaining ones in 2030 increases costs to households by 0.46 bn. EUR (2.2%) and for other consumers by 1.4 bn. EUR (1.7 %) (*Addendum 3a*).

If the remaining plants close in 2040 instead of 2030, costs for households increase by 0.23 bn. EUR (1.1%) and for other consumers by 0.7 bn. EUR (0.9%).

- **Addendum 4: Ambitious EU climate policy increases costs to consumers by up to 12 % –** Corresponding to the significant increase in power prices observed in Addendum 4, costs to final consumers increase as well: Payments from households increase by 12 % (2.7 bn. EUR) and of other consumers including businesses and industrial consumers by 10% (8 bn. EUR).

Figure 11 and **Figure 12** show the impact of the different policy scenarios on the electricity costs of “households” and “business and industrial consumers”.

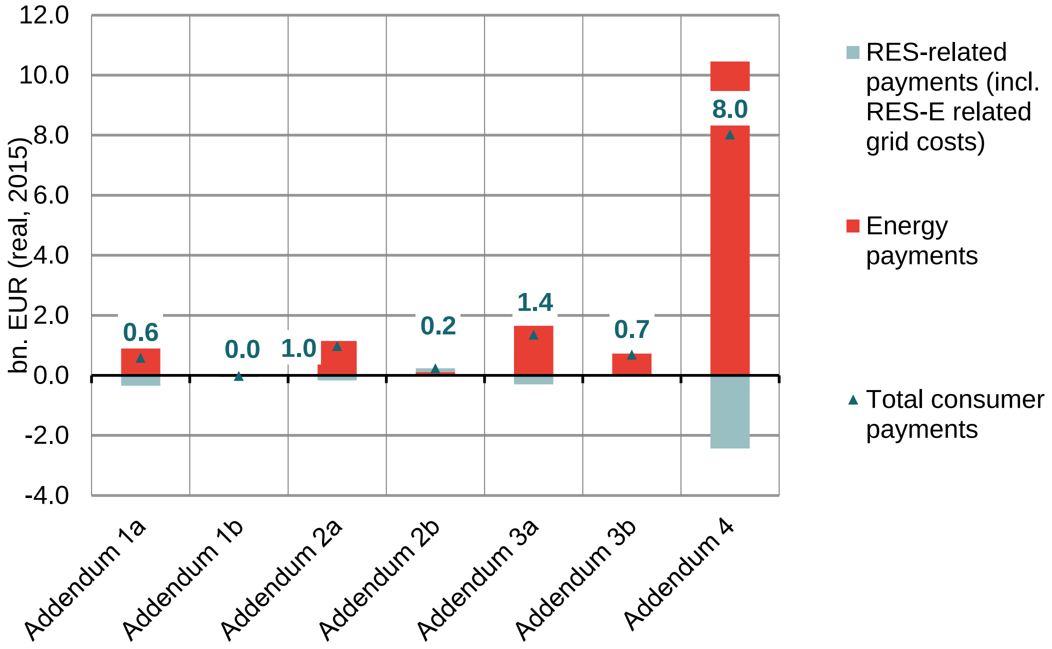
Figure 11. Impact on electricity payments of final consumers (households)



Source: Frontier

Note: Difference to the Reference Case (NPV, 2018-2049)

Figure 12. Impact on electricity payments of final consumers ("business and industrial consumers")



Source: Frontier

Note: Difference to the Reference Case (NPV, 2018-2049)

Table 8 and **Table 9** show the impact on yearly costs in the photo years in absolute cost figures and percentage increase compared to the Reference Case.

Table 8. Impact on yearly costs to consumers (households)

mn. EUR (%)	2018	2020	2025	2030	2035	2040
Addendum 1a	0.0 (0.0 %)	26.7 (2.0 %)	2.7 (0.2 %)	16.8 (0.9 %)	1.8 (0.1 %)	1.0 (0.1 %)
Addendum 1b	0.0 (0.0 %)	0.6 (0.0 %)	-0.4 (0.0 %)	0.3 (0.0 %)	0.7 (0.0 %)	1.0 (0.1 %)
Addendum 2a	-4.0 (-0.3 %)	0.0 (0.0 %)	-3.8 (-0.2 %)	82.5 (4.5 %)	12.4 (0.6 %)	7.4 (0.4 %)
Addendum 2b	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	0.0 (0.0 %)	-1.7 (-0.1 %)	6.9 (0.4 %)
Addendum 3a	-4.0 (-0.3 %)	18.4 (1.4 %)	7.6 (0.5 %)	82.5 (4.5 %)	12.4 (0.6 %)	7.4 (0.4 %)
Addendum 3b	-1.4 (-0.1 %)	18.1 (1.3 %)	7.6 (0.5 %)	16.2 (0.9 %)	-1.7 (-0.1 %)	6.9 (0.4 %)
Addendum 4	0.2 (0.0 %)	6.9 (0.5 %)	256.2 (15.6 %)	389.7 (21.3 %)	155.2 (7.6 %)	142.3 (7.4 %)

Source: Frontier

Note: Difference to the Reference Case

Table 9. Impact on yearly costs to consumers (other consumers)

mn. EUR (%)	2018	2020	2025	2030	2035	2040
Addendum 1a	0 (0.0 %)	110 (2.2 %)	12 (0.2 %)	53 (0.8 %)	7 (0.1 %)	4 (0.1 %)
Addendum 1b	0 (0.0 %)	2 (0.0 %)	-1 (0.0 %)	-1 (0.0 %)	2 (0.0 %)	4 (0.1 %)
Addendum 2a	-11 (-0.2 %)	0 (0.0 %)	-11 (-0.2 %)	277 (4.0 %)	48 (0.6 %)	24 (0.3 %)
Addendum 2b	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	-6 (-0.1 %)	21 (0.3 %)
Addendum 3a	-11 (-0.2 %)	67 (1.3 %)	27 (0.4 %)	277 (4.0 %)	48 (0.6 %)	24 (0.3 %)
Addendum 3b	-5 (-0.1 %)	66 (1.3 %)	27 (0.4 %)	49 (0.7 %)	-6 (-0.1 %)	21 (0.3 %)
Addendum 4	1 (0.0 %)	27 (0.5 %)	991 (16.0 %)	1,464 (21.3 %)	531 (6.9 %)	464 (6.5 %)

Source: Frontier

Note: Difference to the Reference Case

3.6 Security of Supply and import dependency

In the following, we analyse the impact of the policy measures on Security of Supply in The Netherlands by analysing reserve margins of power generation and the import dependency of The Netherlands.

It has to be noted that we do not expect major challenges to Security of Supply of The Netherlands in the Reference Case. There is sufficient power generation capacity available in the Netherlands (including mothballed power plants) as well as in surrounding countries. In the medium term, mothballed power plants can be re-activated if required. However, reactivation of mothballed power plants will depend on the view owners of these plants have on the future of the energy market. Further, the power system is getting more flexible due to increased demand side response. A more detailed analysis and assessment of Security of Supply in the electricity system in The Netherlands can be found in Frontier (2015).[20]

3.6.1 Methodology

We analyse the impact of the policy measure on Security of Supply using the indicators of power generation adequacy, and import dependency:

[20] Frontier (2015): *Scenarios for the Dutch electricity supply system.*

- **Reserve Margins (RM)** inform about the level of de-rated[21] generation capacity compared to peak load. It has to be noted that this indicator only provides a national perspective and does not directly take into account contributions from interconnected countries.[22]
- **Import dependency –** The import dependency from foreign countries is assessed by the development of net-imports from other countries to The Netherlands.

3.6.2 Results

The policy measures have the following impact on Dutch Reserve Margins and import dependency.

Impact on Reserve Margins in The Netherlands

The policy measures have the following impact on the Reserve Margins in The Netherlands:

- **Addendum 1: Only very moderate impact on Reserve Margin by additional abatement measure at the power plants –** Implementing additional abatement measures at the Dutch coal-fired power plants after 2020 does not affect the adequacy of domestic generation sources to a large extent. In *Addendum 1a*, the RM decreases by 0.6 GW in 2030 due to the earlier decommissioning of one coal plant. In the case of *Addendum 1b*, in which additional abatement costs are not allocated to the plant operators, there is no negative impact on the RM.
- **Addendum 2: Closure of coal plants until 2030 or 2040 reduces RM in The Netherlands –** A closure of plants until 2030 (*Addendum 2a*) would result in modest 3.6 and 1.6 GW reduction in RM in 2030 and 2035, respectively. The closure of all or only two coal-fired power plants in The Netherlands is partially compensated by earlier reactivation of mothballed gas-fired plants or increase investment in the long-run. Taking into account the available import capacities, the RM remains positive in all sub-scenarios of Scenario 3.

  In 2040 the reserve margins would be higher by 0.6 GW then in the *Reference Case*. A closure in 2040 (*Addendum 2b*) would only result in 0.2 GW decrease in reserve margins in 2040.
- **Addendum 3: Earlier decommissioning of old coal plants temporarily decreases the RM in The Netherlands –** Closing the two older power plants already in 2020 reduces the reserve margin by 0.5 GW in 2020. The RM inside the Netherlands is tightened in this period. However, since there is vast power generation capacity available in the European power market in the short and medium term, we don't expect a threat for Security of Supply in the Netherlands despite the tighter RM. Furthermore, reactivation of mothballed

[21] Used de-rating factors can be found in the main Study.

[22] An alternative approach to evaluating Security of Supply is represented by the "Loss-of-Load-Expectation" (LOLE), a stochastic indicator that is for example used in the "Generation Adequacy Assessment" of the TSOs in the PLEF: Pentalateral Energy Forum Support Group 2 (2015): *Generation Adequacy Assessment.*

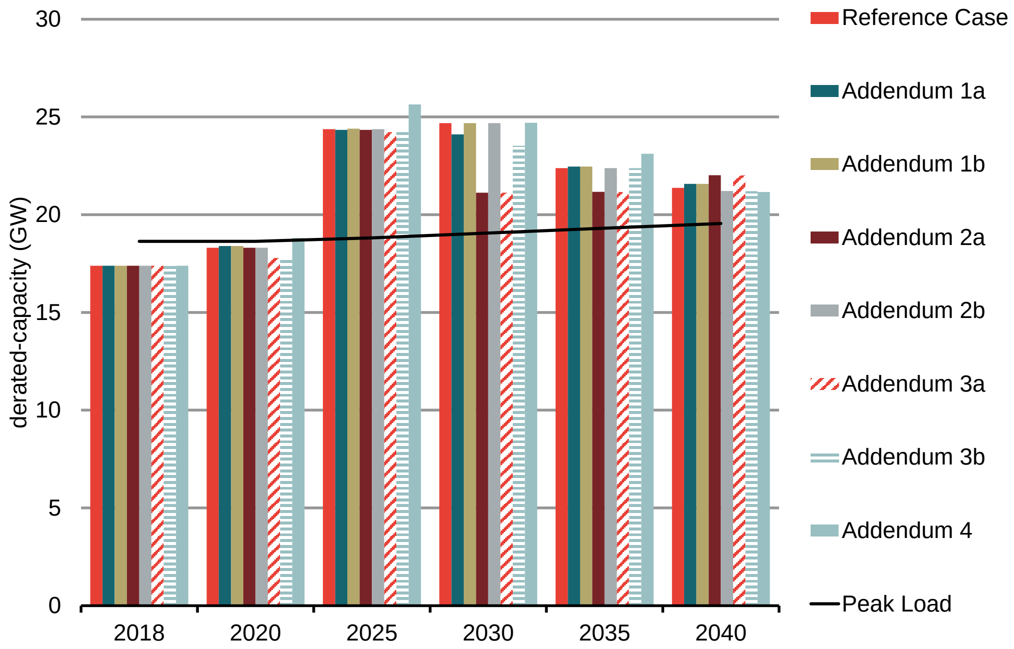
power plants occurs earlier than in the Reference Case. However, a short term closure of a high share of power plants *under short notice* should be avoided from a Security of Supply perspective in order to provide sufficient time for the market participants to react.

Closure of the remaining plants in 2030 (*Addendum 3a*) reduces the operational (de-rated) capacity further and the RM decreases by 1.2 GW compared to the Reference Case. Closure of the remaining plants in 2040 (*Addendum 3b*) results in the same long-term reduction of 0.2 GW as observed in *Addendum 2b.*

- **Addendum 4: High CO_2 price increase capacity level in The Netherlands –** More investment in RES-E as well as the earlier reactivation of gas-fired power plants increase the Reserve Margin in this Addendum by up to 1.5 GW in 2025. On average, the Reserve Margin grows by 300 MW.

Figure 13 compares the level of operational capacities (de-rated[23]) in The Netherlands in the policy scenarios and the Reference Case.

Figure 13. Comparison of operational capacities (NL, de-rated*)



Source: Frontier

*Note: * de-rating factors in Annex of the Study*

Impact on electricity imports and exports

In the Reference Case, The Netherlands will remain a net-importer of power in the short-term. In the medium- to long-term, however, this picture changes to a net-exporting position (see **ANNEX A** of the Study). The impact of the different policy scenarios on the import dependency is determined by the changing supply structure of the Dutch power system: If domestic power generation increases,

[23] De-rating factors are included in the Annexe of the Study.

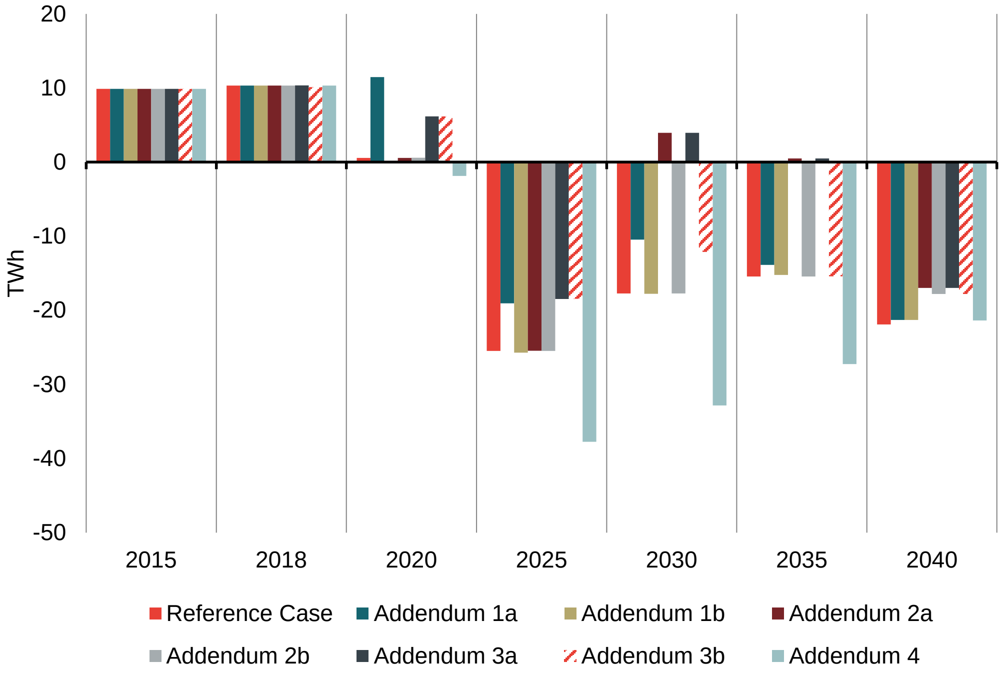
dependency on imports decreases compared to the Reference Case and vice versa:

- **Addendum 1: Additional abatement measures do impact the supply structure of Dutch power structure in the medium term -** If no compensation for additional costs is granted (*Addendum 1a*), utilisation of Dutch coal plants decreases. Net-imports increase by 10.9 TWh in 2020. On average, net-imports increase by 4.3 TWh/a. If the majority of costs are not borne by the operators (*Addendum 1b*), there is almost no impact on the import/export balance.
- **Addendum 2: Closure of coal plants until 2030 increases imports from 2030 onwards substantially –** In *Addendum 2a***,** relative to the Reference Case, net-imports increase in by 21.7 TWh in 2030 and 15.9 in 2035. The trade balance recovers significantly in 2040 where the change in net imports is down to 4.9 TWh. On average, the increase was measured at 7.4 TWh/a. If the closure are set at 2040 (*Addendum 2b*), the average annual impact is only 1.3 TWh/a and all occurring in 2040 where net imports increase by 4.1 TWh/a relative to the Reference Case.
- **Addendum 3: Early closure of older coal plants increases import dependency in the short term –** The Reference Case is characterised by a medium-term net-exporting position of The Netherlands. In *Addendum 3a,* trade balances are mostly in line with that of *Addendum 2a*, but with the earlier closure of the two oldest plants, The Netherlands' net-imports remain higher for longer (in 2020 net-imports in *Addendum 2a* was 0.6 TWh while in *Addendum 3a* they amounted to 6.2 TWh).

  In Addendum 3b the impact of the earlier closure of the two older plants is in part offset by the later closure of the other plants. Net imports stay, on average, 4.1 TWh/a above that of the Reference Case.
- **Addendum 4: High net-exports in the medium term with more ambitious EU climate policy –** The assumed increase in CO_2 prices in this Addendum increases the exports of power from the Netherlands to neighbouring countries in the medium-term. Especially net-exports to Germany temporarily increase by 26 TWh (2030).

Figure 14 shows the level of net-imports in the Reference Case and the different policy scenarios.

Figure 14. Net-imports (NL)



Source: Frontier

Note: Positive values represent net-imports to The Netherlands, negative values net-exports

Table 10 indicates the change of the net-position (net-imports/exports) in The Netherlands compared to the Reference Case.

Table 10. Net-imports (NL) – difference to the Reference Case

GW	2018	2020	2025	2030	2035	2040
Addendum 1a	0.0	10.9	6.4	7.3	1.6	0.6
Addendum 1b	0.0	-0.6	-0.2	0.0	0.2	0.6
Addendum 2a	0.0	0.0	0.0	21.7	15.9	4.9
Addendum 2b	0.0	0.0	0.0	0.0	0.0	4.1
Addendum 3a	0.0	5.6	7.0	21.7	15.9	4.9
Addendum 3b	-0.2	5.6	7.0	5.6	0.0	4.1
Addendum 4	0.0	-2.4	-12.3	-15.1	-11.8	0.5

Source: Frontier

Note: Positive values indicate higher imports / lower exports and vice versa.

3.7 Impact on the development of RES-E

The different policy measures can have an impact on the development of renewable energy sources in The Netherlands either directly through a changing framework for biomass co-firing (e.g. further subsidies for co-firing) or indirectly through a changing market environment (e.g. higher wholesale power prices leading to earlier market driven investment in RES-E).

Impact on the share of renewable energy sources in The Netherlands

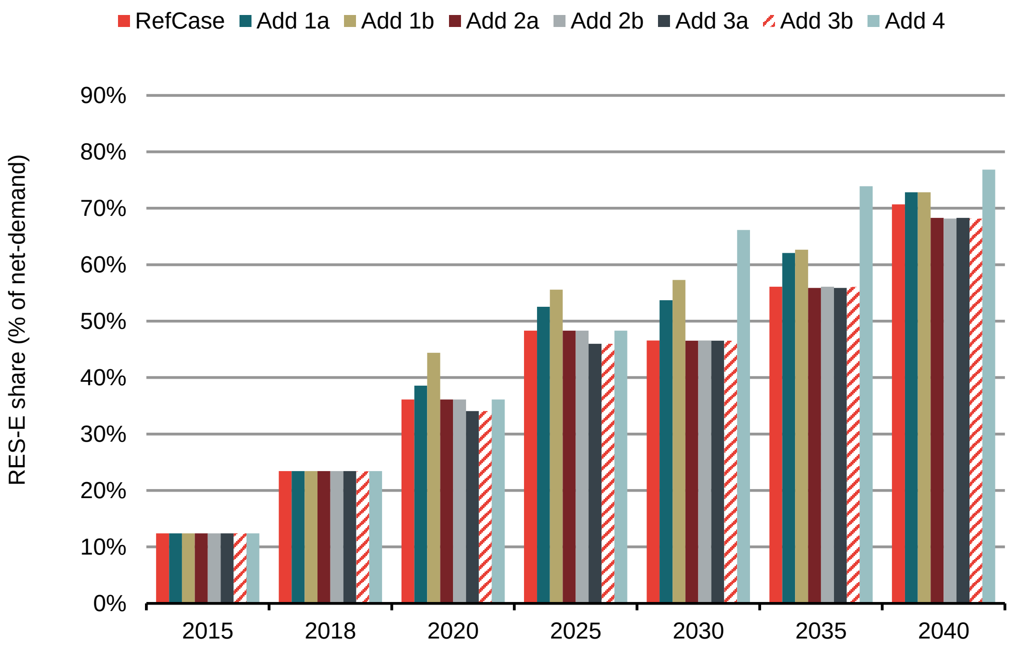
The share of RES-E (expressed in % of net electricity demand) informs about the share of net-demand that is served by renewable energy sources:

- **Addendum 1: Additional abatement measures increase RES-E** – The additional emission reduction achieved in *Addendum 1* is largely based on increased co-firing of biomass in the coal plants. This measure also increases the absolute amount of RES-E in the system.[24] The share of RES-E increases by up to 7-11%-points in 2030 (+ 8-12 TWh). In the long-run, the amount of additional co-firing decreases due to market based co-firing already taking place in the Reference Case (+ 2%-points; + 3 TWh in 2040).
- **Addendum 2: Closure of coal plants does only minimally impact RES-E % –** The early closure of all coal plants in *Addendum 2 a/b* results in a 2 – 3% reduction of the RES-E% in the year 2040 relative to the *Reference Case*. Note that in the Scenario 3 of the Study, in which early closures where modelled in 2020 and 2025, the RES-E share decline was almost twice that of *Addendum 2*.[25] However, in *Addendum 2a* and *3b* the plants are assumed to close in 2030 and 2040 at a time period in which less co-firing takes place. Therefore, the impact of co-firing is only of substance in the years after.
- **Addendum 3**: **Early closure of the two older power plants reduces the RES-E% in the medium term –** In both *Addendum 3a* and *3b* the RES-E% falls by 2% in 2020 and 2025 but recovers and falls again in 2040 due to the closure of the other plants (Addendum 2 assumptions). In 2040,in *Addendum 3* we observe the same RES-E share as in *Addendum 2*, 2–3%-points below that of the **Reference** *Case*.
- **Addendum 4: High CO_2 prices drive RES-E investments –** The ambitious climate policy on European level and the resulting increase in CO_2 prices affect the profitability of renewable technologies in The Netherlands. On the one hand, co-firing of biomass becomes economically viable already in 2030 and on the other hand investments wind and solar increase in the medium-term. Consequently, the share of renewable electricity of net-demand temporarily increases by up to 20 %-points in 2030. In the long-run, the share increases by 6 %-points.

[24] The 25 PJ/a limit on co-firing of biomass of the Reference Case does not apply to Scenario 1 and Scenario 3 (c,d,e) as well as to the Addendum 1 and 4.

[25] The share fell by 6%-points in Scenario 3a/3b as no co-firing of biomass takes place in the closed plants.

Figure 15. Renewable energy share of net-demand



Source: Frontier

Table 11 shows the absolute levels of electricity supply from wind, solar PV and biomass in the Reference Case as well as in the different policy scenarios.

Table 11. Development of net-electricity supply from RES-E

TWh	2018	2020	2025	2030	2035	2040
Reference Case	26.59	41.07	55.37	53.94	65.87	84.26
Addendum 1a	26.59	50.53	63.73	66.51	73.68	86.84
Addendum 1b	26.59	41.07	55.37	53.91	65.64	81.38
Addendum 2a	26.59	41.07	55.37	53.94	65.87	81.23
Addendum 2b	26.59	38.74	52.69	53.91	65.63	81.38
Addendum 3a	26.59	38.74	52.69	53.93	65.87	81.23
Addendum 3b	26.59	43.88	60.24	62.31	72.99	86.84
Addendum 4	26.59	41.07	55.37	76.90	87.06	91.71

Source: Frontier

3.8 Other indicators

In the Study, we have analysed additional indicators to assess the impact of the different policy measures on;

  - Other emissions;
  - Heat networks;
  - Innovation; and
  - Employment.

In the following, we will briefly comment on the above mentioned variables.

- **Other emissions impacted by implementation of policy measures -** Based on the conclusions of the Study, the implementation of additional abatement measures would result in the following change of other emissions:
  - High reduction of SO_2, PM and Hg due to more biomass co-firing in Addendum 1 or due to closure or lower utilisation of coal-plants in Addendum 2 to 4 (no or limited additional emissions from gas plants); and
  - NOx emissions affected to limited extent due to compensating increase of gas-fired generation and emissions from these plants;

  The quantitative impact of the scenarios on “other emissions” will be analysed separately by MinEZ.

- **Policy measures induce need for investment in heat networks –** In all scenarios in which power plants close before the end of their lifetime, heat supplied from those power plants to regional heat networks will have to be replaced by other sources. This could be achieved by
  - connecting the heat network to other heat networks with sufficient capacity to replace the heat from coal/biomass fired power plants;
  - investing in new facilities to provide heat to heat networks. These are likely to be modern gas boilers;
  - discontinue the provision of heat to industry and households by replacing it with local heat production.

  All options will lead to additional costs as investments have to be made into expansion of heat network and new facilities to provide heat. Increase heat supply from coal-plants in Addendum 1 might require additional investment to transport the heat but saves costs of the alternative heat source in the system.

- **Implementation of additional abatement measures can increase innovation** – The earlier implementation of additional abatement measures (2020 instead of 2025 in Addendum 1) can lead to higher innovation with regard to the development of CCS and biomass supply chains. Furthermore, additional co-firing of sustainable biomass could lead to the development of biomass supply chains that comply with Dutch sustainability criteria for biomass (e.g. international implementation of Dutch sustainability criteria for biomass). Closure of coal plants, on the other hand, could lower innovation activities as currently planned testing of CCS might not be realised.

- **The closure of the five coal plants can affect the employment -** Up to 1000 people[26] are directly employed at the five coal-fired plants. After closure

[26] Based on full-time-equivalents (FTE)

of these plants, these employees would have to be transferred into other workplaces. The closure of the plants can have indirect effects on employment especially through multiplier effects. On the other hand, the substitution of coal-fired power generation with power supply from other sources can offset at least to some extent the impacts on employment at the

The quantification of the indirect effects is not subject of this study.

ANNEX A DETAILED RESULTS OF THE ADDITIONAL SCENARIOS

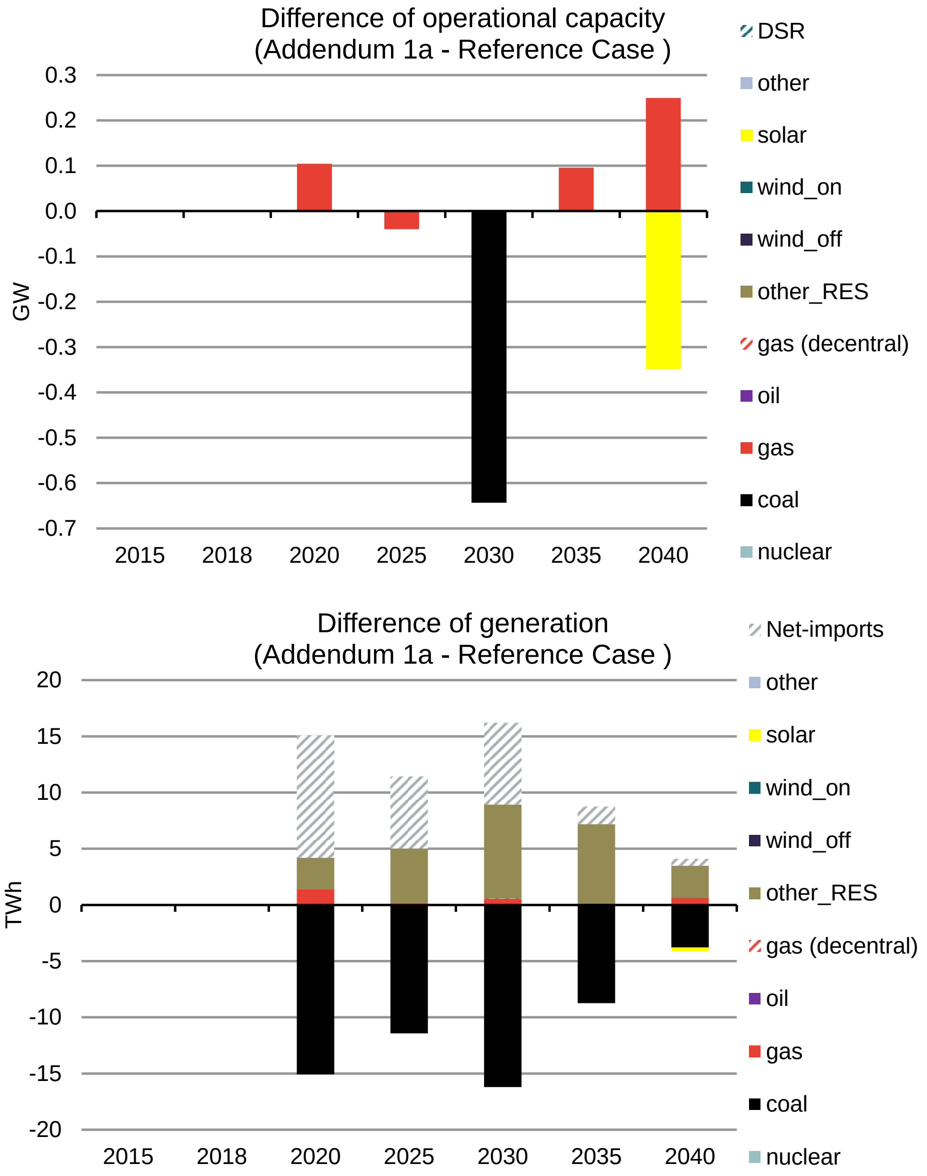
In this section, we provide more detailed information on the results of modelling the impact of the different policy measures compared to the Reference Case. For each policy scenario, we will report:

- Impact on capacities and electricity supply in The Netherlands;
- Impact on capacities and electricity supply in the model region; and
- Impact on imports and exports of power from and to The Netherlands.

A.1 Addendum 1a

The figures below illustrate the impact of the implementation of additional abatement measures at the coal plants in 2020 (costs borne by the companies, Addendum 1a) on the electricity supply in The Netherlands and in all modelled countries.

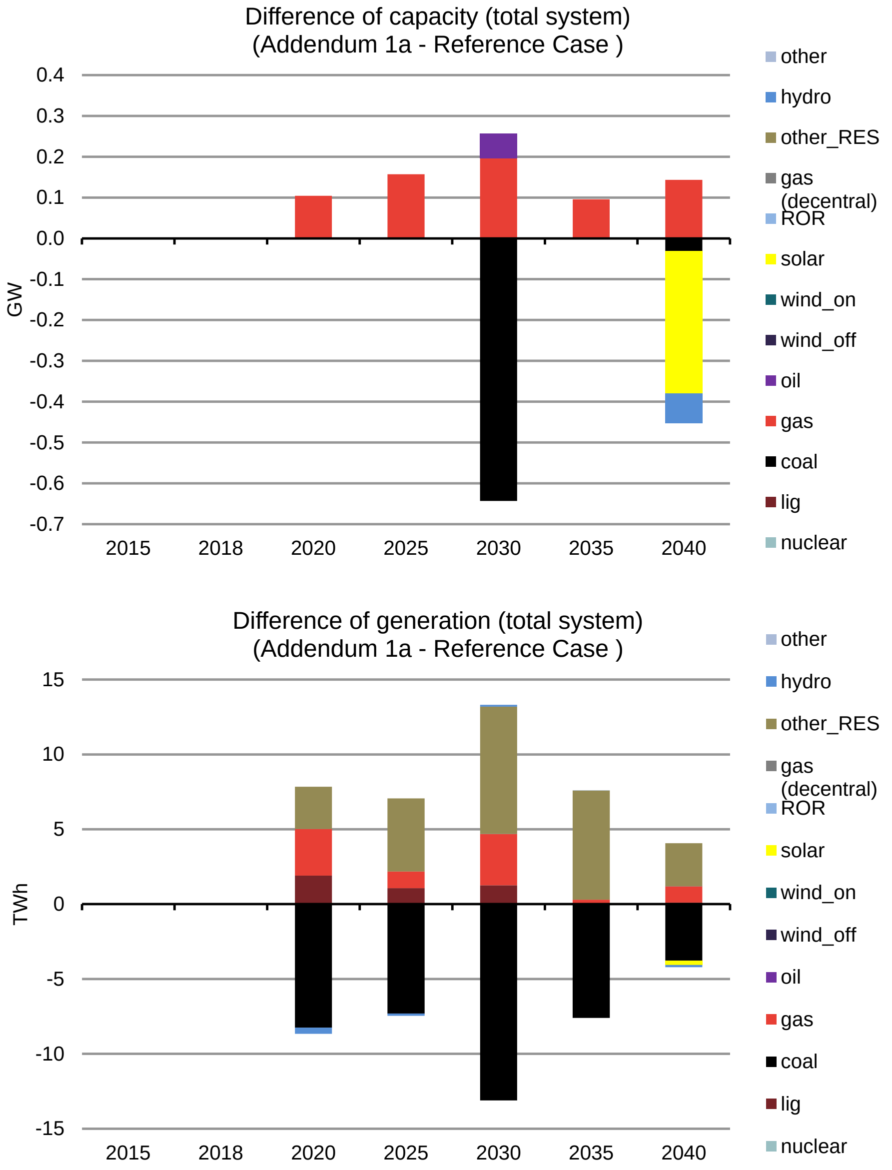
Figure 16. Impact on the Dutch electricity supply (Addendum 1a)



Source: Frontier

Note: Difference to the Reference Case

Figure 17. Impact on electricity supply (model-region) (Addendum 1a)

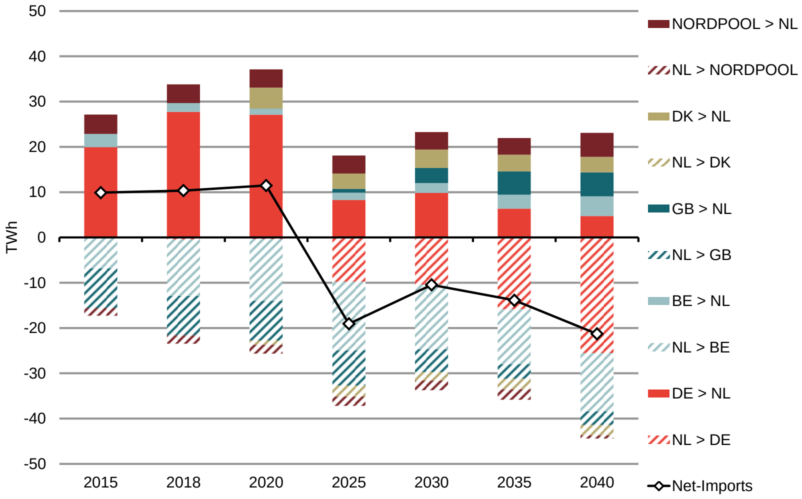


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 18. Imports/ Exports of power (NL) (Addendum 1a)

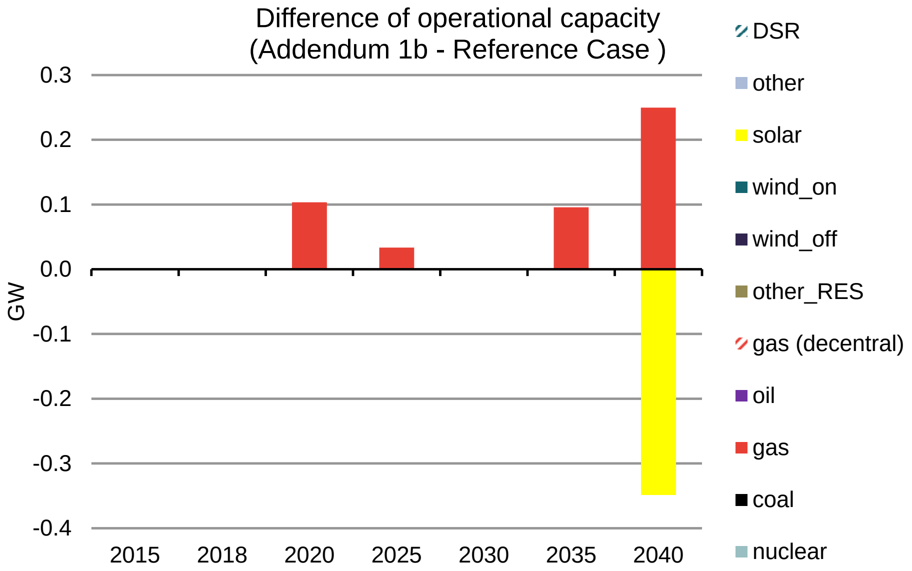


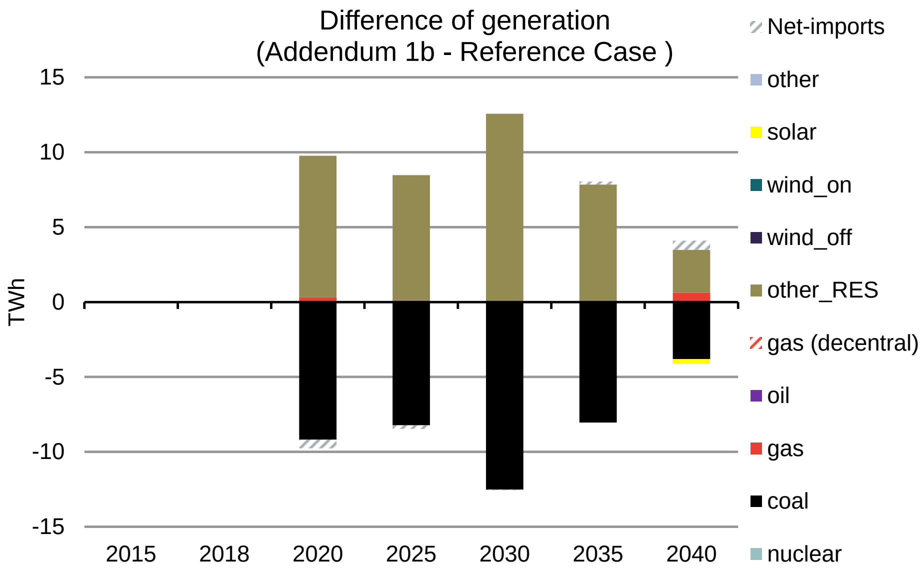
Source: Frontier

A.2 Addendum 1b

The figures below illustrate the impact of the implementation of additional abatement measures at the coal plants in 2020 (costs not borne by the companies, Addendum 1b) on the electricity supply in The Netherlands and in all modelled countries.

Figure 19. Impact on the Dutch electricity supply (Addendum 1b)

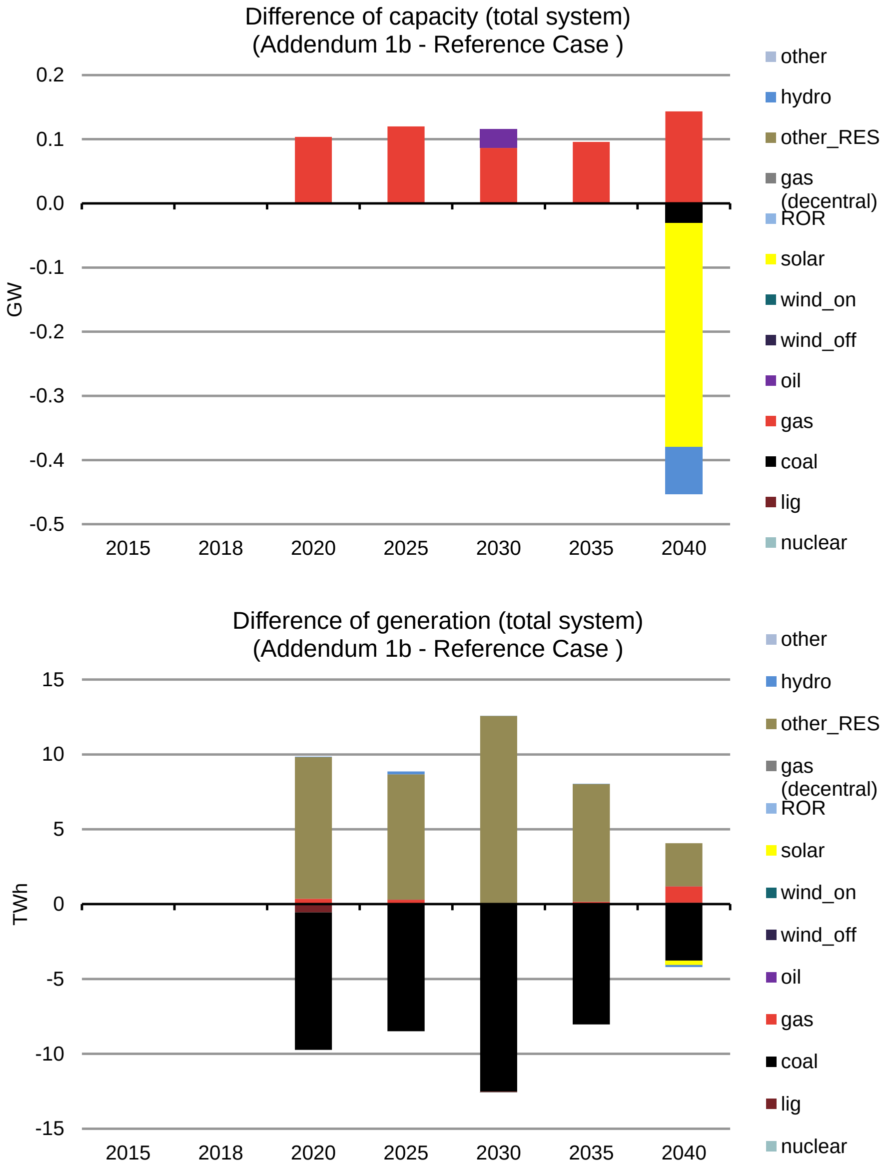




Source: Frontier

Note: Difference to the Reference Case

Figure 20. Impact on electricity supply (model-region) (Addendum 1b)

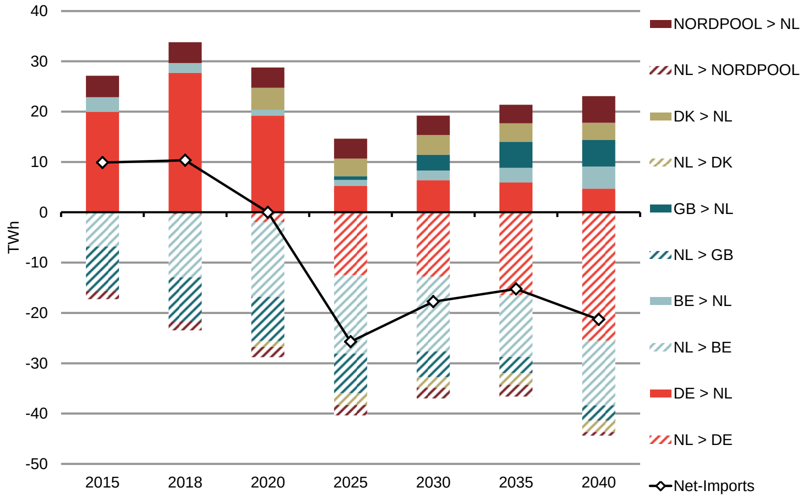


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 21. Imports/ Exports of power (NL) (Addendum 1b)

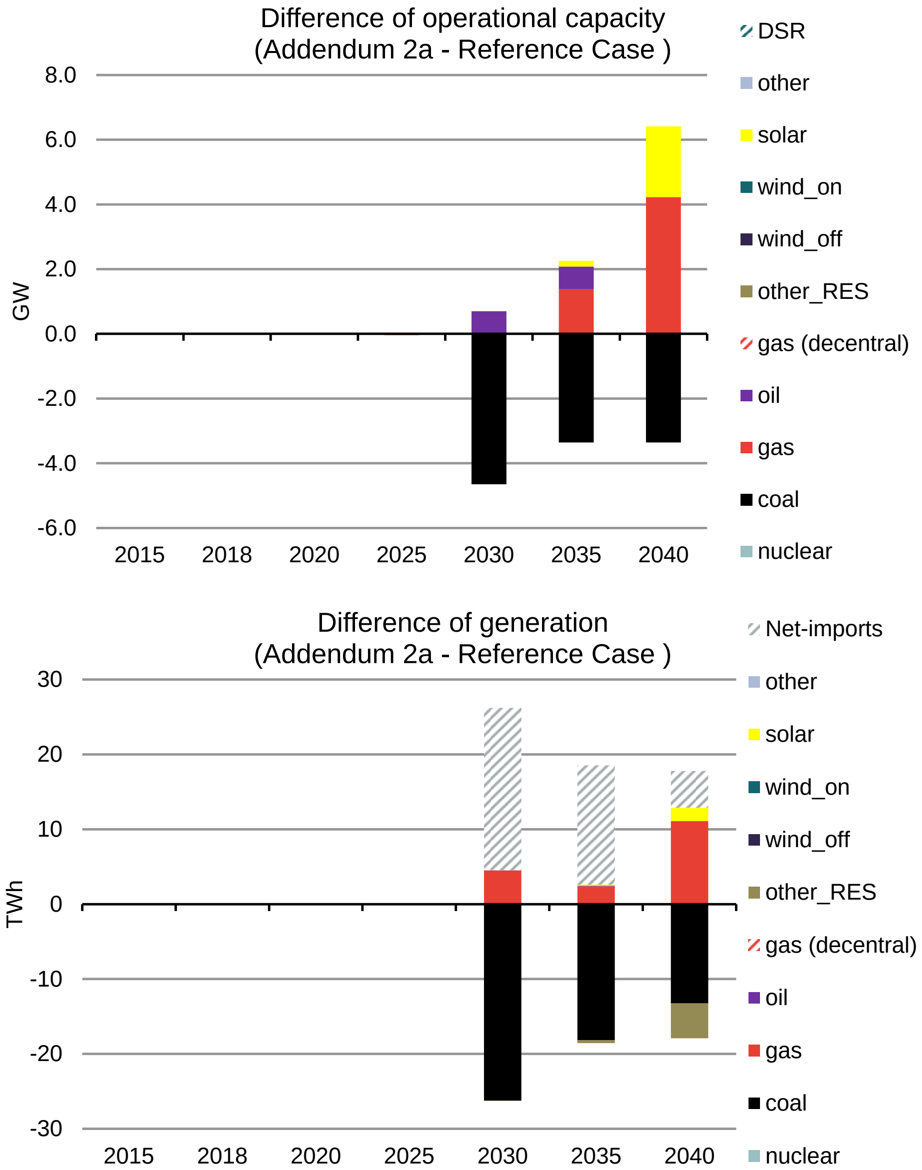


Source: Frontier

A.3 Addendum 2a

The figures below illustrate the impact closure of all coal-fired plants until 2030 on the electricity supply in The Netherlands and in all modelled countries.

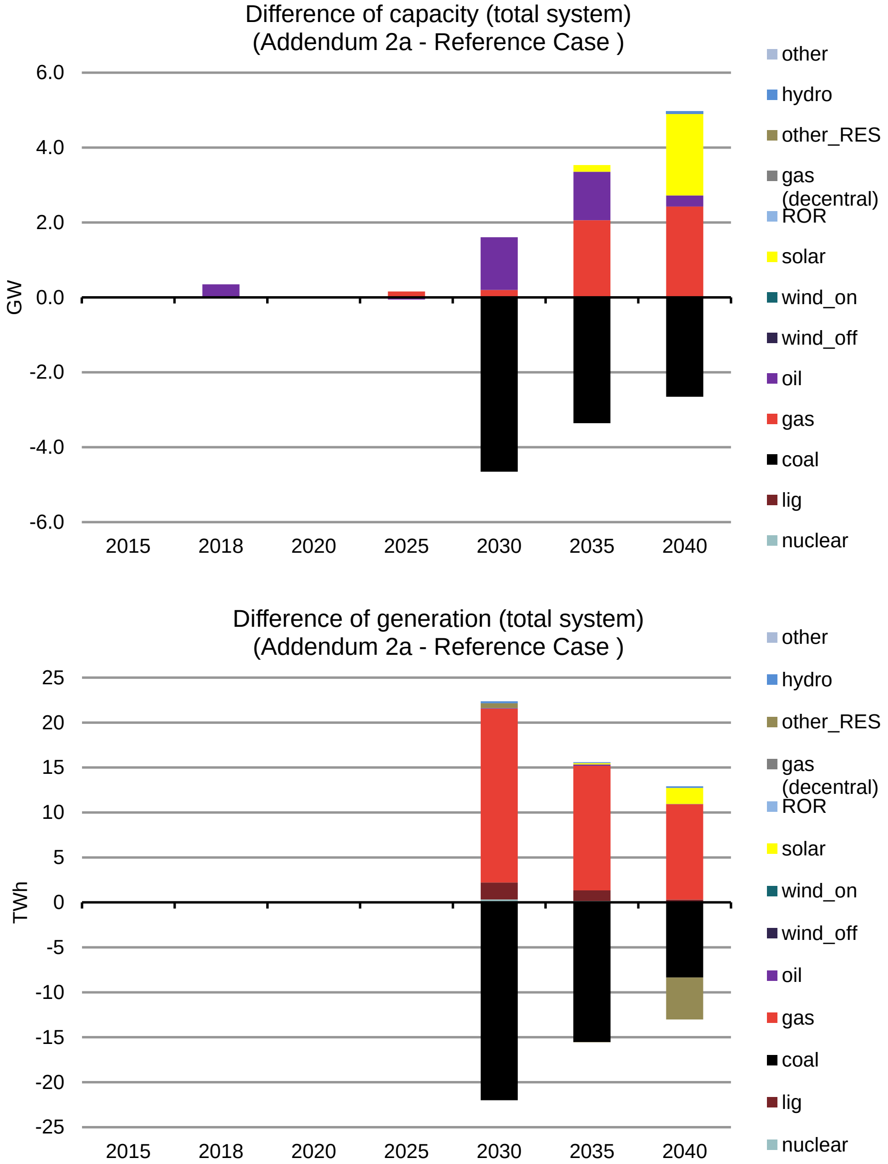
Figure 22. Impact on the Dutch electricity supply (Addendum 2a)



Source: Frontier

Note: Difference to the Reference Case

Figure 23. Impact on electricity supply (model-region) (Addendum 2a)

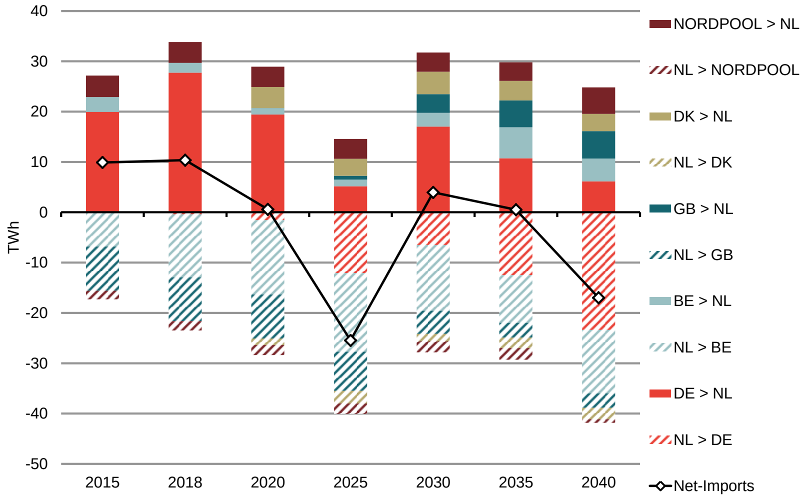


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 24. Imports/ Exports of power (NL) (Addendum 2a)

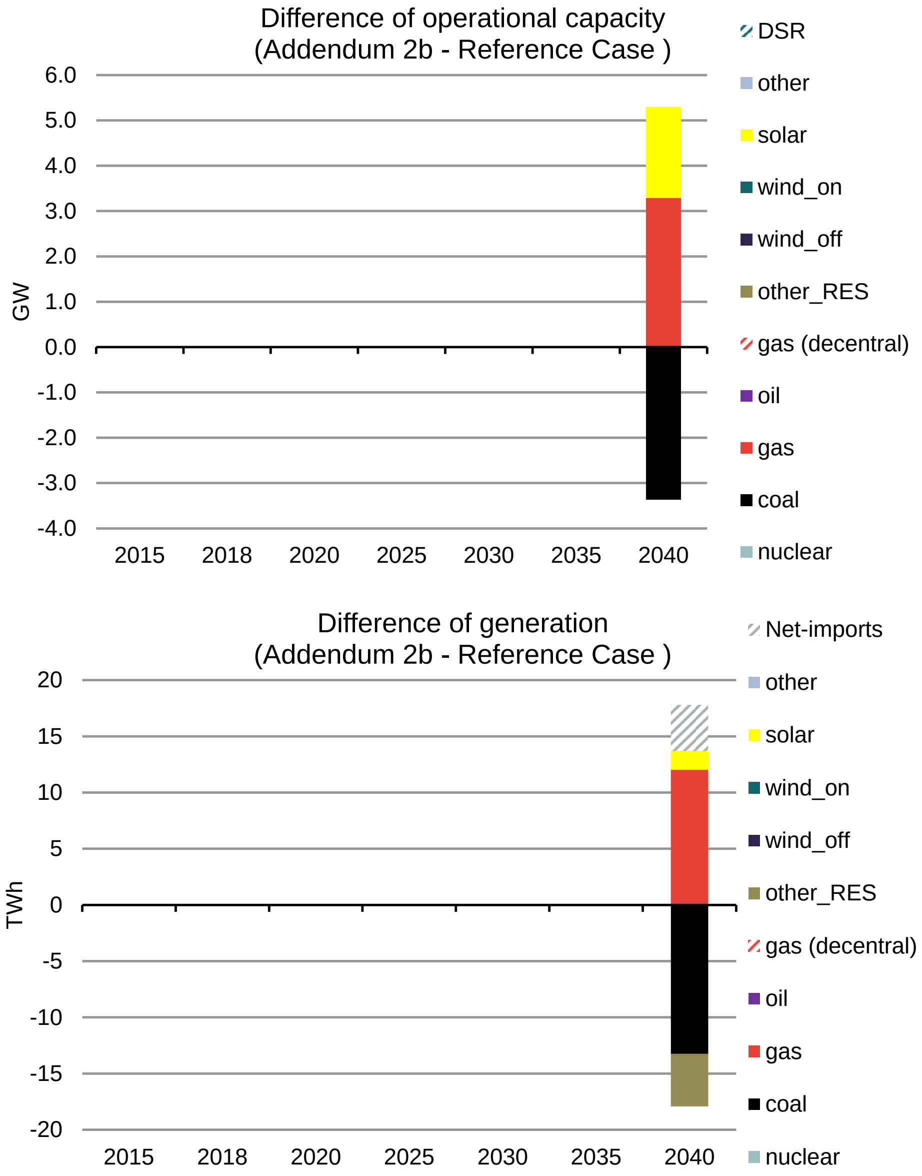


Source: Frontier

A.4 Addendum 2b

The figures below illustrate the impact closure of all coal-fired plants until 2040 on the electricity supply in The Netherlands and in all modelled countries.

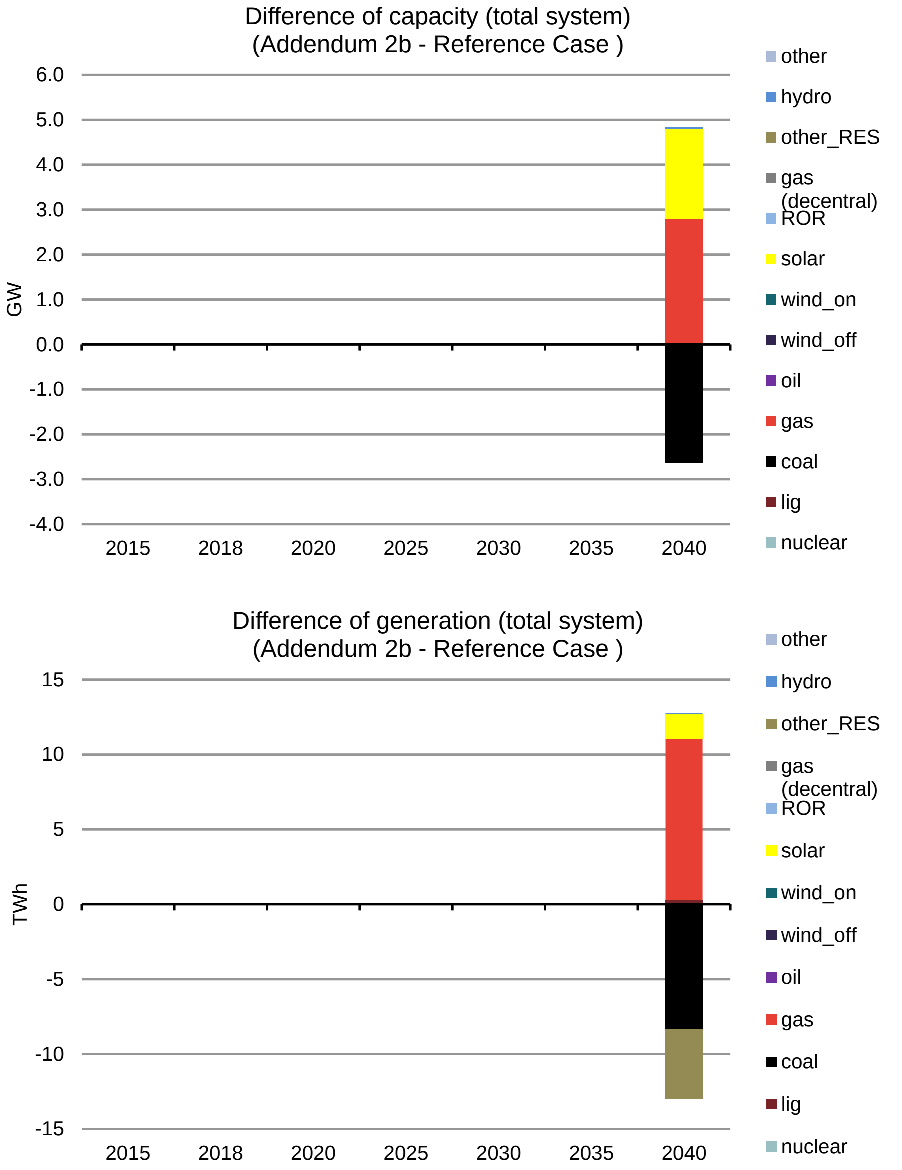
Figure 25. Impact on the Dutch electricity supply (Addendum 2b)



Source: Frontier

Note: Difference to the Reference Case

Figure 26. Impact on electricity supply (model-region) (Addendum 2b)

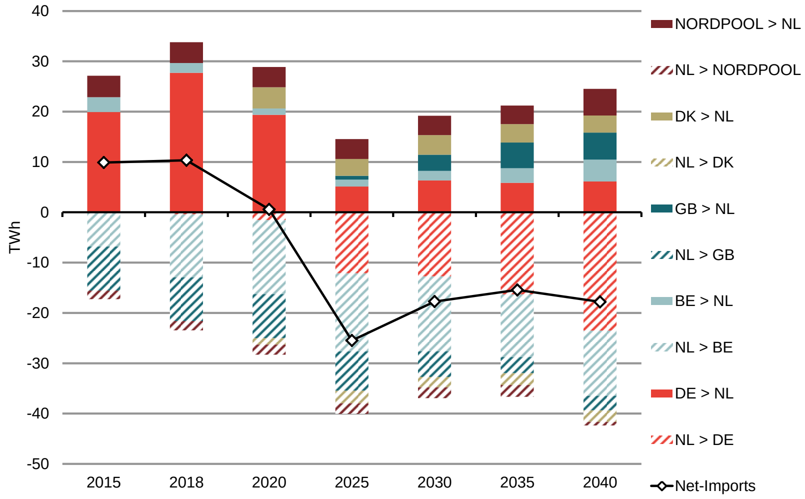


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 27. Imports/ Exports of power (NL) (Addendum 2b)

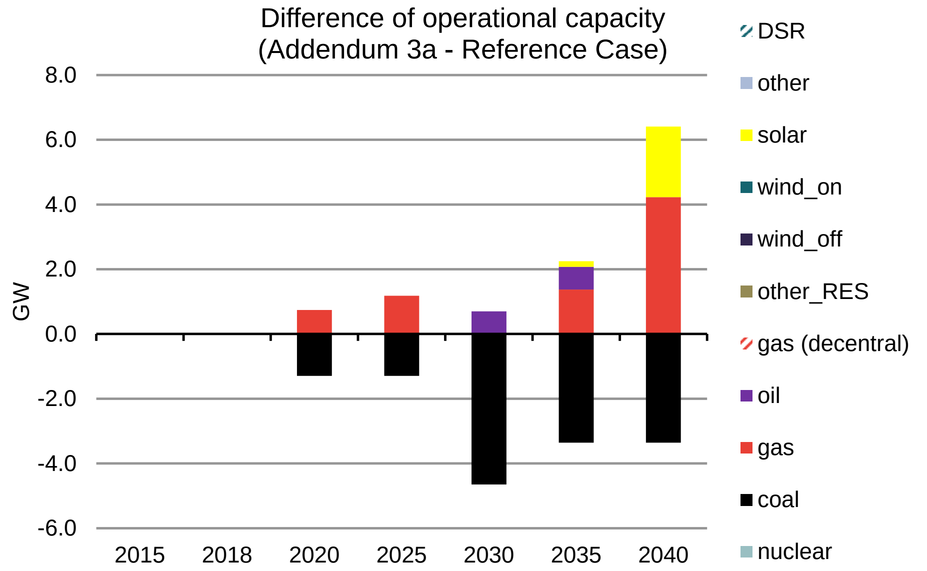


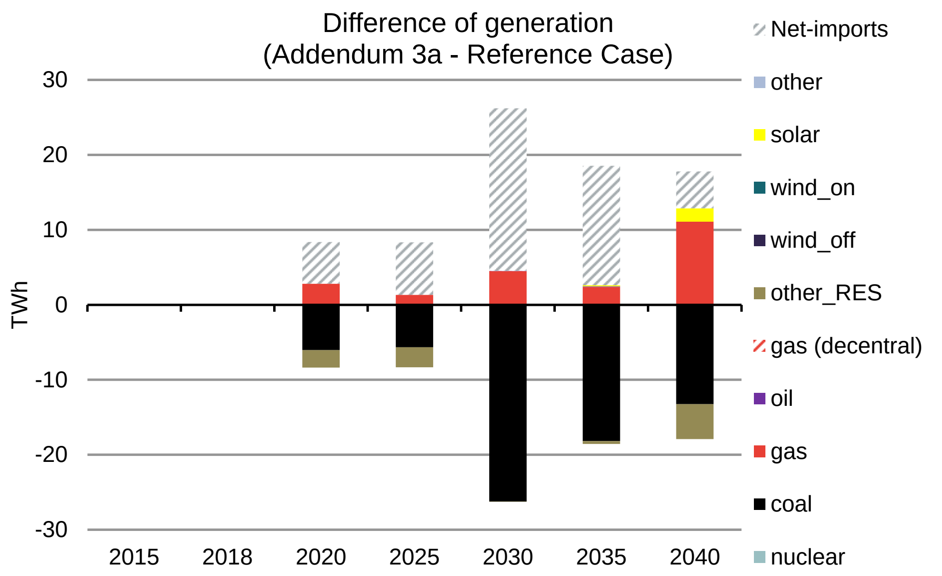
Source: Frontier

A.5 Addendum 3a

The figures below illustrate the impact of a closure of the two oldest coal-fired plants until 2020 and of the remaining plants until 2030 on the electricity supply in The Netherlands and in all modelled countries.

Figure 28. Impact on the Dutch electricity supply (Addendum 3a)

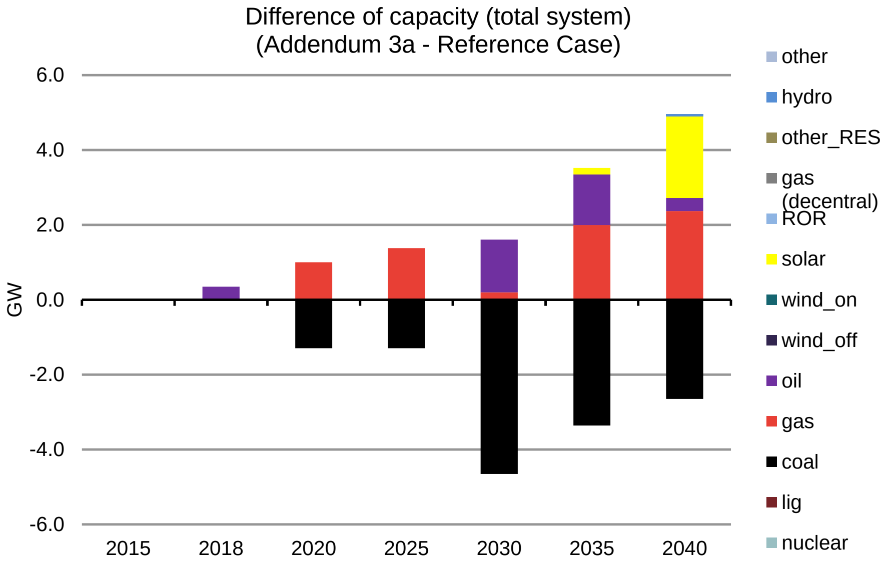


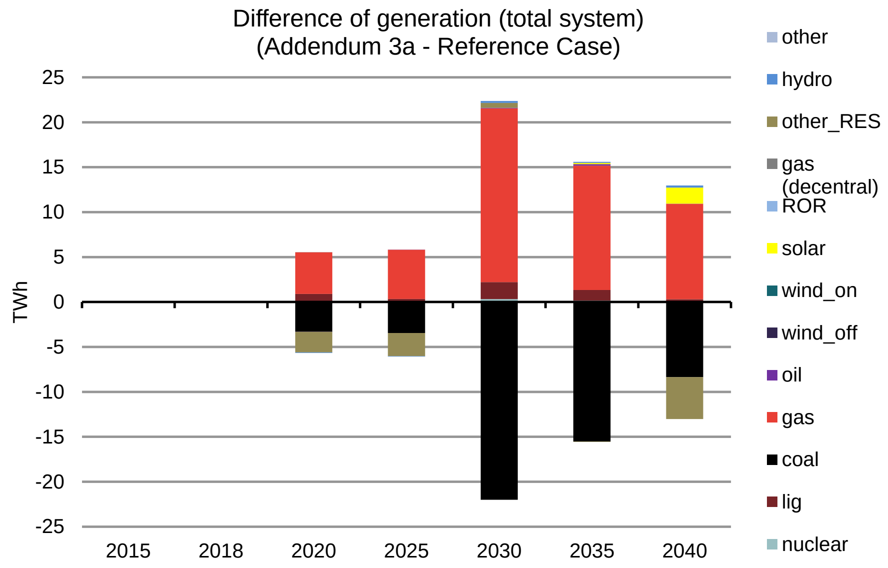


Source: Frontier

Note: Difference to the Reference Case

Figure 29. Impact on electricity supply (model-region) (Addendum 3a)



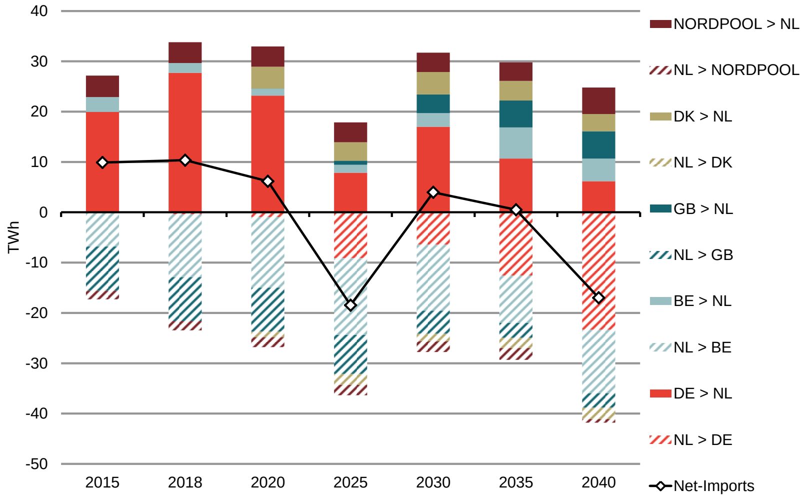


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 30. Imports/ Exports of power (NL) (Addendum 3a)

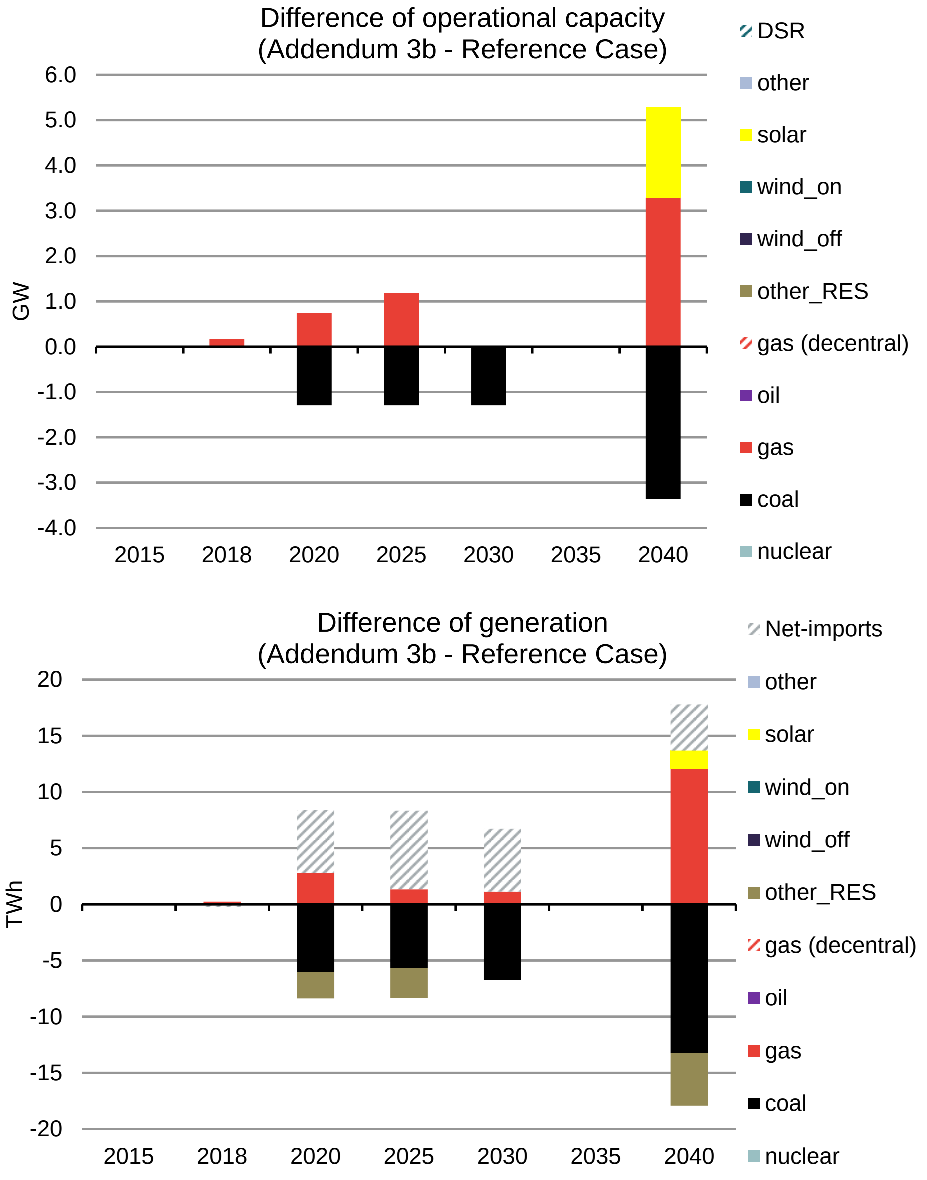


Source: Frontier

A.6 Addendum 3b

The figures below illustrate the impact of a closure of the two oldest coal-fired plants until 2020 and of the remaining plants until 2040 on the electricity supply in The Netherlands and in all modelled countries.

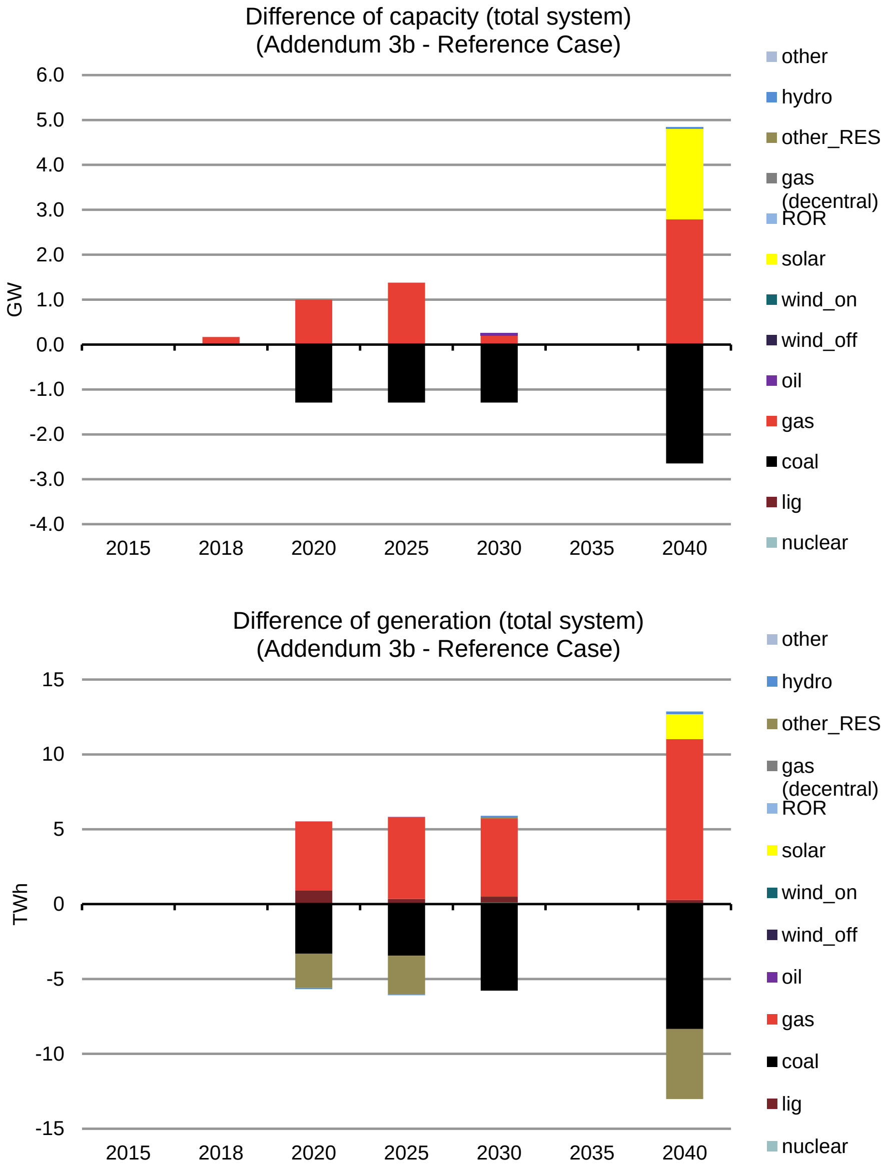
Figure 31. Impact on the Dutch electricity supply (Addendum 3b)



Source: Frontier

Note: Difference to the Reference Case

Figure 32. Impact on electricity supply (model-region) (Addendum 3b)

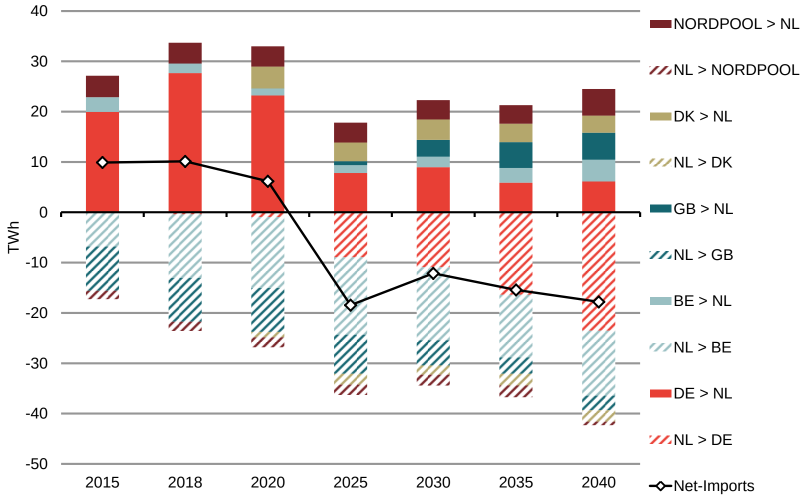


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 33. Imports/ Exports of power (NL) (Addendum 3b)

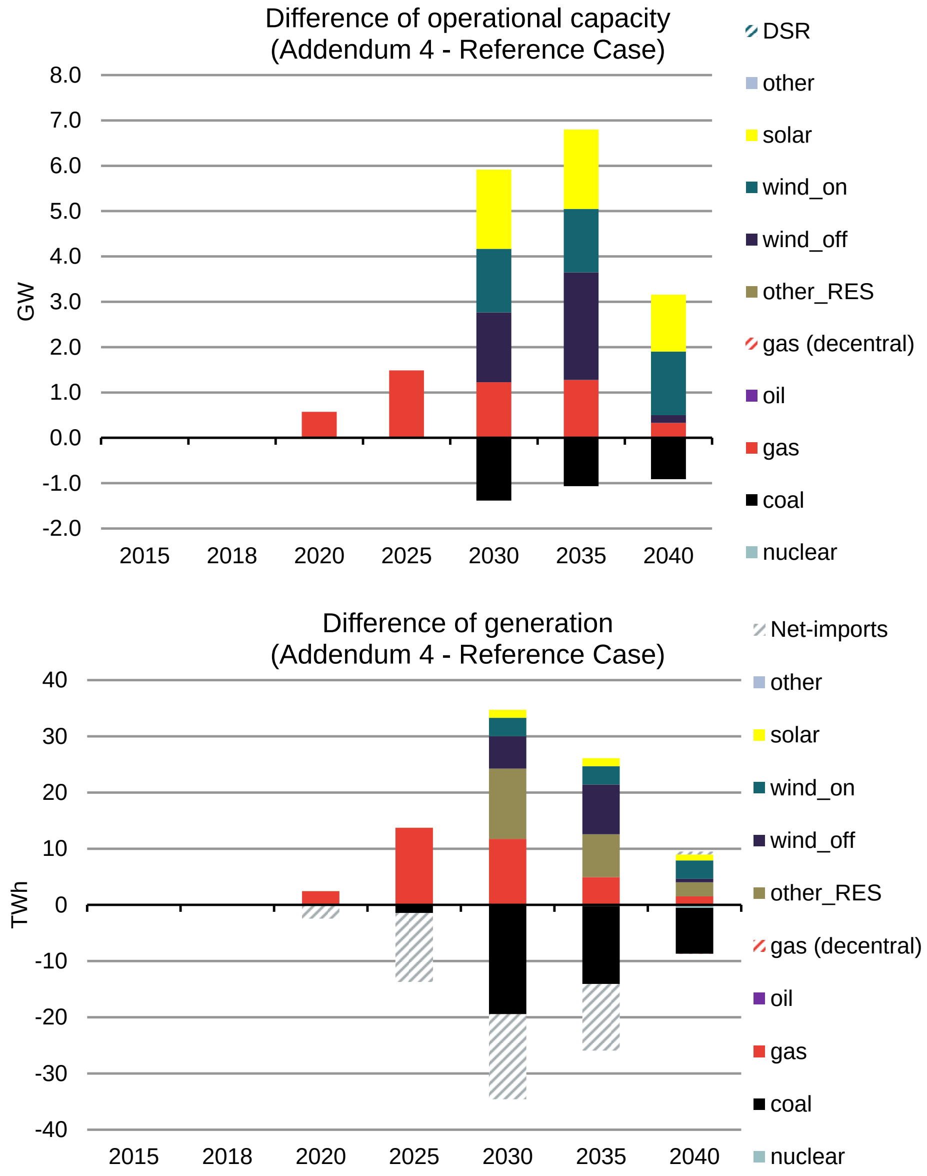


Source: Frontier

A.7 Addendum 4

The figures below illustrate the impact of higher CO_2 prices on the electricity supply in The Netherlands and in all modelled countries.

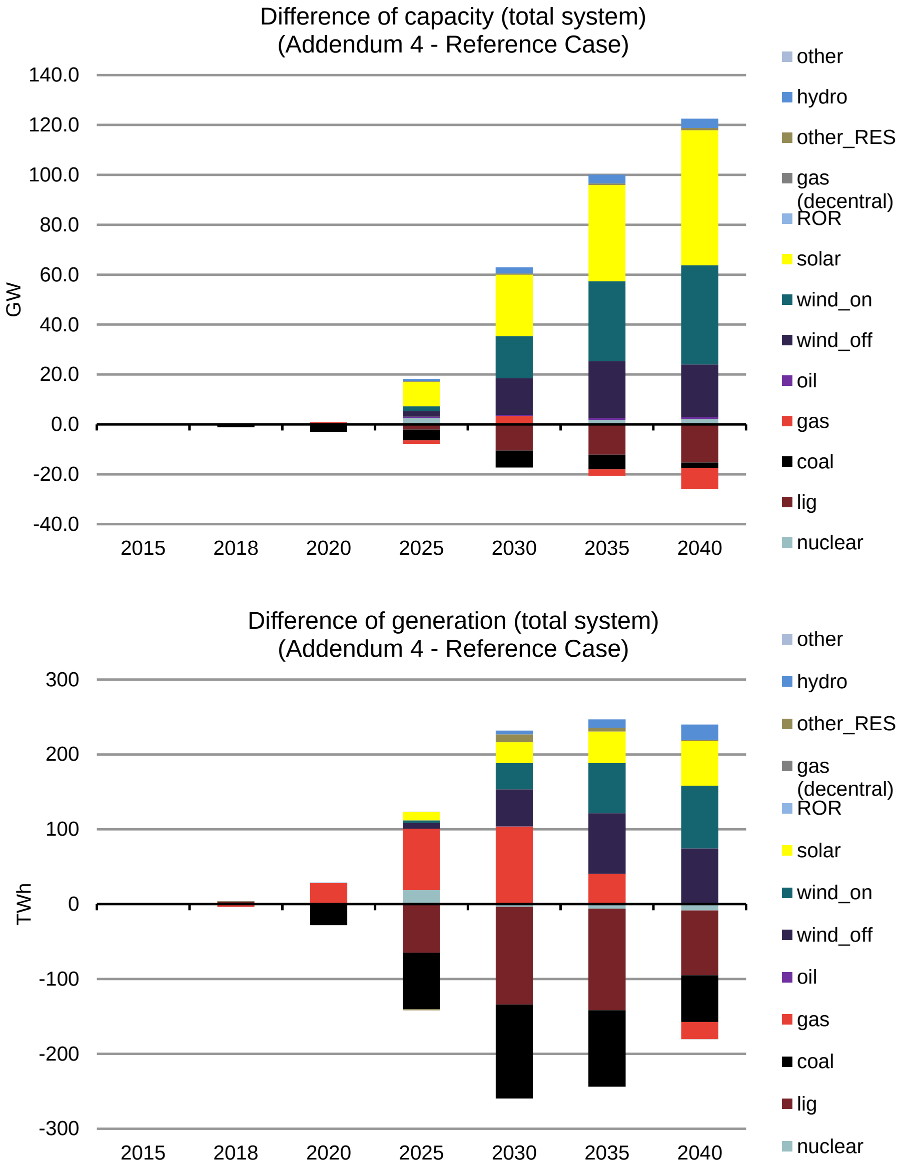
Figure 34. Impact on the Dutch electricity supply (Addendum 4)



Source: Frontier

Note: Difference to the Reference Case

Figure 35. Impact on electricity supply (model-region) (Addendum 4)

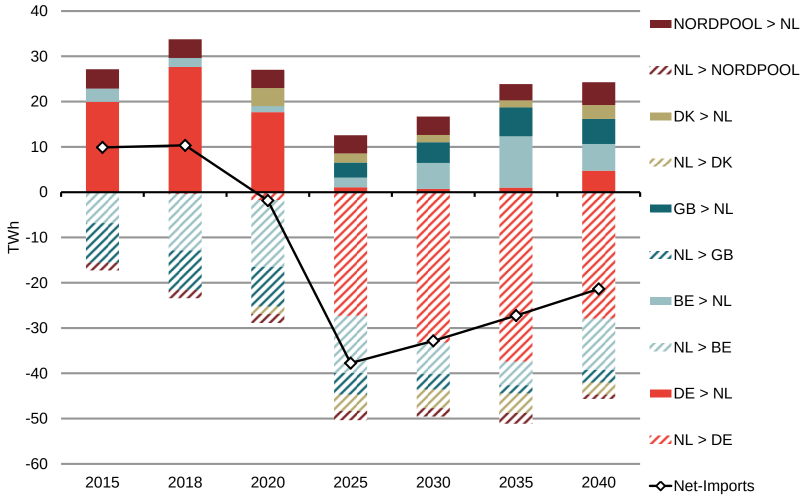


Source: Frontier

Note: Difference to the Reference Case

The figure below shows the level of imports and exports to and from The Netherlands.

Figure 36. Imports/ Exports of power (NL) (Addendum 4)



Source: Frontier

Note: Difference to the Reference Case

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