Energy in the Netherlands

Optimized pathways to CO2 reduction in the Dutch context

Energy Forum NL

The information and conclusions contained in this report represent the collective view of the working groups in this study, not that of any individual company or organization. Any information and conclusions provided in this document are for reference purposes only; they are not intended nor should be used as a substitute for professional advice or judgment in any given circumstance. The companies and organizations involved do not guarantee the adequacy, accuracy, timeliness or completeness of the report's contents. These companies and organizations therefore disclaim any and all warranties and representations concerning said contents, expressed or implied, including any warranties of fitness for a particular purpose or use.

Contents

Introduction

This document reports the findings of research undertaken by the Energy Forum NL (EFNL) which consists of companies active in different parts of the energy sector: DONG Energy, EBN, Eneco, GasTerra, Gasunie, GDF SUEZ, and Shell. The group strives for a more long-term, stable energy policy and investment climate in the Netherlands, one that will help realize overall climate ambitions. This report is part of the group's contribution to the energy debate in the Netherlands; it lays out a fact-based, objective analysis of the potential energy mix if one assumes a continued focus on carbon abatement.

In this report, the Energy Forum NL provides pathways that show how the Netherlands can best contribute to the EU target of 80% CO2e emission reduction by 2050 compared to 1990. They particularly focus on the goal for the next 20 years: reducing CO2e emissions by 40% by 2030 compared to 1990. The Forum selected 40% as a midway target for 80% in 2050; this falls within the EU ambition of 40%-44% in 2030.[1] The period beyond 2030, which is much more uncertain, is modeled in less detail. However, the Forum took care to not let the choice of any pathway during 2010–2030 lock a pathway after 2030 in or out.

A "least cost" approach, which works across sectors, is used to reduce emissions. In a "least cost" approach, all emission reduction measures are ranked on costs and implemented progressively (starting from the cheapest) until the targeted abatement level is reached. In addition, a few developing technologies are implemented even if they are more expensive than alternatives. This choice prevents technology lock-in, ensures a more versatile, resilient energy system and provides a reasonable starting position for the period post-2030.

The report assumes a pan-European approach for the power sector, which is the key sector in the Emissions Trading Scheme (ETS); in this case, Dutch abatement options "compete" with those in other EU countries. For the other sectors it uses a national approach. Non-cost factors, such as ease of implementation (technological and societal), have been taken into account but not to the same degree as costs.

The pathways and sensitivities in this report are meant to provide the reader with a sense of the implications of possible choices, rather than to suggest that any pathway is a hard "truth". It should not be read as recommendations from the Forum in favor of one technology over the other.

---

1 European Commission 'Roadmap for moving to a low carbon economy in 2050,' 2011.

Executive summary

The Netherlands can achieve the derived EU CO2e emission reduction objective of 40% in 2030 versus 1990 levels, as well as the 2050 target of 80% emission reduction. How it will do so, while minimizing costs, greatly depends on the way the EU will implement its targets.

Key messages emerging from the study are:

- Actual emissions in the Netherlands declined 3% between 1990 and 2010. If no further abatement action is taken (the so-called "Business as Usual", or BAU pathway), total emissions in 2030 would increase 11% compared to 1990.
- Reaching the EU ambition of 40% reduction by 2030 compared to 1990 levels is technically possible but will require implementation of almost all currently available and developing technologies as well as increases in energy efficiency. Several routes are possible to achieve this, but each demands additional investments beyond the BAU and a substantial acceleration of current efforts.
- The Netherlands is well positioned to lead the implementation and/or further commercialization of several abatement technologies. These include: biomass; wind off-shore; decentralized heat and cold storage; gas-based decentralized power generation; Carbon Capture and Storage (CCS); hydrogen; and adoption of electric vehicles. In all the explored pathways, gas will continue to play a pivotal role in the residential sector (through current and innovative technologies), the industrial sector, and the power sector (e.g., as base load and a balance for intermittent renewable sources). It could also grow in the road and marine transport sector.
- The costs to Dutch society and routes to implementation vary substantially between the different options. Compared to BAU, the total additional cumulative cost to society in terms of investments and running costs is €10-30 bn for the period 2010-2030 (€20-50 bn when excluding CO2 costs in both BAU and the abatement pathway[2]). These numbers would translate to an increase of €50-185/yr per household including CO2 costs.
- Given the long-term, capital-intensive nature of many energy investments, a stable, long-term policy framework for investments and planning will be indispensible to achieve the targeted abatement across all sectors.

Findings from the abatement options

In this study, the Forum explored several options to reach the targeted 40% emission reduction in 2030 versus the base year of 1990. The options differed only for the power sector and evolved around the regulatory framework and policy choices assumed for that sector.

For the industrial, buildings, transport and agricultural sectors, a national optimization approach was adopted[3]. Abatement options in these sectors were

2 The sectors part of the Emissions Trading System (ETS) must buy permits for CO2e emissions. The costs depend on the amount of emissions and are therefore lower in the implementation options that have lower emissions.

3 While the Industrial sector progressively joins the ETS, this study has not modeled Industrial abatement optimization on an EU level due to its technical and implementation complexity.

ranked on costs to determine which abatement levels per sector yielded the lowest total cost on the national level. The pathway assumed implementation would move from the cheapest to the most expensive measures until it reached the target abatement. This resulted in the following abatement levels: buildings sector 59%, industry 30%, transport 37% and agriculture 23% by 2030, compared to 1990 levels. Abatement costs additional to the BAU would be around €350 mn/year (€810 mn/yr without CO2 costs[4]). This is equivalent to €50 per year per household and €7 bn cumulative for the period 2010-2030.

For the **power sector**[5], the "EU Target" abatement pathway assumes the full implementation of the National Renewable Energy Action Plans (NREAPs) before 2020. It also presumes that ETS will function well, in which case the European power sector would implement the cheapest abatement measures in all EU countries until the EU overall target of 60% is reached. Constraints in inter-country transmission connections are taken into account. In the Netherlands, this "EU Target" pathway would result in a generation mix of 25% renewables (20% wind, 2% dedicated biomass and 3% co-fired biomass[6]), 46% gas, 18% coal, and 10% nuclear. Abatement costs on top of the BAU would be around €150 mn/yr or €3 bn for the period 2010-2030, equivalent to €20 per household. Excluding the avoided CO2e costs would roughly double that cost difference with the BAU, since CO2e emissions are much lower in the pathway with correspondingly lower costs for emission credits under the ETS system.

Power sector emissions in the EU Target pathway fall significantly versus BAU, but rise 7% in 2030 versus the 1990 base (while the EU as a whole reaches a weighted average of 60% reduction in this period). Three factors drive this: first, Dutch power generation capacity will have grown faster than EU average. Second, this growth will give the Netherlands a relatively young generation fleet, which make the abatement measures aimed at older fossil plants more applicable to other countries. Third, in the pathway the Netherlands would be implementing close to the maximum of wind on-shore and biomass, combined with an aggressive growth of wind off-shore. The remaining RES opportunities in the Netherlands are less cost attractive than those in other countries.

The Forum performed three sensitivities on the EU Target pathway. Each explores the impact of a set of different inputs. See exhibit 1 overleaf.

- The **Country target** sensitivity assumes a 60% abatement target for the Dutch power sector in 2030 (without functioning ETS) and the full implementation of NREAP by 2020. Under these assumptions, the Netherlands would stop exporting power in order to decrease emissions. To abate the remaining emissions, wind production share would increase 8% compared to the pathway, 4 GW of coal capacity would be converted to dedicated biomass, and 4 GW of gas would be closed (because of the

---

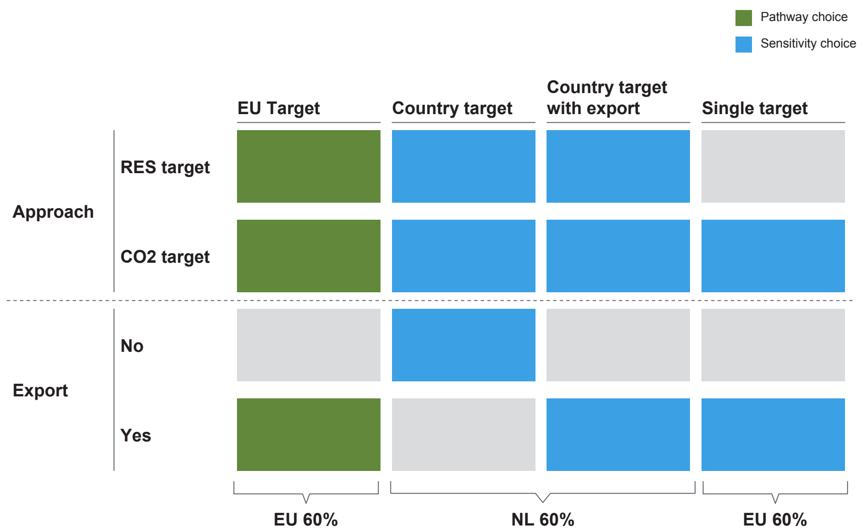
4 The CO2 price used in this study is taken from the IEA, World Energy Outlook, 2009 and rises to €44/ tCO2 in 2030 (starting from €15/tCO2 in 2010).

5 The percentages and capacities used in the power sector options are the result of the modeling and can not be seen as a recommendation by the Forum.

6 Average share of biomass in co-firing plants will be 20-25% of inputs, which translates to 7-8% output share.

Exhibit 1

Overview of input assumptions to reach power sector 60% CO2 target in 2030 for the pathways and sensitivities



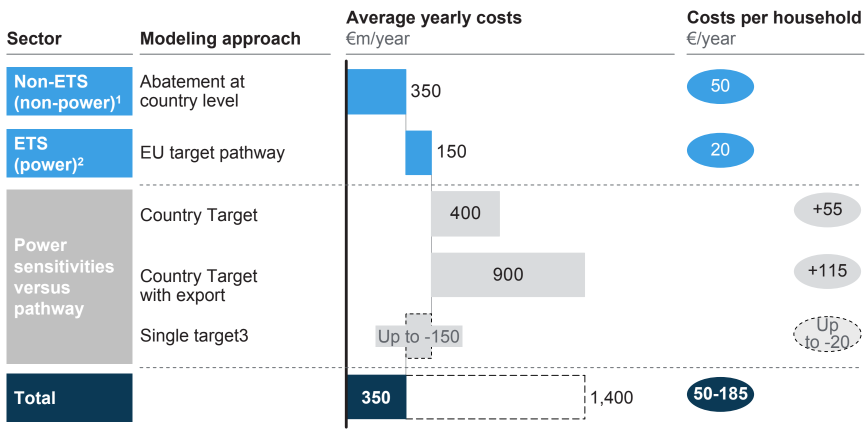
export loss). The total cumulative costs would increase with €8 bn (€17 bn without CO2) compared to the pathway.

- The **Country target with export** sensitivity assumes a 60% abatement target for the Dutch power sector in 2030 (without functioning ETS) but with exports at the level of the EU target pathway (35 TWh). To reach 60% abatement, wind production share would more than double compared to the pathway and 4 GW dedicated biomass would be converted from remaining coal plants. The total cumulative costs would increase to €18 bn compared to the pathway (€21 bn without CO2). These costs are from Dutch demand only and exclude costs or benefits from export. As an alternative to the build-out of 7 GW of wind off-shore, gas plants could be retrofitted with CCS. This would require 6 GW of gas CCS and would reduce additional costs by €11 bn compared to the pathway (€10 bn excluding CO2 costs).
- The **Single target** sensitivity explores the impact if Europe were to meet the 60% abatement ambition for the power sector for 2030 without any other intermediate or derived targets. For the Netherlands, this would result in a power mix of 15% RES, 19% coal, 53% gas, and 12% nuclear. Total production is 20 TWh (14%) less than in the pathway. The total costs compared to the pathway could be somewhat lower (up to 2% of the total power system costs of around €160 bn) for the period 2010-2030, depending on the incentives the Netherlands may have to pay to other countries, and/or the cost to build the RES capacity or to develop alternative abatement options.

Exhibit 2

Abatement costs versus BAU – including costs of CO2

2010–2030



1 Industry sector, even though part of the EU ETS, has been modeled with a domestic perspective in this study and is included in the non-ETS category here, costs including CO2 only consider costs for ETS sectors (industry and power)
2 Costs of the power system are based on consumption, costs of exported power are excluded in these figures
3 Costs depend on incentives NL may have to pay to other countries to build the RES capacity instead and/or to develop alternative abatement options

In summary, the total additional cumulative cost to society in terms of investments and running costs are €10-30 billion higher for the abatement scenarios compared to BAU (and €20-50 bn higher excluding CO2 costs). This corresponds to €50-185 per household (including CO2 costs). See exhibit 2.

Considerations for implementation

From a European perspective, the Netherlands is well positioned to lead abatement in several areas, due to geological and infrastructural advantages. Examples of these include: CCS (above-average geological position, availability of off-shore depleted gas fields and continued use of fossil fuels); biomass (excellent deep-sea harbors and infrastructure, availability of coal plants for co-firing, dense urban clusters for district heating by Combined Heat and Power (CHPs) on biomass); wind off-shore (shallow sea and good wind conditions); and decentralized power generation using existing gas infrastructure (micro-CHP's fuel cells). The Netherlands can also lead in the transport sector thanks to its high density, which is suitable for charging clusters and relatively short distances driven, which benefit the rollout of electrical and hydrogen powered vehicles. Finally, it might be able to gain a competitive advantage by using hydrogen in industry and residential heating.

Gas will continue to play an indispensable role in all abatement options. Total gas demand in the abatement options will be in the range of 42 to 49 BCM per

7 At a calorific value of 35.17 MJ/m3.

year (with a possible peak of 52 BCM)[7]. In power generation, gas is a critical technology in all options, accounting for 35-55% of Dutch power generation and balancing the more intermittent technologies. In buildings, 70% of households will still use gas for heating and warm water in 2030. Furthermore, gas could have a role in decentralized power generation and hydrogen provision for hydrogen-powered technologies.

The Dutch gas transport infrastructure, including the current capacity expansion, will be sufficient to provide the peak gas capacities needed for the EU pathway and all sensitivities discussed in this report. This also holds true in cases with significant wind capacity, where gas is likely to be critical for net balancing.

For sound implementation of any options for significant carbon abatement, a clear policy and investment framework needs to be in place in the Netherlands (and Europe), as well as a strong, functioning ETS. Many of the new technologies described above require substantial investments; even before that, a long-term stable financial outlook is necessary for private parties to invest in them. In addition, development beyond currently known technologies should be encouraged.

The current pace of implementation of the NREAP for the Netherlands is not in line with the ambitious targets for 2020, so a significant acceleration of the current build-out of renewables may be needed if the Netherlands is to meet its 2020 target.

For the period 2030-2050, the research indicates that the Netherlands can reduce its emissions by 80% by 2050 compared to 1990 levels. The pathway described in this study for the period 2010-2030 does not exclude any options nor does it make any much more cost-disadvantaged versus another. Depending on the further maturation of technologies and societal preferences, the Netherlands will need to create the best 2030-2050 pathway in the 2020’s.

1 “Business as Usual” development of the Dutch energy system

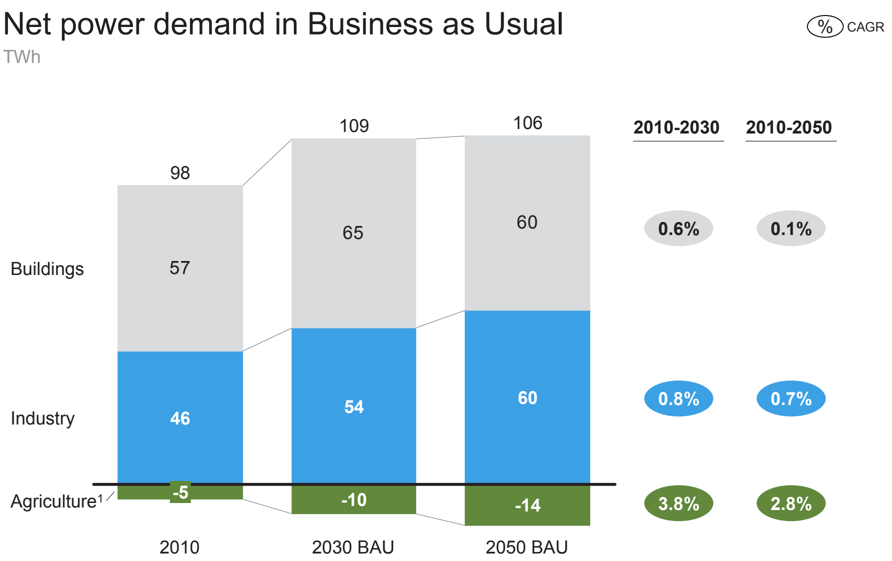
This chapter describes the “Business as Usual” (BAU) pathway, which is based on the ECN ‘BAU with fixed policy’ case[8]. The BAU describes the energy and emission growth per sector from 2010 to 2030, assuming no further abatement measures are taken from today. The BAU can be seen as the pathway that the Netherlands might have adopted if no abatement ambitions existed. It delineates the five main energy-consuming sectors in the Netherlands, including the 1) buildings sector, 2) industry sector, 3) transport sector, 4) agriculture sector and 5) power sector.

1.1 ECONOMY-WIDE BAU

Dutch energy demand is expected to increase from 4100 PJ in 2010 to 4550 PJ in 2030; it should then decrease to 4350 PJ by 2050. A rise in energy consumption in the power (1.7% p.a.), transport (0.3% p.a.) and industry sectors (0.6% p.a.) would drive the increase and more than offset the decrease in the buildings (-0.4% p.a.) and agriculture (-0.2% p.a.) sectors.

More specifically, power demand would increase from 98 TWh in 2010 to 109 TWh in 2030, then decrease to 106 TWh in 2050. The two sectors with growing power demand would be industry (0.7% p.a.) and buildings (0.1% p.a.). The agricultural sector may see a 2.8% p.a. decrease due to the increased use of Combined Heat and Power (CHP) technology. See Exhibit 3 below.

Exhibit 3



1 Negative power demand because of decentralized power generation (CHPs)

SOURCE: ECN

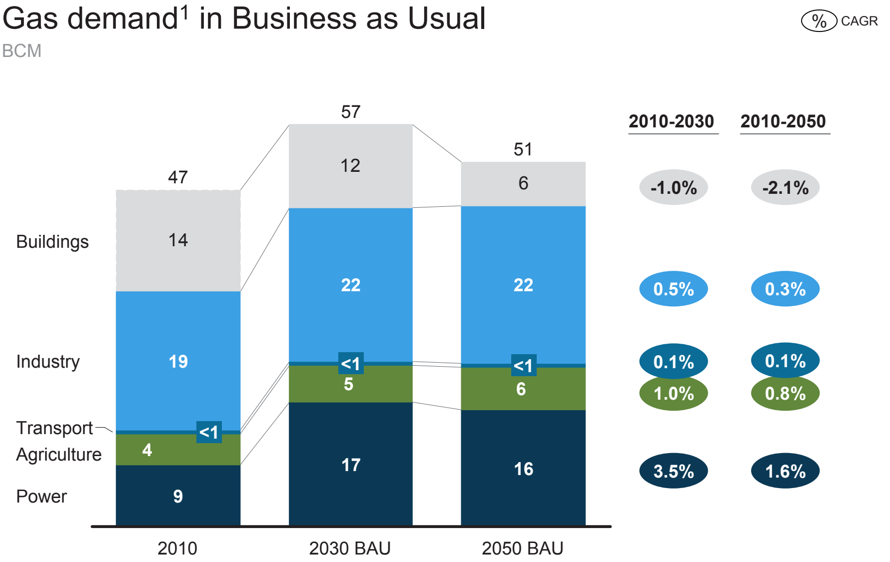
8 *“Referentieraming energie en emissies 2010-2020 - Energiebalans bij vastgesteld nationaal en Europees beleid”, ECN en Planbureau voor de Leefomgeving, april 2010.*

Gas demand would increase from 47 BCM in 2010 to 57 BCM in 2030, then slightly decrease to 51 BCM by 2050 (based on a calorific value of 35.17 MJ/m3). Increases in demand from three sectors will probably drive the increase in gas demand in 2050 compared to 2010: power (1.6% p.a.), agriculture (0.8% p.a.) and industry (0.3% p.a.). The decreased gas demand in the buildings sector (-2.1% p.a.) partially offsets this increase. See Exhibit 4 below.

Exhibit 4

Gas demand[1] in Business as Usual

BCM



1 Gas demand calculations based on the calorific value of Groningen gas (35.17 MJ/m³)

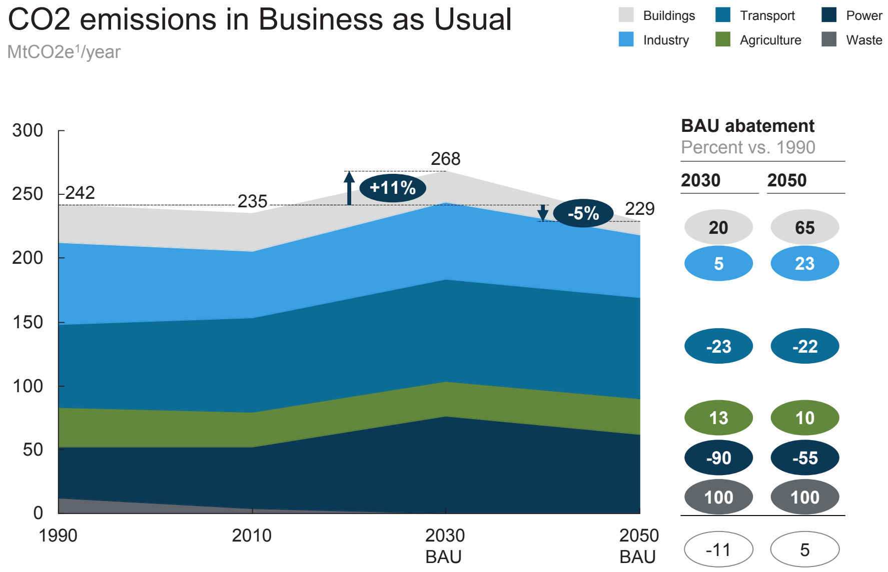
SOURCE: ECN

Emissions in the Netherlands would grow by 11% until 2030 and then decrease by 5% by 2050 compared to 1990. The largest contributors to emissions in 2010 are likely to be the transport (32%, 74 MtCO2e/yr), industry (22%, 52 MtCO2e/yr) and power (20%, 48 MtCO2e/yr) sectors. See Exhibit 5 overleaf. For the 2050 BAU, the abatement pathways are subtracted from the 2030 BAU and then extrapolated as if no additional abatement would take place between 2030 and 2050. This prevents overlap between 2030 and 2050 levers.

Exhibit 5

CO2 emissions in Business as Usual

MtCO2e[1]/year



1 Includes CO2, CH4, N2O, HFKs, PFKs, SF6

SOURCE: ECN

1.2 BUILDINGS SECTOR

The BAU assumes that energy demand in the buildings sector will decrease from 712 PJ in 2010 to 652 PJ in 2030 (8% reduction). The reduction is the net effect of a 14% increase in power demand and an 18% decrease in gas demand. These numbers are based on an extrapolation of the ECN "Without policy", which makes several assumptions including a housing stock of 7.7 million in 2020 and autonomous penetration of efficiency measures (e.g., 86% for condensing boilers and 80% for roof insulation).

Emissions in the buildings sector in 2010 were 30 MtCO2e/yr –13% of overall Dutch emissions. Under BAU, autonomous efficiency measures are expected to reduce this to 6 MtCO2e/yr (20% compared to 1990 levels) by 2030.

1.3 INDUSTRY SECTOR

The BAU assumes energy demand in the industry sector will increase from 1740 PJ in 2010 to 1910 PJ in 2030 (10%).

Emissions in the industry sector in 2010 were 52 MtCO2e/yr or 22% of overall Dutch emissions. Under BAU, emissions are expected to increase to 61 MtCO2e/yr by 2030. This growth is driven by two factors: 1) an output growth of 1.4% in the chemicals sector and 1% in other industrial sectors and 2) a small increase of CHPs (Combined Heat and Power), which increase emissions in industry but reduce emissions in the power sector. When considering the emissions growth, however, it is important to remember that compared to 1990 emissions it is still a reduction of 6% because abatement measures implemented between 1990 and 2010 reduced emissions 12 MtCO2e/yr – more than the expected increase between 2010 and 2030.

The chemical industry has a larger share of emissions in the Netherlands compared to the rest of Europe (32% in NL vs. 11% in EU-27). Around 30% of the emissions in the sector are difficult to abate as they come from chemical conversion processes (e.g., ethylene production) rather than burning fuel. Abating CO2e from these chemical processes would require a large-scale industry shift, which has not been included in the BAU or in the study.

1.4 TRANSPORT SECTOR

The BAU assumes transport sector energy demand will increase slightly from 1030 PJ in 2010 to 1100 PJ in 2030 (6%). The sector's emissions were 74 MtCO2e/yr in 2010, which constituted 31% of overall Dutch emissions. Under BAU, an increase to 80 MtCO2e/yr (23% above 1990 levels) is expected by 2030.

Road and domestic shipping comprise 55% of the energy demand in the transport sector (570 PJ in 2010). The BAU assumes energy demand will increase 12% in this segment to 640 PJ by 2030. Emissions may increase slightly from 42 MtCO2e/yr to 48 MtCO2e/yr, driven mostly by the Medium Duty Vehicle (MDV –small truck and van) and Heavy Duty Vehicle (HDV –large truck) segments. Their combined emissions would increase by 24%, from 19 MtCO2e/yr in 2010 to 24 MtCO2e/yr in 2030 based on the OECD North Europe trend. In a third segment, Light Duty Vehicles (LDV –passenger cars), energy demand and emissions are projected to increase slightly from 22 MtCO2e/yr in 2010 to 23 MtCO2e/yr in 2030. The BAU assumes that the number of light vehicles increases 2.3% until 2030 but that kilometers driven per vehicle remains constant.

The air and maritime segments' combined energy demand (460 PJ) and emissions (32 MtCO2e/yr) appear to remain constant from 2010 to 2030. The energy demand in air transport decreases 15% (161 PJ in 2010 to 137 PJ in 2030), but an equal absolute increase in maritime transport demand compensates for it (299 PJ in 2010 to 324 PJ in 2030). Emissions in 2030 compared to 1990 almost double in air transport (5 to 9 MtCO2e/yr) while maritime transport decreases from 35 MtCO2e/yr to 24 MtCO2e/yr (31% reduction).[9] The BAU also assumes that fuel efficiency does not change in any part of the transport sector (i.e., frozen technologies).

9 Dutch emissions and energy demand from aviation and maritime are taken from the official IPCC calculations for domestic emissions from aviation and maritime. Potential abatement is based on the Dutch share of the total EU abatement potential.

1.5 AGRICULTURE SECTOR

The BAU assumes energy demand in agriculture will decrease from 149 PJ in 2010 to 142 PJ in 2030 (5%). These numbers are based on an extrapolation of the ECN assumptions of a small increase in energy-saving measures in agriculture.

Emissions in the agriculture sector in 2010 are 27 MtCO2e/yr, which contribute 11% to overall Dutch emissions. Under BAU, a reduction of 3 MtCO2e/yr (-10% compared to 1990 levels) is expected by 2030. An increase in energy-saving measures can balance out the growth and intensification of the Dutch greenhouses. Although increased penetration of gas-fired heating with CHPs may raise overall gas demand, CO2e abatement due to electricity feedback from CHPs reduces power sector emissions by reducing power demand.

1.6 POWER SECTOR

BAU in the power sector

The BAU assumes power demand will increase by 10% from 100 TWh in 2010 to 110 TWh in 2030, driven by the buildings (65 TWh), transport (54 TWh) and agriculture (increasingly negative demand due to excess decentralized generation) sectors.

The current power mix in the Netherlands consists of 3.6 GW of coal (18%), 16 GW of gas (67%), 3 GW of RES (13%) and 0.5 GW of nuclear (2%). This produces emissions of 44 MtCO2e/yr, with a CO2e intensity of 0.53 MtCO2e/TWh.

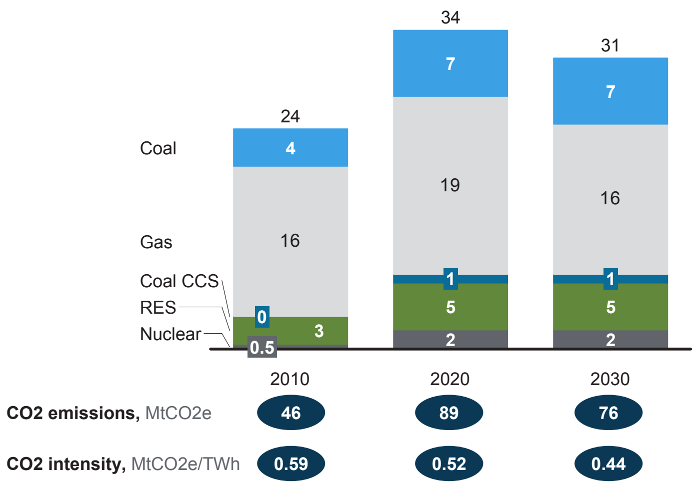
The BAU extrapolates current trends without any abatement ambitions. It assumes the following:

- 0.5 GW of coal and 3 GW of gas plants will retire by 2020 and an additional 3 GW of gas plants will retire between 2020 and 2030 as they reach the end of their economical lifetimes (see Appendix A for details)
- 4.5 GW of coal and 5 GW of gas plants which are currently under construction/planned will be completed by 2020
- Two GW of RES will be developed by 2020 (committed build-out until 2015), which consists of 1.4 GW of wind on-shore and 0.6 of wind off-shore. Since the BAU assumes the most economical technology will be used without additional abatement ambitions, it assumes that no additional RES construction will occur beyond the committed build-outs
- 1.6 GW of nuclear is planned, one reactor of the EPR type that is expected to be operating by 2018
- Between 2020 and 2030, 1 GW of wind on-shore will retire and will be replaced by new wind on-shore
- The Netherlands will become a net exporter by 2013 and will export 30-60 TWh (varies per year) until 2030 (compared to an average import of 16 TWh for the period of 2000-2010)

Exhibit 6

Power generation capacity in Business as Usual

GW



SOURCE: ECN; NREAP

The resulting power mixes in the Netherlands in 2020 and 2030 are given in Exhibit 6. Emissions go up to 89 $MtCO_2e$/yr in 2020 then decrease to 76 $MtCO_2e$/yr in 2030. This absolute emission growth masks an improvement in emission intensity, which falls from 0.59 $MtCO_2e$ / TWh in 2010 to 0.44 $MtCO_2e$ / TWh in 2030.

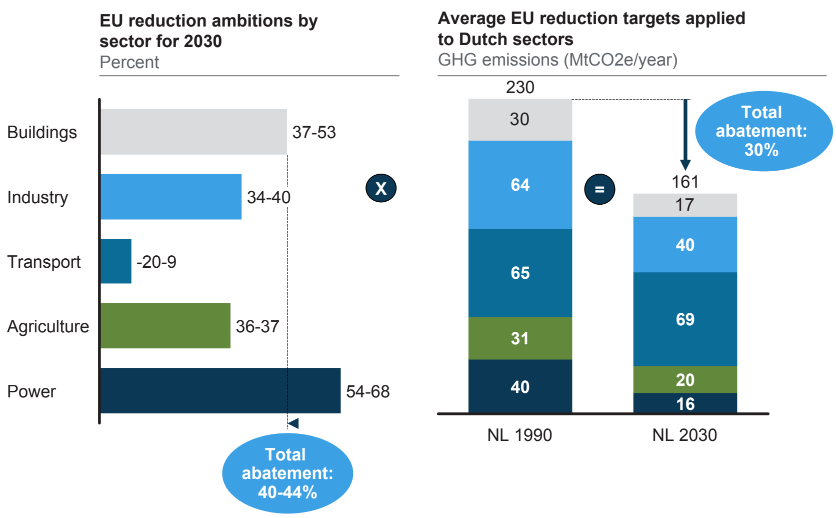
2 Possible abatement pathways

2.1 INTRODUCTION

The EU has formulated sector abatement ambitions for 2030. When applied to the Dutch sectors, these lead to an economy-wide abatement of 30% versus 1990, which is lower than the EU total ambition of 40-44%. See Exhibit 7. The reason why the Netherlands would only reach 30% is that the Dutch industrial, agriculture and power sectors emit relatively more than the EU average.

Exhibit 7

EU reduction ambitions by sector applied to the Netherlands



SOURCE: EU, CBS

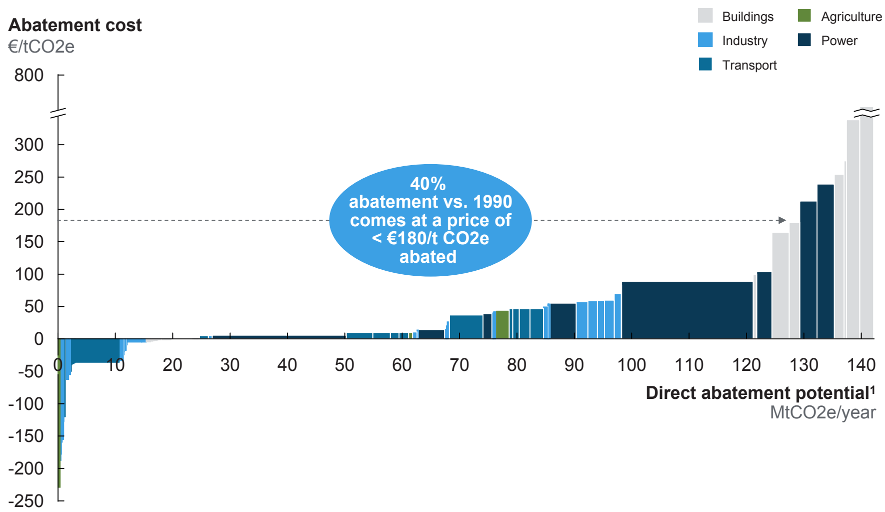
Given this challenge, this study has investigated options for the Netherlands to meet the EU 40% ambition in the most cost-effective way without assuming up-front sector targets.

To establish the lowest possible abatement cost, the study constructed a cross-sector cost curve. See Exhibit 8. This curve ranks potential measures in all sectors by cost. The horizontal axis gives each measure's abatement potential, while the vertical axis shows the cost per ton of CO2e abated. Negative costs mean that these measures are actually saving costs with the assumed commodity prices.

With this cost curve it is possible to determine what measures are necessary to reach a certain level of CO2e abatement or, in other words, how far to the right of the curve one has to go. To reach an economy-wide abatement of 40% in 2030, an additional 130 Mt of CO2e must be abated versus the BAU. According to the graph in Exhibit 8, the measure with highest cost/ton

Exhibit 8

Costs and potential of abatement measures versus BAU



1 EU targets for agriculture include only non-CO2 green house gas abatement
SOURCE: GCC

needed to reach the targeted abatement could have costs of €180/t. The total abatement costs of the non-power sectors combined would be around €800 mn/year on top of the BAU, for the period 2010-2030. Including the avoided costs of CO2 in industry abatement costs would add another €340 mn/year.

The per-sector abatements relative to 1990 derived from the country optimum are given in Exhibit 9 (overleaf) and compared to the EU averages. The individual non-power sectors' abatement options are discussed in more detail in Section 2.2.

A few sector-specific points are worth highlighting:

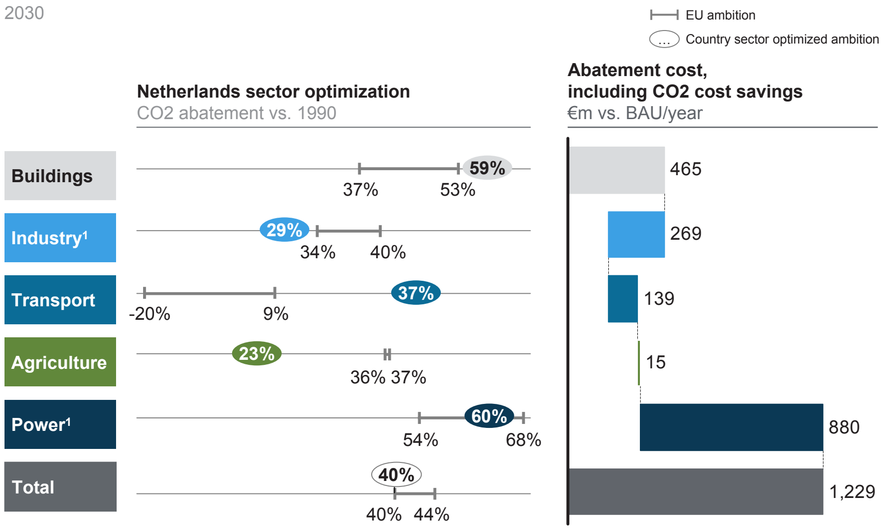
- The buildings and transport sectors would abate more than EU average in relative terms
- The industry and agriculture sectors would abate less than EU average in relative terms
- The power sector would abate at EU average (60%) if a national abatement ambition were assumed. For the power sector[10] an EU-level optimization is also possible; this would use the ETS system. As explained later in Section 2.3, the impact of a country versus an EU-wide approach is significant for the Netherlands, as abatement in the Dutch power sector would be less if EU-wide optimization is applied. Section 2.3 will discuss both options in detail with other sensitivities.

10 The European optimum option is limited to the power sector in this study. The industrial sector is expected to become part of the ETS in the coming 5 years. However, given the uncertainty on how industrial ETS will play out, the lack of historical data and the complexity of modeling a European optimum across countries and industrial sectors has led this study to assume a national target for industrial abatement

Exhibit 9

Country Target optimized sector abatement and costs

2030



1 For industry and power CO2 price of 44 €/tCO2 is assumed (WEO, 2009)

SOURCE: European Commission 'Roadmap for moving to a low carbon economy in 2050, 2011

2.2 NON-POWER SECTOR ABATEMENT IN THE PERIOD 2010-2030

2.2.1 Abatement in the buildings sector

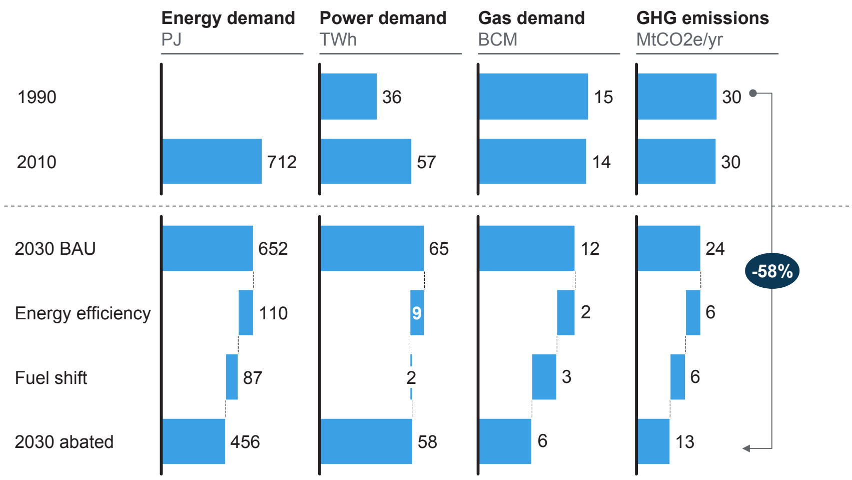
Assuming an economy-wide, cost-optimum abatement ambition of 40% by 2030, the buildings sector would abate 12 MtCO2e/yr (59% of 1990 emissions) through energy efficiency measures (30% abatement, half in autonomous energy improvements in the BAU, half in additional energy efficiencies) and fuel shifts (29% abatement). See Exhibit 10.

The energy efficiency potential abatement measures in the buildings sector and the associated costs are shown in Exhibit 11. Because most measures save rather than cost money, total annual savings could be €8 mn per year in 2030. It is crucial to note, however, that the energy efficiency shift has been difficult to capture in Europe so far.

Fuel shifts can propel further abatement by shifting from heating with a condensed boiler on gas to lower-emitting fuels and technologies. Assessing the abatement potential for fuel shifts relies on economic and “resilience” factors. First, the analysis includes a wide mix of technologies because their cost and development are uncertain. Second, each technology’s costs and potential are calculated as much as possible, creating the cost curve in Exhibit 12 (overleaf). Third, where feasible technologies are split into application segments because

Exhibit 10

Implications of abatement measures in the buildings sector

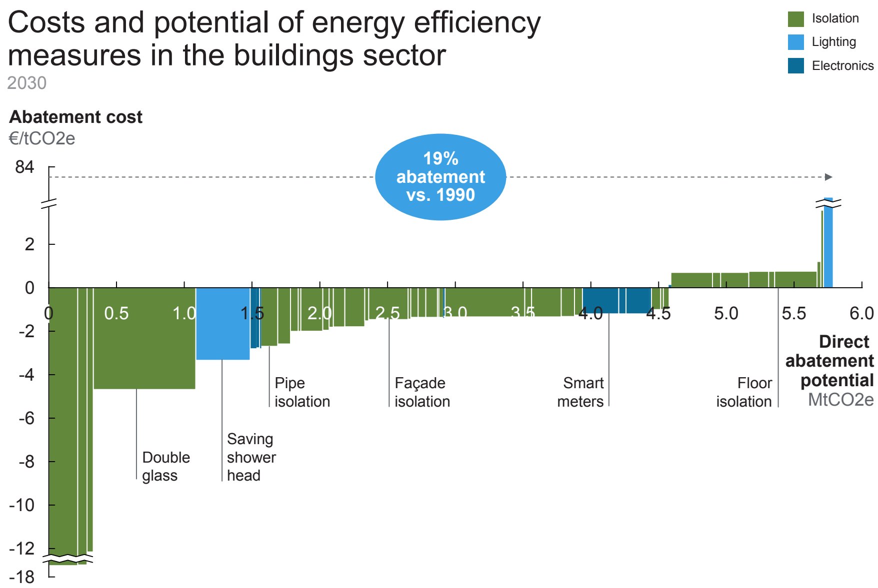


SOURCE: ECN, Energie Nederland

Exhibit 11

Costs and potential of energy efficiency measures in the buildings sector

2030

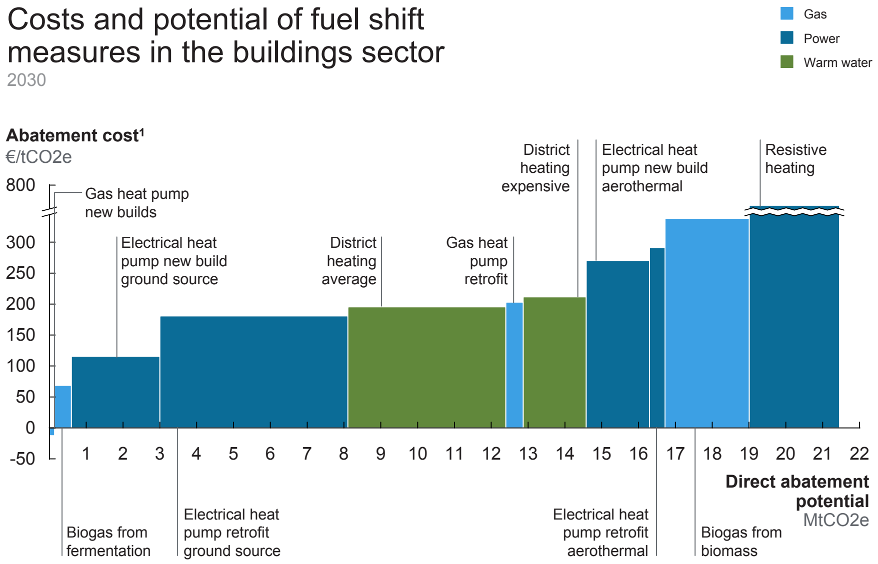


SOURCE: Meer met minder

Exhibit 12

Costs and potential of fuel shift measures in the buildings sector

2030



1 Gas price: €0.67/m^3, Calorific value of gas 31.65 PJ/BCM; Electricity price: €0.23/kWh

their cost can differ greatly from location to location (e.g., the cost of district heating depends greatly on the distance to the heat source; the differential cost of a heat pump in new builds is much lower than in a retrofit). Finally, demand could change (e.g., more need for cooling, different demand patterns due to electrical vehicles), suiting some technologies better than others.

The abatement pathway this study assumes achieves 6 MtCO2e/yr abatement through fuel shifts and maintains a diverse mix of technologies.. It is based on:

- Micro-CHPs (5% penetration). Micro-CHPs have no direct abatement potential because they use the same amount of gas as a condensing boiler (both have a thermal efficiency of 95%). Their electric efficiency is 14%, but only when the device is used for heating, which limits their potential for decentralized electricity generation. Once micro-CHP fuel cells are commercially viable, decentralized electricity generation might become more attractive; their electricity efficiency is likely to be around 45-55% depending on the technology. This study assumed that fuel cells do not become commercially available on a large scale before 2030.
- Ground source heat pumps (21% penetration). Around 2018 (in the EU Target pathway), Dutch power is assumed to reach an emission intensity level that would make a power-based heat pump more CO2e effective than conventional gas-based heating technologies. Installation of heat pumps in combination with heat cold storage could enhance efficiency (and cooling)

and reduce peak capacity. As a result, heat pumps could have a "market share" of 50% of new builds and 25% of non-urban existing buildings with a total penetration of 21% by 2030.

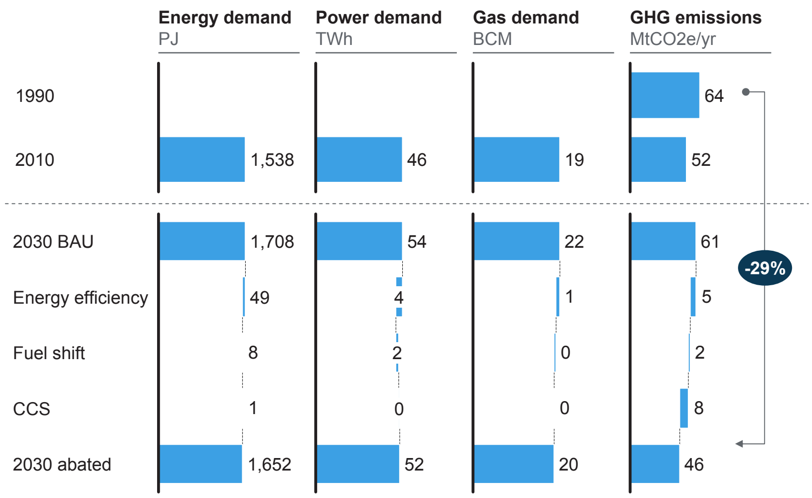
- District heating (7% penetration). Higher penetrations are technically possible, but at costs that are unattractive under the current regulation that district heating cannot cost more than gas heating for end users. Heat production from biomass and deep geothermal heat can function as a sustainable addition to district heating by residual heat.
- Gas heat pumps in commercial buildings (1%)
- Biogas from fermentation (0.5 BCM) (assumes 30% of the total production capacity)
- Condensing boiler using natural gas (67% penetration)
- See Appendix B for further explanations of each technology and the choices made about the fuel shifts.

2.2.2 Abatement in the industry sector

Industry would abate 15 MtCO2e/yr (29% of 1990 emissions) in 2030; this assumes an economy-wide, cost-optimum abatement ambition of 40% in 2030. The abatement measures include energy efficiencies (11%), fuel shifts (4%) and CCS (15 %.) See Exhibit 13 below.

Exhibit 13

Implications of abatement measures in the industry sector



SOURCE: ECN; Energie Nederland; Global Cost Curve (GCC) CO2 abatement model

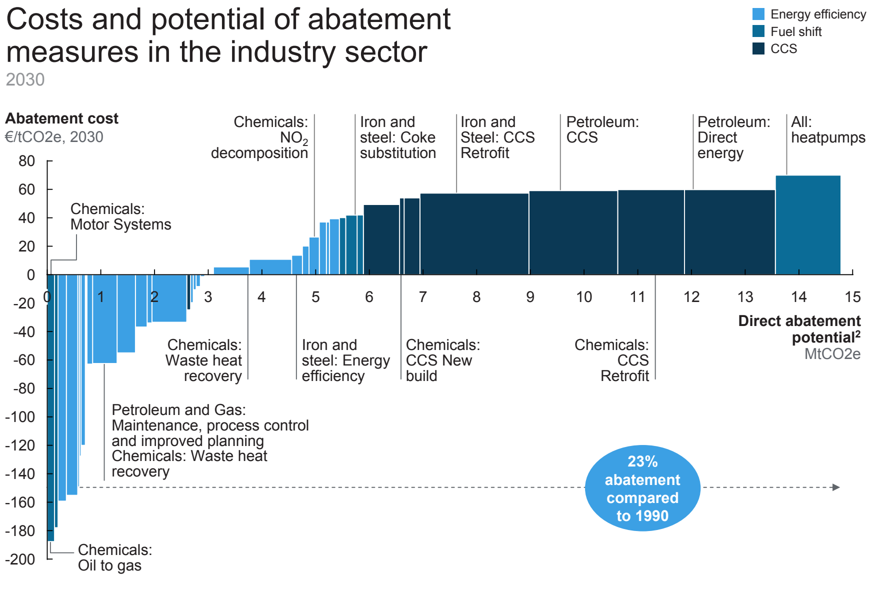
Abatement drivers include (see Exhibit 14):

- Energy Efficiency. Energy Efficiency has a potential of 5 MtCO2e/yr and consists of a wide variety of abatement levers, including: waste heat recovery, improved maintenance and process control, smelt reduction (Iron and Steel sector) and CHPs.
- Fuel shifts. Heat pumps can replace low grade heating at a cost of €60-80/t, with a total potential of 2 MtCO2e/yr
- CCS. CCS has a potential of 8 MtCO2e/yr at a cost of up to €60/t. The potential is limited because only large point emitters are suitable for CCS and additional CCS infrastructure is still needed.
- Large-scale process shifts. It is technically possible to shift to completely new ways of production. For example, a plant could change iron making from a conventional blast furnace to a Cyclone Converter Furnace, a technique currently in the laboratory stage. However, this study excluded these options because they would require large CAPEX investments that could also be made outside Europe.

Exhibit 14

Costs and potential of abatement measures in the industry sector

2030



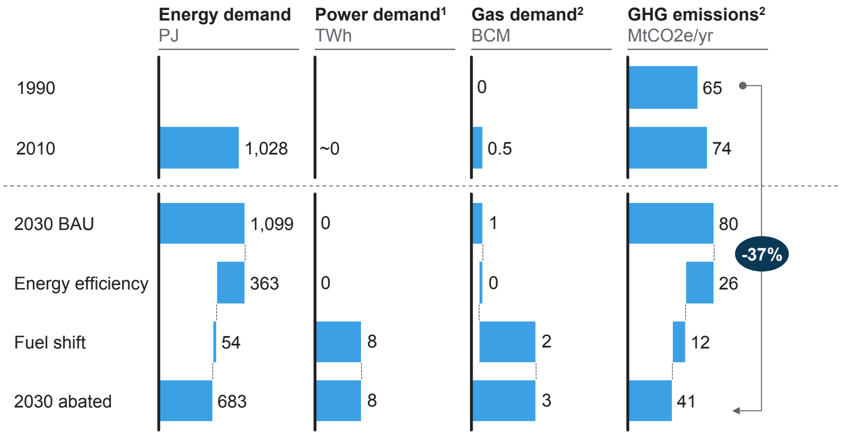
SOURCE: EU, "Energy in figures 2010, CO2 Emissions by sector"; GCC CO2 Abatement model; Expert interviews; Eurostat

2.2.3 Abatement in the transport sector

The transport sector would abate 39 MtCO2e/yr (37% of 1990 emissions) in 2030, assuming an economy-wide abatement ambition of 40% by 2030. Energy efficiency measures (up to 25%) and fuel shifts (up to 12%) contribute to the abatement. Of the 39 MtCO2e/yr, 25 MtCO2e/yr is abated in the road sector, 4 MtCO2e/yr in the air sector and 10 MtCO2e/yr in the marine sector. See Exhibit 15 below.

Exhibit 15

Implications of abatement measures in the transport sector – road, marine and air



1 Fuel shift reduces energy demand because well-to-tank efficiencies are not in scope of transport sector
2 Gas demand and greenhouse gases only include what is directly linked to transport. It excludes gas usage for making hydrogen or emissions to generate power; this is dealt with in the respective sectors

SOURCE: EEA; IEA

Modal shifts (e.g., a shift from using cars to trains) were not included. The most economical fuel shift varies by each type of transport. Generally, electric solutions are most attractive for small cars that do not frequently drive long distances. Hydrogen technology is most attractive for larger LDVs and MDVs.

This study assumed the following, based on several studies that favored the cost-optimal technology without completely locking out technologies that might experience cost breakthroughs (see Exhibit 16 overleaf):

- Energy Efficiency. Energy efficiency has a potential of 26 MtCO2e/yr, of which efficiency improvements in the Internal Combustion Engine (ICE) are the largest lever (7.7 MtCO2e/yr).
- Electric. This technology (plug-in hybrids and electric batteries) could penetrate the light duty vehicle (LDV) fleet by up to 43% in 2030 and 85% in 2050. Plug-in hybrids account for most of the electrification, with 33% in 2030 and 66% in 2050; they are cheaper than electric battery vehicles and enjoy a longer driving range.
- Hydrogen. This technology could penetrate up to 11% of the light duty vehicle fleet (25% in the high penetration scenario) and 40% of the heavy duty vehicle fleet in 2050. Hydrogen has a much longer driving range than pure electric vehicles; as a result, the pathway assumed a higher hydrogen penetration for heavy duty vehicles.

- Biofuels. This energy carrier is attractive for all parts of the transport sector and is expected to help abate emissions. This study assumes constrained supply in Europe, which must overcome uncertainties and barriers in regulation, land use, and transportation. Biofuels are allocated to sectors where alternative abatement options are scarce, e.g., mainly aviation and HDVs. The total abatement potential through biofuels in aviation is 25% (1.7 MtCO2e/yr) in 2030 at a cost of around €10/tCO2.

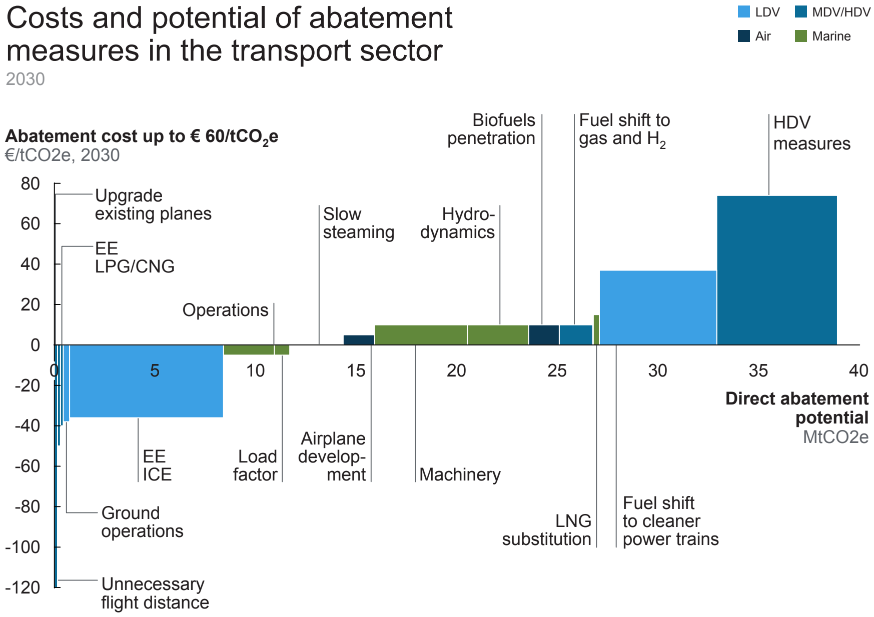
2.2.4 Abatement in the agriculture sector

Agriculture would abate 4 MtCO2e/yr (23% of 1990 emissions) in 2030 assuming an economy-wide, cost-optimum abatement ambition of 40% by

Exhibit 16

Costs and potential of abatement measures in the transport sector

2030



2030. The 2030 BAU's abatement is 10% compared to 1990 levels as shown in the previous chapter. The agricultural sector could abate an additional 4 MtCO2e/yr (13% of 1990 levels) through implementation of heat pumps in 4500 hectares of greenhouses and of (semi)-closed greenhouses in 2,270 hectares of greenhouses at a cost of up to €50/t CO2e abated.

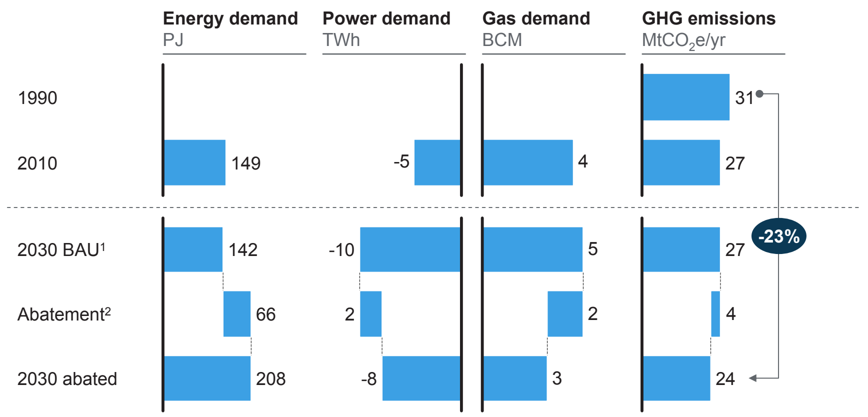
The Dutch abatement potential of 23% for the agriculture sector is still less than the published EU abatement ambition of 36-37% by 2030 compared to 1990. The main reason for this is the Netherlands' relatively large number of greenhouses as compared to other European countries and the energy-efficiency of these, many of whom (60%) already used CHPs in 2010. Further penetration of CHPs can reduce power sector emissions (as they lower power demand). The remaining solutions in agriculture – (semi)-closed greenhouses, heat pumps and livestock management – do not reach the European ambition of 36-37% abatement. See Exhibit 18 overleaf.

2.3 POWER SECTOR ABATEMENT IN THE PERIOD 2010-2030

The power sector plays a crucial role in overall abatement; it reduces emissions in the power sector and it provides "clean power" to facilitate shifts from other fuels to electricity. Because of the sector's importance, this section covers three areas. First, it describes the available abatement levers for the sector. Second, it discusses the EU Target pathway where the EU power sector reaches 60% abatement in the most cost-optimal manner. Third, it demonstrates three sensitivities: one where 60% abatement is achieved at a country level without export; one where 60% abatement is achieved at a country level with export; and one where a CO2 focus is assumed with no targets other than the 60% EU target.

Exhibit 17

Implications of abatement measures in the agriculture sector

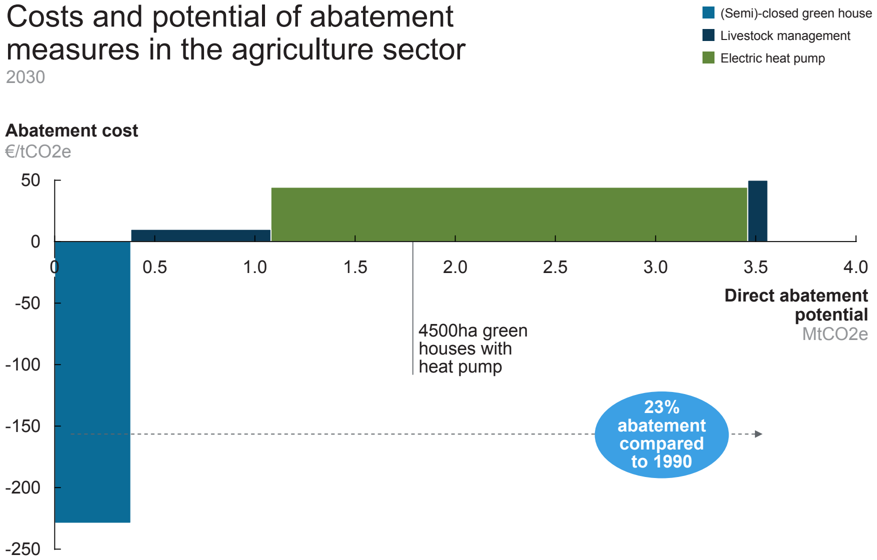


1 Under sensitivity without policy
2 Extrapolation of 2015-2020 trend, assumes only half the abatement per decade from 2020-2050 as compared to 2010-2020
SOURCE: ECN

Exhibit 18

Costs and potential of abatement measures in the agriculture sector

2030



SOURCE: ECN 2010, "Reference projection energy and emissions 2010-2020"; Platform kas als energiebron 2010, "Jaarplan 2011"; Wagening UR 2010, "Energiebenutting WKK in Nederlandse glastuinbouw"; CBS, "Tuinbouw onder glas"

2.3.1 Potential abatement levers in the power sector

The Dutch power sector could potentially decrease the total amount of CO2e emitted from its current fleet with the following abatement levers:

- Increase the number of CO2e neutral plants by installing CCS on CO2e emitting coal and gas plants. Coal plants could also increase biomass co-firing or convert to biomass dedicated plants
- Replace CO2e emitting plants with CO2e neutral ways of power generation. Options include: replace coal or gas plants with nuclear or RES capacity, increase gas-fired production and decrease coal-fired production
- Stop producing for export, thus lowering total production

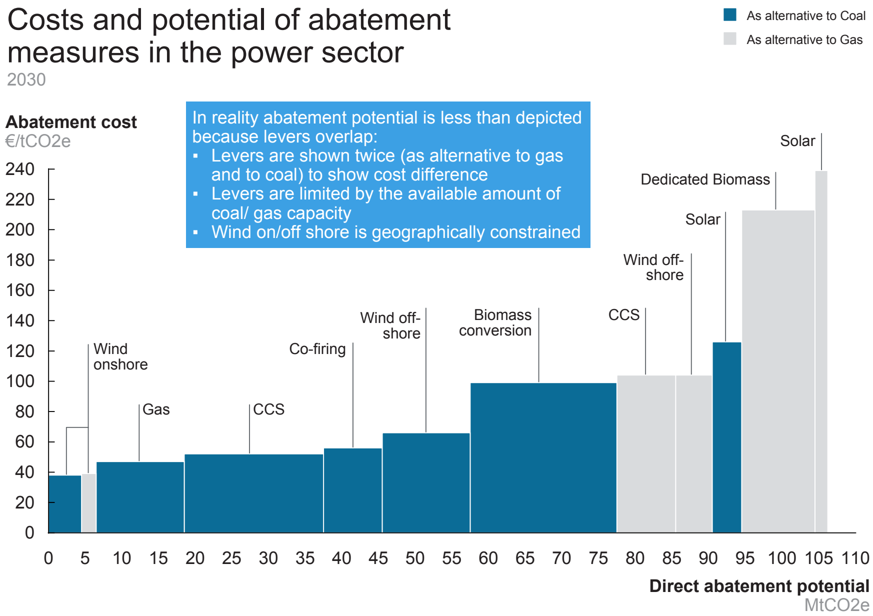
The abatement cost curve compares abatement costs of different levers to the costs of "non-abatement" technologies that would be built in Business as Usual. The abatement costs of the options are technology and plant specific. See Exhibit 19 for the cost curve See Chapter 3 (Exhibit 29) for a discussion on production costs for new builds (in €/MWh) of each technology.

The vertical axis in Exhibit 19 shows abatement costs per lever. These are the costs of applying a lever as alternative to a coal or gas plant (the BAU technology). The x-axis shows the abatement potential per lever. The depicted cost curve deviates from other cost curves in the report in the sense that it has substantial overlap. In reality and in the modeling, each lever's potential is constrained by a combination of four factors: how much capacity already exists (e.g. switching coal to biomass); geographic limitations that cap potential (e.g. wind on/off-shore); political and societal choices (e.g., new nuclear capacity); and/or relative cost attractiveness. More detail follows on each of these constraints:

- Replace fossil power production. The assumption that none of the new coal plants (4.5 GW) built after 2010 will be shut off significantly constrains the potential for switching away from coal. The assumed potential for switching from gas does not have a technical maximum, although costs can make this unattractive in some cases.

Exhibit 19

Costs and potential of abatement measures in the power sector
2030



- Switch to CO2e neutral technologies
  - Wind on-shore. The potential to switch to wind on-shore is limited by its maximum assumed 5 GW capacity.
  - Wind off-shore. The potential to switch to wind off-shore is limited by its maximum assumed 15 GW capacity by 2030.
  - Solar PV. While possible, this option has not been studied in detail as the costs currently make it very unattractive
  - Dedicated biomass. Retrofits for existing coal plants are limited by the capacity of coal plants built after 2010 (4.5 GW).
  - CCS. This study assumes a maximum of 1 large coal plant to be fully CCS equipped by 2030. A sensitivity to apply more CCS is included in Appendix A.

- **Change load factors of existing plants.** From a CO2e perspective, this aspect could only increase gas production at the expense of unabated coal production. The maximum potential is 34 TWh, which is driven by the difference between gas plants' current load factors and their assumed maximum of 60% (which allows gas plants to balance the system)
- **Reduce export production.** The Netherlands' installed capacity is more than it needs to meet Dutch power demand. It could potentially close production capacity and cut off exports. The cost of such a closure before the technical end-of-lifetime of an asset could be forfeited margins, estimated to be around €5/MWh for coal and gas.

2.3.2 EU Target pathway for power sector abatement

The EU Target pathway assumes the following:

Implement the National Renewable Energy Action Plans (NREAPs) in full and on time across the EU, including the Netherlands. The NREAPs are the plans each member state has developed to reach the "20-20-20" targets agreed by the EU. Currently, most countries are not on track with this implementation, as shown in Exhibit 20 for wind. However, given these are mutually agreed upon official targets, this study assumes that the goals will be reached.

The Netherlands' current plans do not yet amount to the full NREAP. As Exhibit 21 shows, the 2015 ambition is unlikely to be achieved unless the current trend changes. Publicly available data also reveals that the more than four-fold increase in off-shore capacity between 2015 and 2020 lacks concrete plans. Wind on-shore has less plan transparency, but it is unclear whether the doubling by 2015 or the tripling by 2020 is on track.

Realize an EU-wide power sector abatement ambition in a cost-optimum way. The EU will realize its 60% power sector abatement ambition on an EU level in 2030 versus 1990 by implementing the lowest-cost measures irrespective of their member states. Whoever takes an abatement measure will receive the incentive of the ETS carbon price. For this study, this means the Dutch power sector has no fixed abatement ambition. To develop the Dutch abatement numbers, the study first modeled the cost-optimum 60% abatement of the entire EU power sector. It then calculated the Netherlands' share of this overall EU optimum power sector solution.

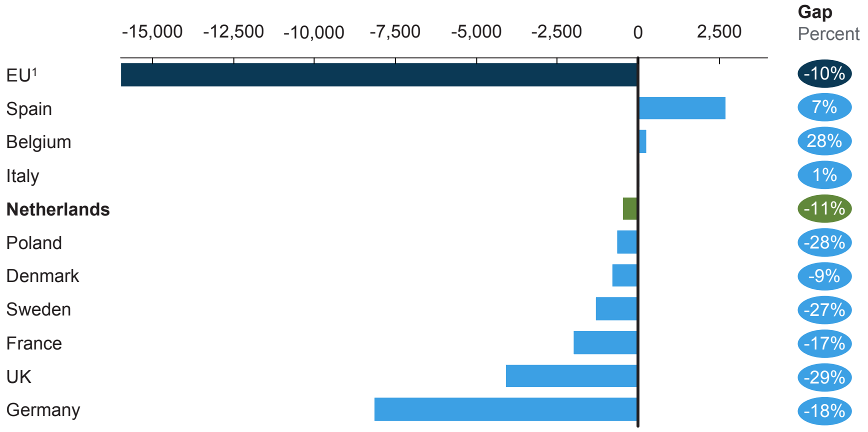
Completion of all coal and gas plants under construction. Currently 4.5 GW of coal and 5.3 GW of gas are being built in the Netherlands. This study assumes that one of the new coal plants will be fully fitted with Carbon Capture and Storage (CCS) by 2025.

IEA prices for oil, coal, gas and CO2. The IEA WEO 2009 was used for all commodities, except for gas. For gas, the IEA Golden Age of Gas price (2011) was used. See Appendix A for details.

Exhibit 20

Difference between NREAPs' targets for wind generation and actual performance in 2010

Generated power, GWh



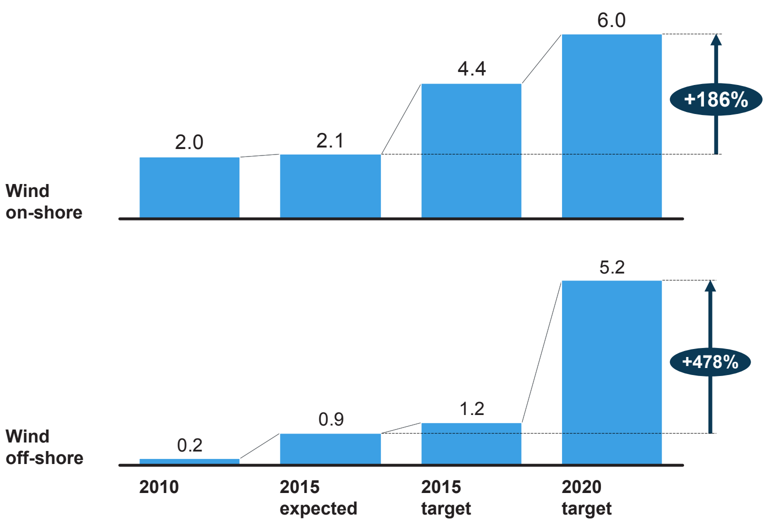
1 Only most relevant EU countries are shown
Note: 2010 was a year with relatively limited wind. In 75% of the years, there is more wind. Normalizing results for average wind speeds over last 50 years would increase generated power by ~5% (based on NL data)

SOURCE: ECN; KNMI; IEA

Exhibit 21

Actual and targeted wind capacity in the Netherlands

GW



SOURCE: Expert interviews; Global Data; NREAP; NWEA

With these assumptions and inputs from the EU Target pathway, the Dutch Power sector would evolve as follows from 2010 to 2030:

- RES build-out of 10 GW in line with the NREAPs
- Biomass co-fired production will increase to 10 TWh in 2020 (average of 20-25% co-firing)
- 1 coal CCS plant operating by 2016 with carbon storage from 2025
- No additional build of non-renewable plants beyond the coal and gas plants already announced and the one additional nuclear plant
- Closure of all coal plants older than 30 years (3.6 GW), which is the most cost effective way to abate CO2
- Closure of 1 GW of gas plants, which is partly replaced by production from new RES assets

The BAU calculated a domestic demand of 110 TWh in 2030. After adding the increase in power demand from fuel shifts after abating the other sectors, domestic demand would be 125 TWh. The total 2030 production in the EU Target pathway would be 160 TWh, which would allow an export of 35 TWh in 2030. This almost doubles production versus 2010 production of 82 TWh. Power sector emissions would be 50 MtCO2e, equivalent to an increase of 25% versus the 1990 base of 40 MtCO2e. See Exhibit 22.

Total power system costs additional to the BAU would be around €3 bn for the period 2010-2030, including the avoided CO2 costs (€13 bn excluding the CO2 costs).[11] This is 2% of the BAU costs of €110 bn for that period. CAPEX would increase 70% versus BAU, equivalent to a rise of €14 bn. All these costs are based on consumption; in other words, export costs are excluded.

2.3.3 Power sector sensitivities

This section describes sensitivities and their potential impact compared to the EU Target pathway described above:

The **Country target sensitivity** assumes that the Netherlands must meet the 60% abatement ambition within the country, without the option to buy (or sell) additional credits through ETS. The 60% comes from the country optimization explained in section 2.1. The 60% starting point makes it unattractive to produce emissions for export-power; not only that, these emissions count towards the Dutch ambition. As a result, this pathway assumes no export, effectively lowering production by 35 TWh to 125 TWh in 2030. However, reducing the volume to match domestic demand is insufficient to meet the 2030 ambition, which means that the carbon intensity of production must be improved as well.

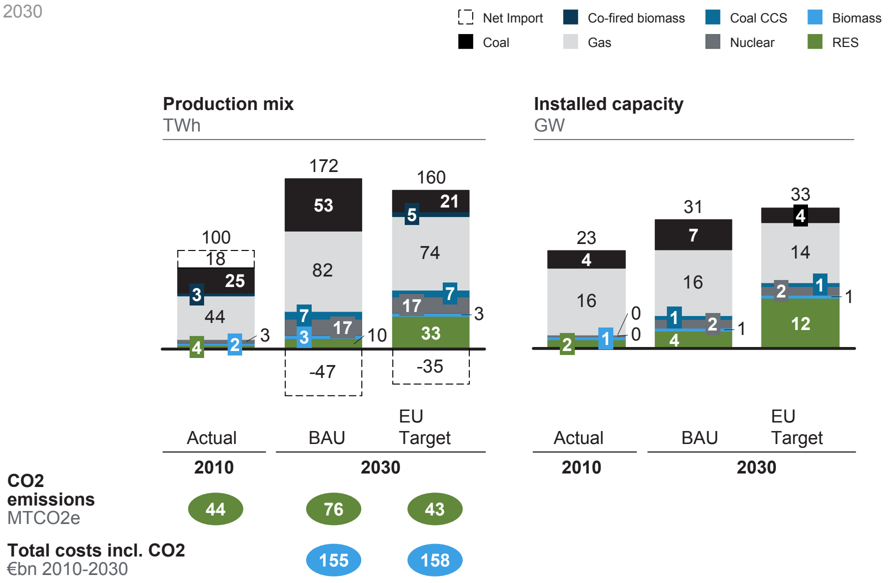
If CCS and closing plants that are built after 2010 are not options, then the Netherlands will need to convert the 3.5 GW of coal capacity built after 2010 to dedicated biomass plants. It will also need to close around 28 TWh (4.5 GW)

11 CO2 price assumed is > €44/tCO2 in 2030 (from €15/tCO2 in 2010), taken from the IEA, World Energy Outlook, 2009.

Exhibit 22

Power mix – EU Target pathway compared to BAU

2030



of gas capacity to compensate for lower demand. Finally, it will need to build 1 GW of renewables on top of the NREAP requirements. Costs in addition to the pathway would be around €410 mn/year for the power sector, which is €55 p.a. per household. Total costs for 2010-2030 would amount to an additional €8 bn compared to the pathway (€7 bn additional CAPEX). Excluding the avoided costs of CO2 total additional costs for 2010-2030 would be €17 bn.

The **Country target with export sensitivity** is based on the assumption that the existing capacity (including NREAP) will be used and not mothballed prematurely. It also maintains the 60% abatement ambition in the Netherlands. In addition to the changes in the Country target sensitivity, 35 TWh of wind (11 GW) supplies more clean power. Costs, including cost savings for CO2, would be around €900 mn/year compared to the pathway or 120 p.a. per household. Total costs for 2010-2030 would add to an additional €21 bn on top of BAU (€36 bn additional CAPEX costs). If the avoided costs of CO2 were excluded, the total additional costs for 2010-2030 would be €34 bn.

Instead of the wind build-out, it is also possible to continue export from gas-fired plants by applying CCS on 8 GW of gas-fired capacity. Costs including CO2 would be around €350 mn/year compared to the pathway or €50 p.a per household. Total costs for 2010-2030 would be an additional €10 bn on top of BAU (€26 bn CAPEX). If the avoided cost of CO2 were excluded, the total additional cost for 2010-2030 would be €24 bn.

The **Single target sensitivity** explores the impact of focusing on the single target of 60% emission reduction for the power sector in 2030, without assuming any intermediate or derived targets (e.g., a technology penetration target). It optimizes emissions on the European level. This approach leads to the following mix in the Dutch power sector: 15% RES (6 GW of RES including 1 GW of dedicated biomass), 19% coal (4 GW), 53% gas (14 GW), and 12% nuclear (2 GW). Costs would be up to €3 bn less than the pathway, although some to all of this amount could be needed to motivate other countries to increase their RES build-out and compensate for the lower capacity in the Netherlands. Alternatively, the Netherlands could invest this money into further developing other abatement options (e.g., hydrogen-based) to maintain its contribution to the overall EU abatement effort. Excluding CO2 costs, this would be up to €8 bn.

The production mix, costs and emissions of the power sector sensitivities are in Exhibit 23.

2.3.4 Summary of Economic implications

- The BAU power sector costs for the period 2010-2030 are around €155 bn cumulative (€111 bn excluding CO2 costs). The cumulative CAPEX for this period is €20 bn.
- The EU Target pathway has costs of around €3 bn additional to the BAU (€13 bn excluding CO2 costs). Its cumulative CAPEX is €14 bn higher. The further costs per household are €25 per year.
- The power sector sensitivities' costs are expressed as the difference with the EU Target pathway. The Country target sensitivity and the Country target with export sensitivity have total expected costs of around €8 bn respectively with €18 bn on top of the EU Target pathway (€17 bn respective to €21 bn excluding CO2 costs). The additional costs per household are €55 respective to €115 per year. The Single target sensitivity would have costs of €0-3 bn less compared to the pathway, translating to potential household savings of € 0 to 20 per year.

See Exhibit 24.

Exhibit 23

Power mix for sensitivities

2030

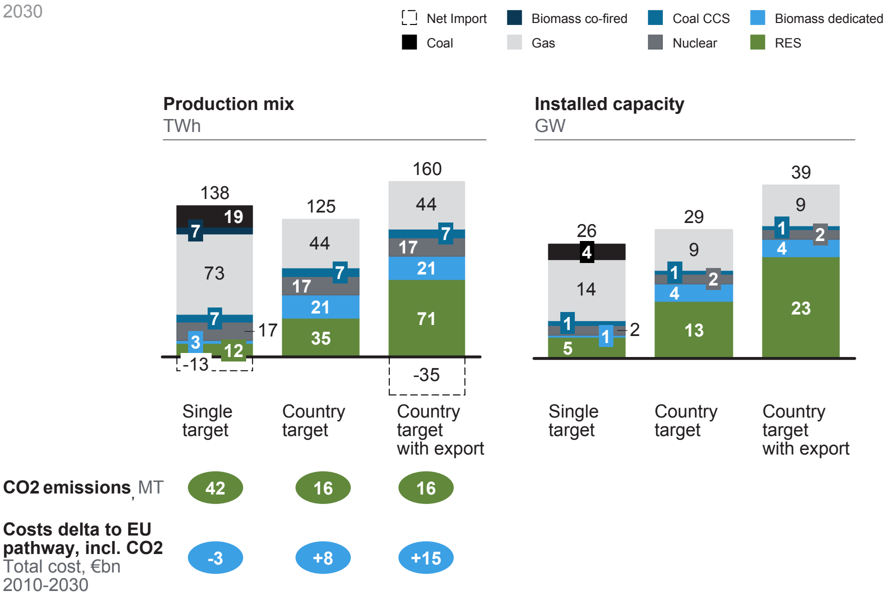
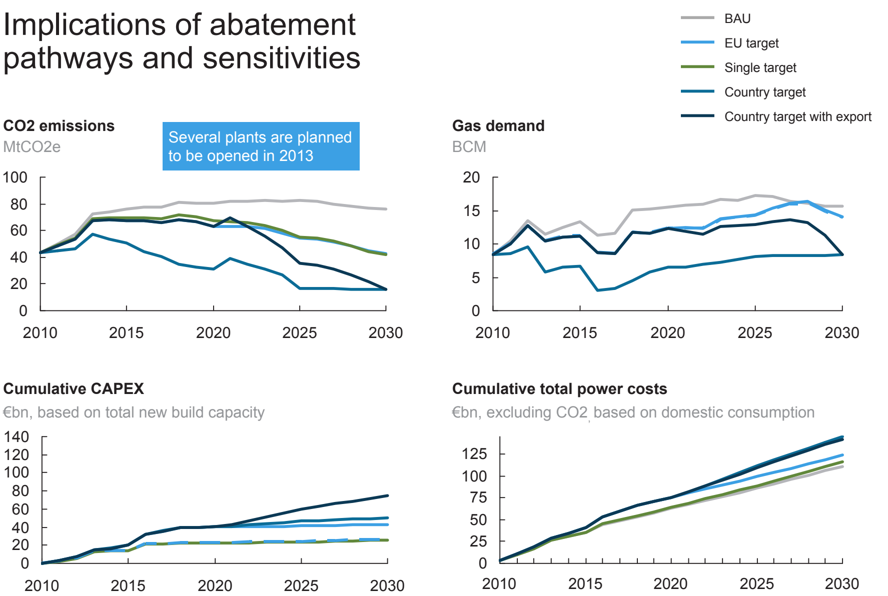


Exhibit 24

Implications of abatement pathways and sensitivities



SOURCE: IEA; Platts; ECF Roadmap 2050

2.4 ABATEMENT IN THE PERIOD 2030-2050

All statements and calculations for the period 2030-2050 must be treated carefully and be viewed as directional and indicative. This is because visibility into technical and cost developments over such long timeframes is very limited. Given these constraints, this study focused on determining whether any pathway choice for the period 2010 – 2030 excluded any particular 2030 – 2050 option, rather than on identifying the best option for the 2030-2050 timeframe.

2.4.1 Non-power sector abatement for the period 2030-2050

The buildings sector will continue to rely on a mix of increased energy efficiencies and further fuel shifts to reach the 2050 abatement ambition of 95% versus 1990 (assuming the 2030 abatement of 60%). The energy efficiency (EE) improvement in this period is assumed to come exclusively from the improved building codes of new builds (assumed EPC code of 0.4); it would produce an additional 10% abatement versus 1990. More fuel shifts would provide the remaining 25% as electrical heat pumps penetrate the market further (e.g., 75% of new builds, growth of biogas to 2.8 BCM, and 21% of district heating). When combined, these levers could generate the required 9 MtCO2e/yr required to reach 95% abatement in 2050 versus 1990. It is important to note that alternative developments – the introduction of hydrogen-burning micro-CHPs, decentralized power generation or combined heat and cold storage – may become more attractive or realistic in the meantime.

The industry sector abatement potential in the period 2030-2050 is assumed to equal the energy efficiencies and fuel shift during 2010-2030 in absolute size. More CCS will also be needed. On top of the 8 MT CCS abatement between 2010 and 2030, an additional 20 Mt of CCS would be required for 2030 - 2050. The total CCS amount of 28 Mt in 2050 is roughly equal to the total 2010 industrial emissions in the Rotterdam area and is about half of the total 2050 industrial emissions. Storage potential in the Netherlands is sufficient (around 2.2 GtCO2) and abatement costs will depend on the progress of further commercialization. Currently, full costs (including capture, transport and storage) will range from 60- 200 €/tCO2 depending on the CO2 intensity of the industry point emitter and the storage location. Using hydrogen as a fuel in industry could potentially bring down costs further, especially if CO2 storage could be done relatively easily at the point where hydrogen would be produced from natural gas.

Combining these industrial abatement levers would result in a 60% abatement in 2050 versus 1990 (up from a 30% abatement in 2030).

The transport sector abatement could reach 95% in 2050 compared to 1990. Efficiency improvements may enable a 31 MtCO2e/yr abatement of emissions compared to 2050 BAU and fuel shifts could account for an additional 46 MtCO2e/yr abatement. Road transport would need to shift more to electric vehicles and hydrogen in the LDV segment and move toward compressed natural gas (CNG), hydrogen and biofuels in the HDV segment. Maritime transport could further increase abatement through continued improvements in energy efficiency measures and possibly by shifting to cleaner burning fuels. Raising the penetration of biofuel in aviation accounts for the rest of the abatement improvements in 2050 compared to 2030.

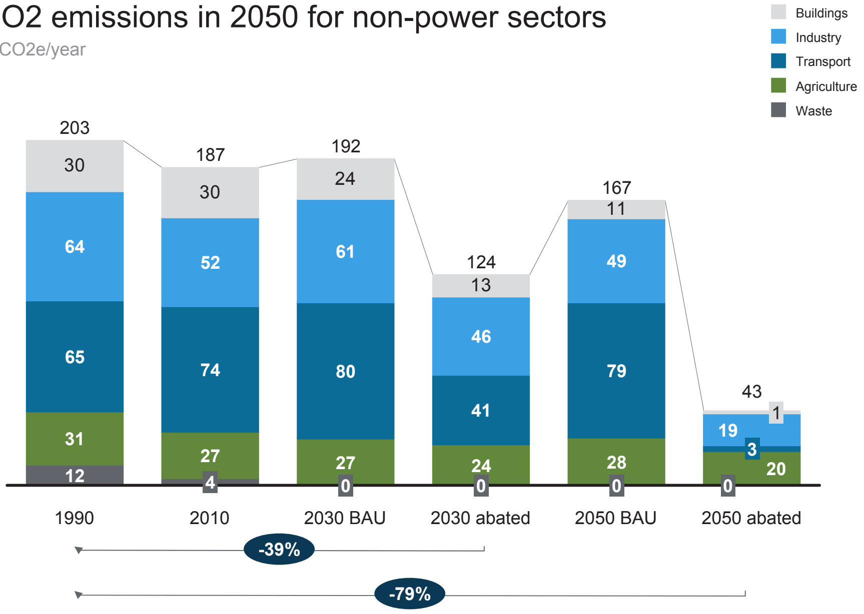
The **agriculture** sector could abate 8 MtCO2e/yr (34% of 1990 emissions) in 2050. The abatement potential from energy-saving measures in greenhouses (e.g., heat pumps and (semi)-closed green houses) and livestock management is assumed to double in 2030-2050 compared to 2010-2030.

See Exhibit 25 below for an overview of CO2e reductions in the non-power sector.

Exhibit 25

CO2 emissions in 2050 for non-power sectors

MtCO2e/year



2.4.2 Power sector abatement for the period 2030-2050

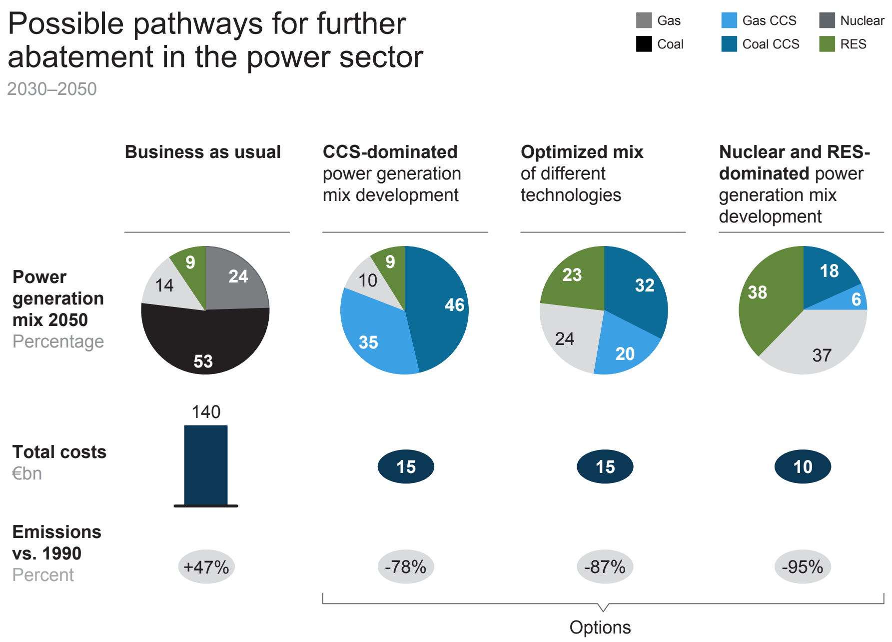
The power sector has, in addition to energy efficiency, roughly three technologies that it could use to achieve more abatement: Renewable energy sources (RES), CCS, and nuclear. While it is of limited use to predict what mix of these will ultimately prevail, it is critical to understand if any 2010-2030 abatement pathway locks-out any of these options. To investigate this possibility, this study developed three scenarios that lead to 95% abatement. The results revealed that all options are still open at roughly equal costs of 10% additional to the BAU.

- **CCS-dominated mix** assumes a 50:50 gas and coal CCS build-out, both to replace older conventional fossil plants and to satisfy demand growth. Nuclear and renewable capacities remain. This scenario leads to 78% abatement compared to 1990 levels; gas demand is 11 BCM. Total system costs are €155 bn of which €25 bn is CAPEX.
- **Nuclear and RES-dominated mix** assumes a 50:50 nuclear and wind build-out to replace conventional fuels after retirement and satisfy new demand. CCS retrofit is applied to plants that will be built between 2010 and 2030. This scenario leads to 95% abatement compared to 1990 levels and gas demand drops to 2 BCM. Total system costs are €150 bn of which €40 bn is CAPEX.
- **Optimized mix** of different technologies assumes a 50:50 mix between the Nuclear and RES-dominated mix and the CCS-dominated mix. This scenario leads to 87% abatement compared to 1990 levels and gas demand will be 6 BCM. Total system costs are €155 bn of which €30 bn is CAPEX.
- Each of these scenarios can be attained from any start point in 2030. See Exhibit 26.

Exhibit 26

Possible pathways for further abatement in the power sector

2030–2050



3 Implications

This study showed that the Netherlands could meet the 2030 and 2050 abatement ambitions despite its projected emissions growth in the coming years. Abatement could be achieved most cost-effectively in a European context, where each country implements those levers that are the most attractive for it. This chapter discusses the primary implications of the pathways covered earlier, including:

- The Netherlands could take the lead in Europe in several abatement areas (section 3.1)
- Gas will still play a role as an energy carrier (section 3.2) and
- The need for a stable policy scheme given the long asset life of many technologies and the need to foster a wide range of available technologies (section 3.3)

3.1 Potential areas where the Netherlands could lead abatement within the EU

Several areas exist where the Netherlands could take the lead in a European context:

- Carbon Capture and Storage (CCS). The Netherlands' depleted gas fields offer potential on-shore and off-shore storage spaces that are easily available. A number of areas with concentrations of several large-emitting installations also make capture and transport relatively attractive (e.g., Rotterdam, Amsterdam, and Eemshaven). Total potential is 2.2 Gt; the CCS pathway described in Chapter 2 assumes 50 Mt/yr from 2025-2030.
- Biomass and modern coal plants. Both biomass and coal will need to be shipped in large quantities to Europe, mainly overseas. Netherlands' deep-sea harbors, modern coal plants and space to build additional near-shore power plants (e.g., Rotterdam-Maasvlakte, Eemshaven) gives it an advantaged position in these technologies. The "Country Target" pathway described in Chapter 2 assumes 7-12 Mt of biomass per year, equivalent to 5-10 times the 2010 total of EU imports, or 50% more than the current weight of Dutch coal imports.
- Wind off-shore. The wind conditions, accessibility and shallow depth of the potential Dutch off-shore locations are relatively attractive in a European context. As a result, the Netherlands could become one of the leaders in wind off-shore deployment in Europe. The Chapter 2 pathway assumes 6 GW out of the total potential of 15 GW.
- Gas residential solutions. The high penetration of the residential gas network in the Netherlands gives it a head start with innovative gas residential solutions like micro-CHP's Fuel Cells that convert natural gas into heat and power (e.g. the SOFC or the PEM[12] with reformer).
- Hydrogen in Industry. Clean hydrogen could reduce industry emissions at a similar cost and with less hassle than post-combustion retrofit CCS. Dutch industry's concentrated layout underlines this point; hydrogen could be produced centrally (with central CCS capture), then transported to the

12 SOFC=Solid Oxide Fuel Cell, PEM=Proton Exchange Mebrane fuel cell.

furnaces. CCS would have to retrofit each furnace locally. Running 20% of the industrial furnaces on hydrogen could abate an additional 1 MtCO2e/yr in 2050. The current pathway has not assumed this option.

- Hydrogen and Electric vehicles. The Netherlands' high population density could make the conversion to a hydrogen infrastructure relatively less costly than in countries where people are more dispersed. On the supply side, the availability of natural gas and CCS makes hydrogen production relatively attractive. Electric vehicles could also be attractive due to the relatively short distances driven in the Netherlands. The current pathway assumes a 20% penetration of hydrogen for medium and heavy duty vehicles and a 15% electric vehicle penetration of light vehicles.

Nurturing a diverse technology mix will be essential to reach the targeted abatement. This is true for not only the technologies above, but also for other potential technologies that may further mature, e.g. biochemicals or innovative agricultural techniques. It enables the continued commercialization of technologies and the subsequent cost improvements. It will also help create a fleet of technologies, both in the power and in the non-power sectors, which will eventually become a more resilient energy system. Such a system can help companies deal with commodity markets and environmental regulations that are continuously in flux.

3.2 Role of gas

Gas is and will remain an indispensible energy carrier for realizing the intended abatement. It contributes in multiple sectors, ranging from housing to transport. It is used in about 70% of residential buildings, is crucial in the industrial sector as feedstock and for high-grade heat, and contributes to abatement in transport by directly fueling MDV and HDV and indirectly causing fuel shifts to hydrogen.

In the power sector, it will produce between 35% and 50% of the power, depending on the pathway. Power generation with gas instead of coal halves emissions per unit of energy generated - the CO2e intensity of gas in the Netherlands is 0.35-0.45 tCO2/MWh, while the CO2e intensity of coal is 0.77-1.0 tCO2/MWh. Gas-fired power can help meet the ambitious CO2e reductions when combined with the Netherlands' unique CCS position. Gas for power generation also has more upside potential for a cleaner power sector:

- Flexibility. Gas could be crucial in the journey toward a sustainable country CO2e abatement in the future:
  - Gas could accommodate high energy intensities during peak demand, while the present electricity infrastructure in the Netherlands would require significant infrastructure investments as a result of a large-scale energy transition
  - Gas could act as back-up for intermittent power generation, such as wind energy and solar PV

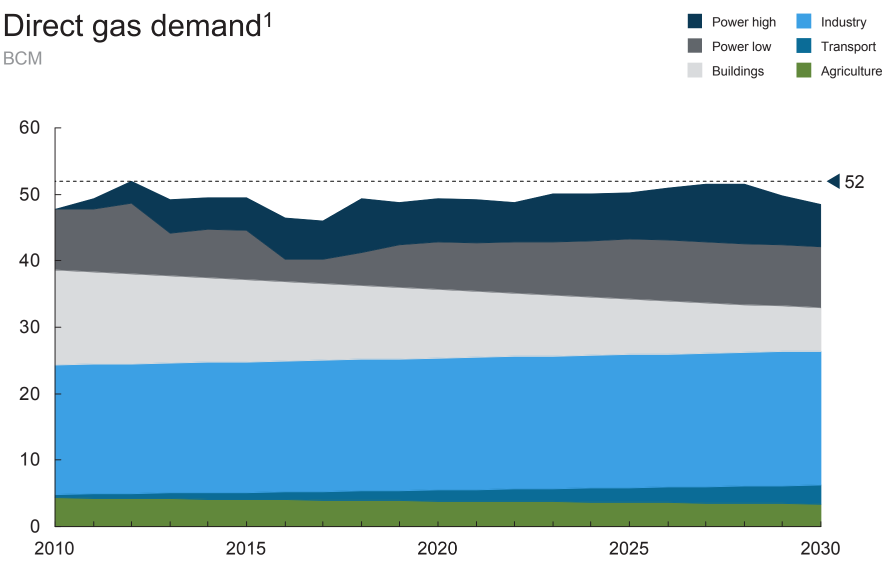
- **Security of supply.** The available gas supply and the reliability of the gas network puts the Netherlands in an excellent position to use gas for power, to export gas for power abroad or to overcome implementation issues
  - The proven gas reserves of both the Netherlands and Europe and an increasing number of suppliers decrease risks of supply defaults from any source
  - The Netherlands has sufficient gas infrastructure in place ("Gasrotonde") to support the increased transmission capacity needed to fulfill higher gas demand in Europe
  - The maturity of the gas network is a clear advantage over less mature technologies

In terms of overall volumes in the abatement pathways, gas demand will grow from 48 to 52 BCM from 2010-2012, then slowly decline to 46 in 2017, grow back to 52 in 2028 and slightly decline to 49 in 2030. See Exhibit 27 below.

Exhibit 27

Direct gas demand[1]

BCM



1 Gas demand is calculated at a calorific value of 35.71 Mj/m³

SOURCE: ECN; Energie Nederland; Team analysis

3.3 Implementation

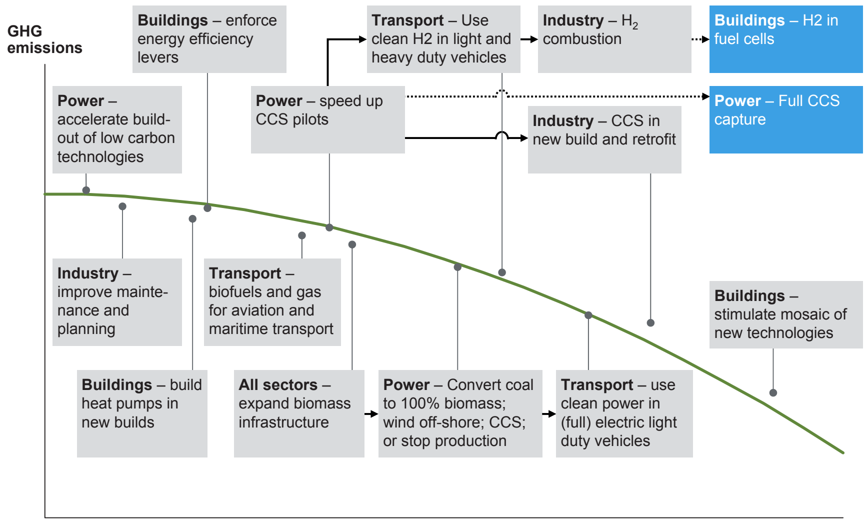
In order to reach the abatement ambition in 2030, the Netherlands will need to ambitiously implement all the available abatement options (e.g. energy efficiency, fuel shift) and technologies (e.g. CCS, wind, biomass, nuclear, district heating). A stable, long-term policy outlook will be indispensible as well.

Navigating key inflection points in each sector will be crucial in the coming 20 years. These allow for implementation of all available technological options and ensure that any scenario is still feasible beyond 2030. Key inflection points include: enforcing energy efficiency in the buildings sector, accelerating build-out of low carbon technologies in the power sector and speeding up CCS pilots to have CCS available for the industry sector before 2030 and the power sector beyond 2030. Exhibit 28 shows a few examples of inflection points that the Netherlands would need to achieve to be on track for the 2030 abatement target. The order and precise timing of these measures are approximate.

Exhibit 28

Cross-sector examples of inflection points to reach the Dutch abatement target

Open trajectory towards 2050



The perspective of power companies

This study takes the societal perspective, which means that it optimizes for the lowest costs to society. Power companies take a different perspective: they look at their potential revenue and profits when considering what technologies to build and how to run them with existing assets.

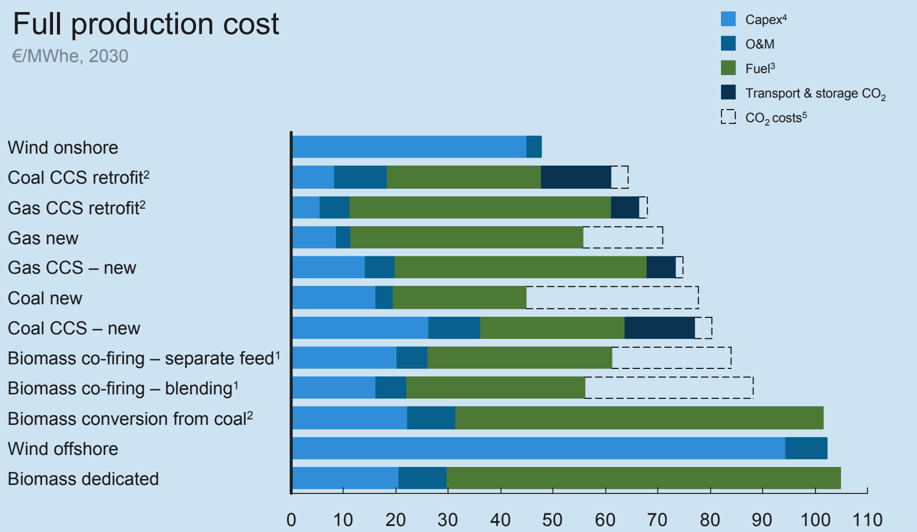
The metric they most often use is the Levelized Cost of Electricity (LCOE). This describes the cost of producing one MWh with a certain technology, under certain assumptions about commodity prices and investment costs. Loosely speaking, if the revenues from that MWh exceed the LCOE, the plant would generate a profit; if not, it would be unprofitable.

In the exhibit below, the LCOEs are given for the power production technologies used in this study (see Appendix A for details). It shows that the majority of technologies fall within the same price range, making investment attractiveness of one technology over the other very sensitive to assumptions (i.e. learning rates and fuel prices) and regulatory interventions.

Exhibit 29

Full production cost

€/MWhe, 2030



1 Assuming 10% cofiring for blending and 40% for seperate feed
2 Only capex for retrofitting is taken into account
3 Fuel prices, coal $109/ton, gas $10.10/mmbtu, biomass €130/ton. Efficienciies coal 44%, gas 58%
4 Loadfactors coal, gas and biomass at 86%, wind onshore 24%, wind offshore 40%
5 CO2 price assumed is 44 EUR/ MtCO2 in 2030 (starting from 15 EUR/MtCO2 in 2010), taken from the IEA, World Energy Outlook, 2009

It is unclear to what extent the current Dutch and European regulation and market pricing mechanisms provide power companies with the right incentives to realize the abatement ambitions. If not, this could be a barrier towards realization of the pathway. This aspect has not been subject of this study.

3.4 Conclusion

Reaching the EU ambition of 40% reduction by 2030 compared to 1990 levels is technically possible; however, it will require implementation of almost all currently available and developing technologies and increases in energy efficiency. Given the long-term capital-intensive nature of many energy investments, a stable, long-term policy framework for investments and planning will be indispensible to achieve the targeted abatement across all sectors. If such a pathway is chosen the Netherlands could take the lead in a European context on several areas for which it already has an advantageous starting position, such as CCS, Wind off-shore, Biomass, Gas residential solutions and Hydrogen. Throughout, gas will remain an important efficient energy carrier and in certain areas can facilitate abatement, e.g. balancing wind power generation, transport fuel shifts and further development of decentralized power generation (Micro-CHPs fuel cells) in buildings.

Glossary

BAU	Business As Usual
CAPEX	Capital expenditures (investments)
CCS	Carbon capture and storage
CHP	Combined Heat and Power system
CO2e	Carbon dioxide equivalent
COP	Coefficient of Performance
OGF	Depleted Oil and Gas Fields
ECF	European Climate Foundation
ECN	Energy research Centre of the Netherlands
EE	Energy Efficiency measure for CO2e abatement
ETS	Emissions Trading Scheme of the European Union
FS	Fuel Shift measure for CO2e abatement
GHG	Greenhouse Gas
HDV	Heavy Duty Vehicle (heavy trucks)
LDV	Light Duty Vehicle (mainly passenger cars)
MDV	Medium Duty Vehicle (vans)
NREAP	National Renewable Energy Action Plans. These plans have been submitted by all member states to the EU; they outline how each member state will realize its share of the EU 20-20-20 targets
OPEX	Operational expenditures
RES	Renewable Energy Sources

A Appendix A: Power Sector – Methodology and assumptions

This section outlines the methodology and assumptions the study uses for the power sector. It also provides details on the pathways described in Chapter 3 of the report.

A.1 METHODOLOGY

Power demand is assumed to be the same across all pathways. The baseline's starting point is ECN, adjusted for other sectors' efficiency gains and fuel shifts.

The study contains four sensitivities that the Netherlands could use to achieve the abatement ambition for 2030. These sensitivities are built around two dimensions: (1) CO_2e emission reduction ambitions are applied at either a country or EU-level; and (2) NREAPs are implemented in full by 2020. See Exhibit 30 for the methodology used to create the sensitivities.

A base case and three sensitivities are described below:

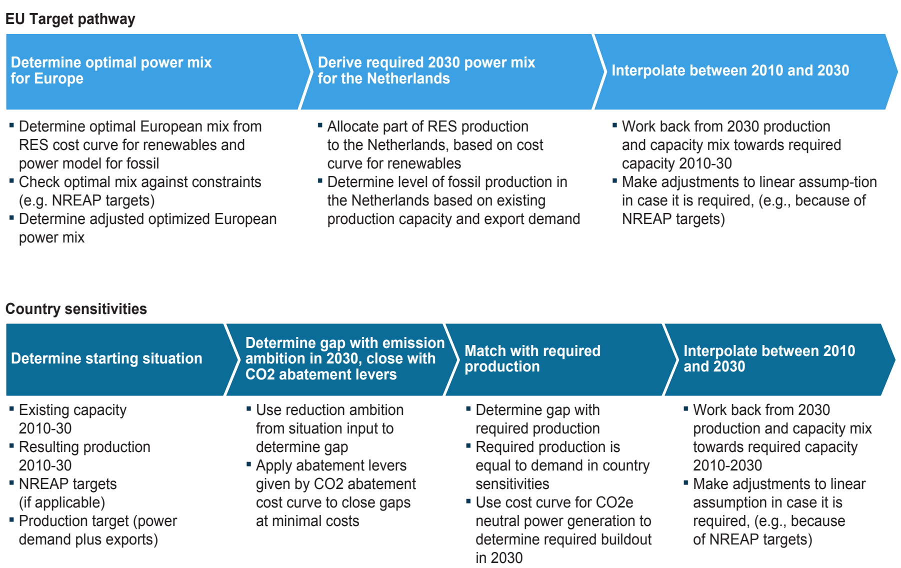
The EU Target pathway is the base case. It assumes that abatement ambitions are met at the pan-European level and that individual countries meet their NREAP targets by 2020. See Exhibit 31 for its specific logic and methodology.

This rest of this section contains three sensitivities to the base case.

The Country target sensitivity assumes that abatement ambitions are met at the country instead of the pan-European level. NREAPs will be implemented in

Exhibit 30

Methodology



full by 2020 and the Netherlands would meet its abatement ambition in 2030. Exhibit 32 (overleaf) highlights this sensitivity's logic and methodology.

The Country target with export sensitivity assumes that abatement ambitions are met at a country level. Export would remain equal to base case levels, so Netherlands cannot eliminate export to meet its abatement ambitions. The way this sensitivity would work is outlined in Exhibit 33 (overleaf).

The Single target assumes that abatement ambitions are met at the pan-European level and at the lowest cost possible. It does not take any other targets into account. Exhibit 34 offers more detail on how it works.

Exhibit 31

EU target: Pathway logic and methodology

Logic

- **Abatement ambitions**
  - 2030 CO2 target of 60% reduction is met in cost optimized way for the whole of Europe
  - "20-20-20" targets are achieved according to NREAP
- **Buildout rationale**
  - NL and EU achieve "20-20-20" targets as planned through NREAPs in 2020
  - After 2020, additional capacity will be built on lowest overall cost logic while achieving abatement ambitions
- **Exports / imports**
  - Imports and exports of power are possible to arrive at a cost optimal power generation mix in Europe
  - Total power demand changes from 172 TWh in 2030 in BAU to 160 TWh as higher RES in rest of Europe limits demand for power from The Netherlands
- **Constraints**
  - Nuclear capacity is limited at 2.1 GW, in 2030 (1 additional plant)
  - Coal plants can only be closed if they are older than 30 years

Methodology

- **1. Determine optimal power mix for Europe**
  - Total power demand is 4,072 TWh
  - Nuclear is economically attractive, but capacity is constrained at 1,032 TWh (136 GW)
  - Coal plants older than 30 years are closed down, leading to remaining capacity of 330 TWh of which 130 TWh coal CCS (64 GW of which 17 GW coal CCS)
  - Gas is the cheapest technology, however total production is limited to 1,136 TWh (216 GW) due to CO2 constraints
  - The remainder of 1,575 TWh is fulfilled by RES, according to the European RES cost curve, constrained by NREAP targets
- **2. Derive required 2030 power mix for the Netherlands**
  - The total RES mix for Europe would not result in further additional buildout of RES in the Netherlands
  - The load factor of gas increases up to the level that gas plants can still back-up intermittent RES and supply peak demand, to make up for the closure of old coal plants, leading to remaining production of 26 TWh by coal plants (5 TWh co-fired biomass) and 74 TWh by gas-fired plants
- **3. Interpolate between 2010 and 2030**
  - Coal retirements are done by 2020
  - Gas production is used as a balancing fuel to meet power demand

Exhibit 32

Country target: Logic and methodology

Logic

- **Abatement ambitions**
  - In 2030, a reduction of 60% needs to be realized in Europe as well as in the Netherlands
  - This translates to maximum emissions for the power sector in the Netherlands of 16 MtCO2 in 2030
- **Buildout rationale**
  - NL achieves "20-20-20" targets as planned through NREAPs in 2020
  - Additional capacity will be built on lowest overall cost logic while achieving abatement ambitions
- **Exports/imports**
  - There are no exports or imports of power
- **Constraints**
  - Nuclear capacity is limited at 2.1 GW in 2030 (1 additional plant)
  - Coal plants can only be closed if they are older than 30 years (Max 3.6 GW)
  - Gas plants can only be closed if they are older than 20 years (Max 6.5 GW)

Methodology

- **1. Determine starting position**
  - Existing capacity 2010-2030 is based on current installed capacity and estimated lifetimes
  - New build RES capacity based on "20-20-20" targets
  - New build fossil capacity based on current building plans
- **2. Determine gap with emission ambition, apply CO_2 abatement levers to close gap in 2030**
  - The gap with the abatement ambition is 53 MtCO2
  - Based on the abatement cost curve, this gap can be closed by eliminating exports by retiring 27 TWh of coal (3.6 GW) and 15 TWh of gas, retrofitting new coal plants (3.5 GW) to biomass (26 TWh), and by switching 3 TWh from gas to wind off-shore. Total gas capacity that retires is 6.5 GW
- **3. Match with required production**
  - In 2030, there is no gap with required production
- **4. Interpolate between 2010 and 2030**
  - Coal retrofit to biomass is implemented as of 2015, coal retirements are done by 2020, wind offshore is built between 2020 and 2030
  - Gas production is used as a balancing fuel to meet power demand, plants are retired between 2011 and 2030

Exhibit 33

Country target with export: sensitivity logic and methodology

Logic

- **Abatement ambitions**
  - In 2030, a reduction of 60% needs to be realized in Europe as well as in the Netherlands
  - This translates to maximum emissions for the power sector in the Netherlands of 16 MtCO2 in 2030
- **Buildout rationale**
  - NL achieves "20-20-20" targets as planned through NREAPs in 2020
  - Additional capacity will be built on lowest overall cost logic while achieving abatement ambitions
- **Exports/imports**
  - There are no exports or imports of power
- **Constraints**
  - Nuclear capacity is limited at 2.1 GW in 2030 (1 additional plant)
  - Coal plants can only be closed if they are older than 30 years (Max 3.6 GW)
  - Gas plants can only be closed if they are older than 20 years (Max 6.5 GW)

Methodology

- **1. Determine starting position**
  - Existing capacity 2010-2030 is based on current installed capacity and estimated lifetimes
  - New build RES capacity based on "20-20-20" targets
  - New build fossil capacity based on current building plans
- **2. Determine gap with emission ambition, apply CO2 abatement levers to close gap in 2030**
  - The gap with the abatement ambition is 53 MtCO2
  - Based on the abatement cost curve, this gap can be closed by eliminating exports by retiring 27 TWh of coal (3.6 GW) and 15 TWh of gas, retrofitting new coal plants (3.5 GW) to biomass (26 TWh), and by switching 3 TWh from gas to wind off-shore. Total gas capacity that retires is 6.5 GW
- **3. Match with required production**
  - The gap with required production is 35 TWh. As there is still wind off-shore potential in the lever, the whole 35 TWh is accounted for by wind off-shore
- **4. Interpolate between 2010 and 2030**
  - Coal retrofit to biomass is implemented as of 2015, coal retirements are done by 2020, wind off-shore is built between 2020 and 2030
  - Gas production is used as a balancing fuel to meet power demand, plants are retired between 2011 and 2030

Exhibit 34

EU Single target: sensitivity logic and methodology

Logic

- **Abatement ambitions**
  - 2030 CO2 ambition of 60% reduction is met in cost optimized way for the whole of Europe
  - "20-20-20" target not a goal in itself, but could be met "naturally"
- **Buildout rationale**
  - Committed capacity is built in Europe
  - Beyond committed capacity, additional capacity will be built on lowest overall cost logic while achieving abatement ambitions
- **Exports / imports**
  - Imports and exports of power are possible to arrive at a cost optimal power generation mix in Europe
  - Total power demand changes from 172 TWh in 2030 in BAU to 138 TWh as higher RES in rest of Europe limits demand for power from the Netherlands
- **Constraints**
  - Nuclear capacity is limited at 2.1 GW in 2030 (1 additional plant)
  - Coal plants can only be closed if they are older than 30 years

Methodology

- **1. Determine optimal power mix for Europe 2030**
  - Total power demand is 4,072 TWh
  - Nuclear is economically attractive, but capacity is constrained at 1,032 TWh (136 GW)
  - Coal plants older than 30 years are closed down, leading to remaining capacity of 330 TWh of which 130 TWh coal CCS (64 GW of which 17 GW coal is CCS)
  - Gas is the cheapest technology, however total production is limited to 1,136 TWh (216 GW) due to CO2 constraints
  - The remainder of 1,575 TWh is fulfilled by RES, according to the European RES cost curve
- **2. Derive required 2030 power mix for the Netherlands**
  - The total RES mix for Europe results in an additional buildout of 1.3 TWh of wind on-shore and 6.6 TWh of biomass which is all assumed to be co-fired
  - The load factor of gas increases up to the level that gas plants can still back-up intermittent RES and supply peak demand; this makes up for the closure of old coal plants and leads to remaining production of 26 TWh by coal plants (6.6 TWh co-fired biomass) and 73 TWh gas-fired plants
- **3. Interpolate between 2010 and 2030**
  - Coal retirements are done by 2020
  - Gas production is used as a balancing fuel to meet power demand

A. 2 INPUT ASSUMPTIONS

Oil, gas, coal, nuclear, CO2e prices

Commodity prices are based on the IEA World Energy Outlook (WEO) 2009. Gas price growth is based on IEA – golden age of gas ($7.4/mmbtu in 2009 to $10.1/mmbtu in 2030).

Power generation technologies

The key assumptions come from the European Climate Foundation (ECF) 'Roadmap 2050' report. These include current and future construction and operation costs, fuel efficiencies, plant lifetimes and learning rates, as detailed below in Exhibit 35.

Exhibit 35

Assumptions on generation technologies

Type of generation		Generation technologies	Capex 2010 €/kW	Capex 2030 €/kW	Maximum loadfactor Percent	Lifetime Years
Fossil		Coal Conventional	1,400-1,600	1,250-1,450	86	40
		Gas Conventional	700-800	650-750	60[1]	30
		Coal CCS	2,700-2,900	2,000-2,200	85	40
		Gas CCS	1,500-1,600	1,000-1,200	60	30
		Coal CCS retrofit	1,250-1,450	600-800	85	40
		Gas CCS retrofit	750-950	350-550	60	30
Nuclear		Nuclear	2,700-3,300	2,700-3,300	90	45
RES	Intermittent	Wind On-shore	1,000-1,300	900-1,200	25	25
		Wind Off-shore	3,000-3,600	2,000-2,400	40	25
		Solar PV	2,400-2,700	1,000-1,400	10	25
	Non-Intermittent	Solar CSP	4,000-6,000	2,900-3,500	47	30
		Biomass dedicated	2,300-2,600	1,600-1,900	60	30
		Geothermal	2,700-3,300	2,000-2,400	91	30
		Hydro	1,800-2,200	1,750-2,000	~35	50

1 Maximum possible load factor is >85%, maximum load factor of 60% assumed to take into account required backup capacity for power demand fluctuations and supply fluctuations due to intermittent power generation

SOURCE: ECF roadmap 2050; NREAP

Technical sensitivities

The study also modeled the effects of several key technical uncertainties on achieving the NL target. These included:

a) Biomass/coal CCS effects:

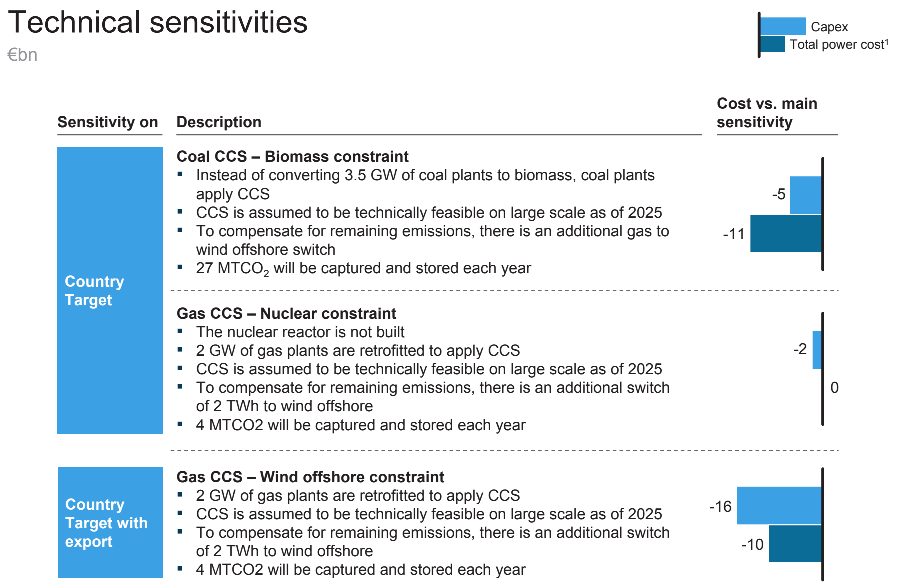
The current sensitivities assume that all coal plants without CCS that are less than 30 years old in 2030 will be converted to 100% dedicated biomass plants, which would produce 18 TWh more from biomass. Current biomass production in the Netherlands is 3 TWh, which means biomass will total 21

TWh by 2030. Said in a different way, the Netherlands will have to increase its imports of biomass sevenfold. The cumulative 2010-2030 costs under this assumption would be around €13 bn lower than the Country target sensitivity where €5 bn is CAPEX.

b) Nuclear/gas CCS effects:

In all power model options discussed in this report the nuclear build-out is capped at 1 new nuclear reactor by 2030. A sensitivity has been added for the likelihood that this reactor may not be built. Assuming that gas CCS provides the additional low-carbon production, the cumulative costs would be similar to the Country target sensitivity because decreases in CAPEX of around €2 bn offset fuel cost increases.

Exhibit 36



1 Total system costs for domestic consumption, excl. CO2 costs

c) Wind off-hore/gas CCS effects:

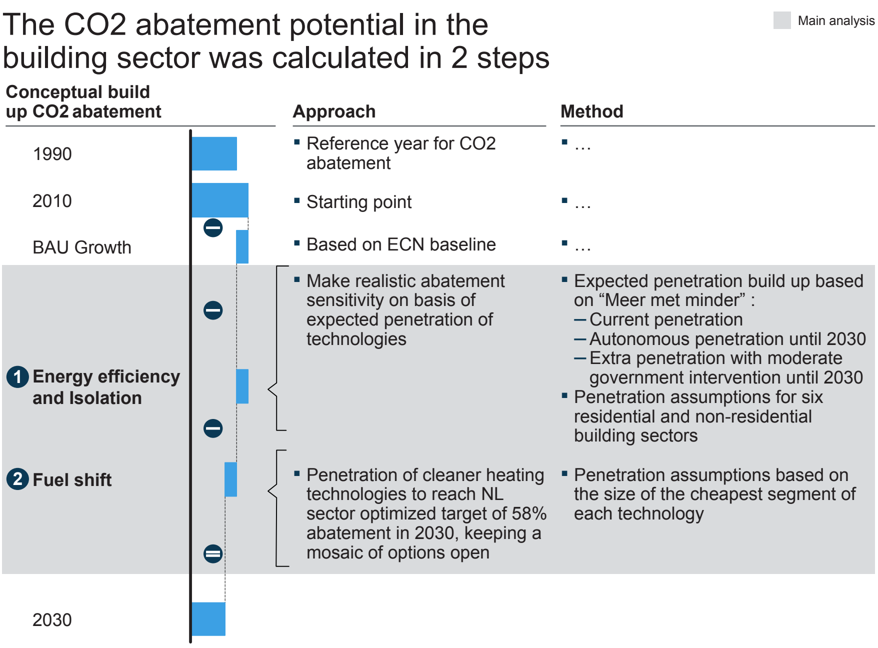
In the Country target with export sensitivity, the Netherlands would build additional wind off-shore to achieve the abatement ambition while meeting the base case export level. Alternatively, it could retrofit gas plants with CCS. Under current assumptions the latter would be cheaper, but large-scale CCS availability before 2030 is uncertain and has therefore not been assumed in this study. If it becomes available for this purpose, total costs would be around €10 bn lower than the Country Target scenario, driven by €16 bn lower CAPEX and €6 bn higher OPEX.

B Appendix B: Buildings Sector – Methodology and key technologies

B. 1 METHODOLOGY

In the buildings sector, the BAU is based on the baseline from the Reference Projection Energy and Emissions 2010-2020 report, which ECN/PBL published in 2010. It shows that increased energy efficiency will reduce energy demand for heating. The projected abatement sensitivities for 2030 assume even further energy efficiencies and insulation measures. To help achieve additional CO2e abatement, this study evaluated a fuel shift toward more CO2e neutral heating in buildings. It compared efficiencies, energy use and CO2e emissions from several technologies – e.g., heat pumps, district heating and micro-CHPs –to a conventional condensing boiler using natural gas. A fuel shift to biogas was also considered.

Exhibit 37



Energy efficiency

Extra penetration above the autonomous penetration of energy efficiency measures (BAU) uses the potential of the “Meer met minder” (More with Less) policy for six residential and non-residential segments (e.g., rental houses, offices). The abatement cost curve methodology is the analysis used to calculate the abatement potential and abatement costs for energy efficiency measures in the Dutch buildings sector.

Exhibit 38

Penetration assumptions behind energy efficiency abatement

Penetration percentage, 2030

Care
P : Pathway
A : Autonomous

		Residential						Non-residential					
		Privately owned		Private rental		Social sector rental		Offices		Edu-cation		Care	
		P	A	P	A	P	A	P	A	P	A	P	A
Energy efficiency and lightning	Time switch	40	30	51	30	51	30						
	Energy efficient computers, faxes and copiers							58	40	58	40	58	40
	Fridge A+++ label	53	6	53	5	53	5						
	Smart meter	99	5	99	5	99	5						
	Efficient shower heads	89	77	89	77	89	77						
	Efficient light bulbs/ LED-lamps	83	32	83	32	83	32						
	Stanby killer	83	30	83	30	83	30						
	Dish washer A-label	73	66	70	66	70	66						
	Lighting							65	30	65	30	68	35
	Dryer A-label	28	5	28	5	28	5						
	Washing machine AAA-label	55	10	55	10	55	10						
Isolation	Roof isolation	84	80	84	80	84	80	77	54	71	41	78	55
	Front house isolation	86	71	87	74	87	74	73	46	68	36	72	43
	HR combi	86	86	86	86	86	86						
	Double glass	85	70	79	70	79	70	69	37	38	12	56	11
	Kettel							84	82	78	75	66	65
	Glutter isolation	78	56	78	56	78	56						
	Maintainance of installations							59	42	59	42	59	42
	Thermostatic radiator valves	70	40			34	5						
	Crack sealing	83	65	76	65	83	65						
	Floor isolation	80	59	75	49	75	49	68	36	65	30	68	36
	Demand driven ventilation	29	7	29	7	28	5						

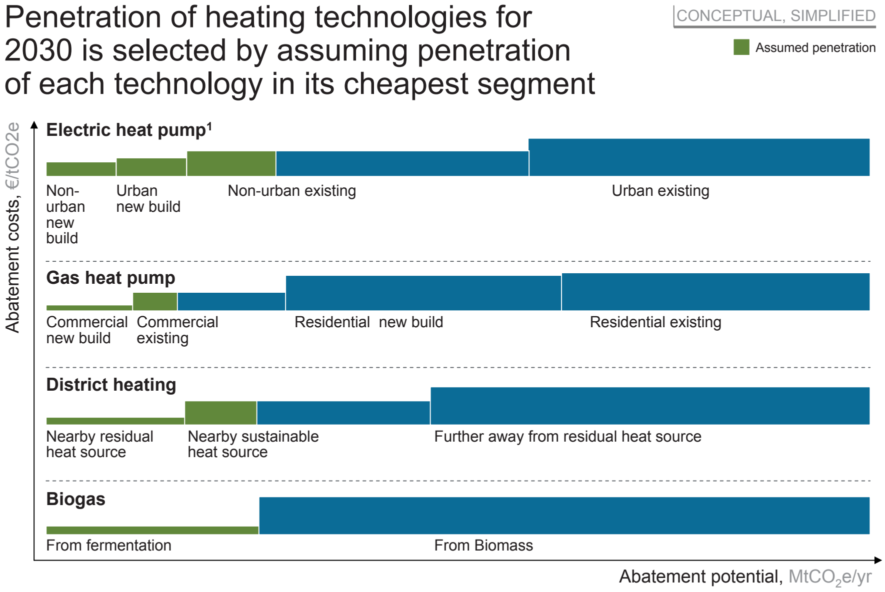
SOURCE: Meer met minder; CBS; Duurzame Energie.nl; SenterNovem; EBM; Milieucentraal.nl; Home onderzoek; Oxxio.nl; ECOFYS

Fuel shift

Realizing additional CO2e abatement requires a fuel shift in buildings towards more CO2e neutral heating. Heating technologies' penetration in 2030 is determined by each technology's penetration in its cheapest segment (Exhibit 39). The abatement potential and cost calculations for each technology and segment are analyzed with the abatement cost curve methodology, which is comparable to the one used for the energy efficiency measures in the buildings sector.

Exhibit 39

Penetration of heating technologies for 2030 is selected by assuming penetration of each technology in its cheapest segment



1 Geothermal only, since abatement cost of aerothermal heat pumps lie >400 €/tCO2

B. 2 HEATING TECHNOLOGIES

Electric heat pumps

Electric heat pumps are the most energy efficient technology for heating buildings. They divert heat stored in the surrounding air (aerothermal) or ground (ground source) to the building. Efficiencies are expressed in the "coefficient of performance" (COP), which usually has values between 2 and 4. The COP level depends on the heat source. Aerothermal heat pumps tend to have an average COP of 2.0 while ground source heat pumps tend to one of 3.25.

Currently, the CAPEX needed to install a heat pump is higher than that for installing conventional heating technologies, especially when it requires the installation of a ground well. This study assumed a 21% heat pump share in 2030, mainly in new buildings and non-urban existing buildings. Both segments have the space needed to implement a heat pump system. New builds also benefit from a CAPEX reduction when heat pumps are implemented in projects that contain several buildings. Additional infrastructure costs caused by the increased electricity demand from heat pumps are included in the CAPEX calculations. These costs depend greatly on the location, number and type of heat pumps installed.

Abatement calculations from electric heat pumps subtract the power plant CO2e emissions required to produce the electricity for a heat pump from the avoided CO2e, which is the amount that would be emitted by a conventional condensing boiler, taking into account a grid loss of 10.5%.

Gas heat pumps

Gas heat pumps use the same thermodynamic principles as the electric heat pump. The difference between a gas-powered heat pump and an electric-powered heat pump is the energy source. Gas heat pumps use gas, whereas electric heat pumps use electricity from the grid or a decentralized, sustainable electricity source (e.g., a hydrogen-powered fuel cell). Gas heat pumps are currently available only for commercial buildings. The dense Dutch gas infrastructure could support increased gas demand from gas heat pumps. This would offer an advantage over the electric heat pump, where increases in peak power demand in a cold spell could raise the chance of a power blackout if the infrastructure were not strengthened sufficiently.

The emission abatement from gas-powered heat pumps has been calculated as the difference between the emissions from a condensing boiler and those from a gas-fired heat pump

District heating

District heating is a centralized heating technology that uses residual or sustainable heat from heat sources such as power plants, waste burning or industrial processes. Heat is transferred from the source to the city through a system of insulated pipelines. Warm water then reaches the end user via a heat exchanger at a building or neighborhood level. A 7% district heating share is assumed in 2030, which corresponds to 15 PJ residual heat use and 15 PJ sustainable heat use, with 5 PJ biomass and 10 PJ deep geothermal heat.

The savings are calculated in the avoided emissions from local CO2 boilers, minus the power used to transport the heat from the central source to the end users.

CO2e abatement from district heating comes from the amount of natural gas it prevents from being burned in home to produce heat, minus the CO2 emitted to transport the heat from the heat sources to the homes.

Micro-CHP

Micro-CHP is a technology that combines decentralized heat and electricity production. The technology is either based on a gas-powered combustion cycle (Micro-CHP Stirling) or a hydrogen-based fuel cell (Micro-CHP PEM or SOFC). Currently, the customer still needs to make high up-front CAPEX investments in this technology. However, CHPs possess multiple advantages over other heating technologies, including: 1) they can be easily retrofitted; 2) the current Netherlands' gas infrastructure can support them; and 3) they can help balance peaks in electricity demand. Customers benefit because CHPs co-produce electricity, which lowers electricity bills. However, micro-CHP Stirling makes only limited contributions to abatement because it has the same thermal efficiency as a conventional condensing boiler and only produces 14% electricity when the device is turned on. The study assumes a 5% penetration of CHPs in 2030.

CO2e abatement from CHPs comes from the avoided CO2 for power production and transport that is now produced by the CHP.

Hydrogen

Fuel cell micro-CHPs are one form of hydrogen fuel. One micro-CHP fuel cell that runs continuously with stored heat could power 5 heat pumps, or around 2.5 households. Currently, prices of Solid-Oxide Fuel Cell micro-CHP fuel cells (SOFCs), which internally convert gas into hydrogen, are around €25,000 but some experts expect prices to drop to under €7,000. This study assumes no fuel cells before 2030.

In the long-term, hydrogen may be cost-attractive in the buildings sector as a Proton Exchange Membrane Fuel Cell micro-CHP (PEM,). No hydrogen use is assumed before 2030 as the commercial availability of fuel cell PEMs is assumed to happen after 2030.

Biogas

Biogas from fermentation, assumed to be CO2e neutral in this study, is included as an abatement lever. By 2030, 0.5 BCM biogas is assumed to be available to fuel gas-powered heating devices in the building sector. Fermenting manure of all stock in the Netherlands (1.6 mn cows and 8 mn pigs) would result in a total production potential of 1.7 BCM. Current market fermentation shares in the Netherlands are low (0.2%) compared to other countries such as Germany (18%) and Denmark (7%)[13]. By assuming a fermentation share of 30% of total production potential, the Netherlands can achieve 0.5 BCM of biogas in 2030.

Exhibit 40 below summarizes the assumed penetration levels for 2030. Exhibit 41 shows the input assumptions per technology.

---

13 Ecofys, 2003. Internationale verkenning mestvergisting.

Exhibit 40

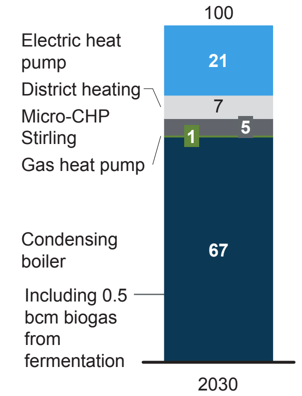
Penetration levels and assumptions

2030

Penetration assumptions

Electric heat pump	50% in urban/ non-urban new build, 25% in non urban retrofit
Gas heat pumps	Commercial only: new build 20%, renovation 20%, retrofit 20%
District heating	▪Residual heat: 15 PJ production[1] ▪Sustainable heat: 5 PJ biomass (~1.4 TWh_e, ~7 sea containers a year); 10 PJ from deep geothermal (currently known potential in NL is 7-11PJ and 5 PJ from Biomass)[2]
Micro-CHP Stirling	Only 5% penetration, since little abatement benefit, assuming “cleaner” power mix

Penetration levels (% households)



1 The “Sector Akkoord Energie” aims to have 25 PJ sustainable district heating in 2020 in addition to 2010, the ministry and IPO formulated ambition of a total of 52 PJ sustainable district heating in 2020
2 IPO 2009, “ Routekaart Warmte”

SOURCE: ECN 2010 “Benutting restwarmte”; IPO 2009, “Routekaart Warmte”

Exhibit 41

Input assumptions capex, maintenance, and technological efficiencies

NB = new builds

€

Technology	Investment: Purchase 2010	Investment: Purchase 2030	Investment: Installation	Investment: Total 2010	Maintenance per year[1]	Efficiency
Condensing boiler	1,000	1,000	500[1]	1,500	40	Thermal: 0.95
Micro-CHP stirling (certified)	10,500	5,000[2]	700[1]	11,200	60	Thermal: 0.95[6] Electric: 0.14[6]
Micro-CHP fuelcell (500 We, Hyteon PEM)	35,000	10,000[3]	1,000	36,000	250	Thermal:0.52[6] Electric: 0.43[6]
Micro-CHP fuelcell (SOFC)	25,000	7,000[3]	1,000	26,000	250	Thermal: 0.42 Electric: 0.45
Gas heat pump (geothermal NB)	11,000	6,600	1,500[1]	12,000	140	COP: 1.40
Electric heat pump (geothermal NB)	10,000[4]	6,000	1,000[1]	11,000	140	COP: 3.25

1 Kema “Integratie van MicroWKK in de woonomgeving”, 2009 i.o. GasUnie
2 Micro-CHP Stirling price of 5,000 is likely to be reached within 5 years from now
3 Micro-CHP fuelcell PEM price of 10,000 and SOFC price of 7,000 is likely to be reached within 5 years from now;
4 SENTER NOVEM “Statusrapport warmtepompen in Nederland in 2008”, 2009
5 Gasterra, Gaswarmtepompen, 2010; 6 Werkgroep decentrale Gastoepassingen, “Energie- en CO2 besparingspotentieel van micro-wkk in Nederland (2010-2030), 2008

C Appendix C: Biomass

Biomass is a key component for the Netherlands to use in the power sector to abate its carbon footprint. Currently, dedicated biomass plants produce 2 TWh of power and coal plants that co-fire biomass put out 3 TWh. In their NREAP, the Netherlands plan to increase their use of solid biomass to 12 TWh by 2020.

In the sensitivities where the Dutch power sector abates 60% by 2030, this study assumed that coal plants younger than 30 years (3.6 GW) would be converted to 100% dedicated biomass plants, preventing premature closure of new coal plants and adding 18 TWh of biomass in 2030. The total biomass production would be 21% (the 18% plus the current 3% in the Netherlands). Co-firing would need to go up to 28% of energy input (6.6 TWh of electricity).

Biomass is an area where the Netherlands has advantages due to its relatively numerous existing and new coal plants and deep-sea ports. Supply, however, could be constrained. See Exhibits 42 and 43. As the Netherlands would need to import wood pellets the availability of these pellets at favorable costs will be key. At this point, the Netherlands already has a 40% share of EU exports.

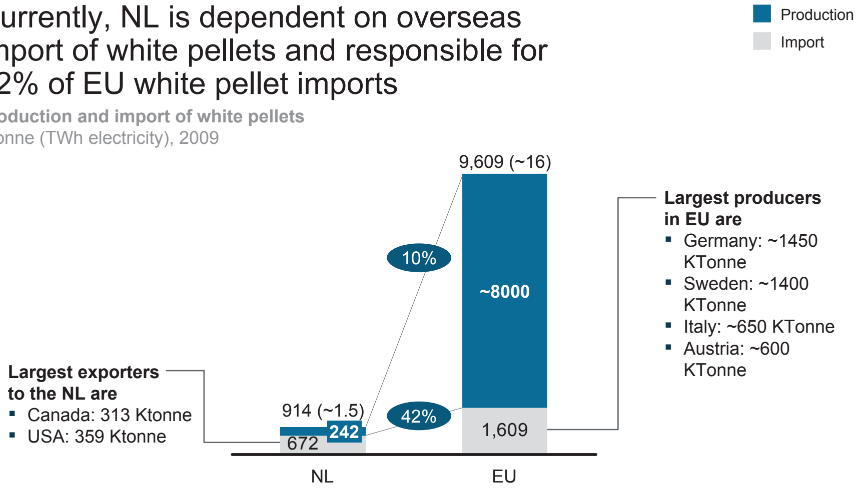
Costs are currently around €110-140/ton (more than three times those of coal and reflecting the lower energy efficiency of biomass vs. coal). If demand for solid biomass increases, these costs may not decrease.

To reach the 12 TWh of electricity production from biomass that the NREAPs plan for 2020, the Netherlands would need to import 5-10 mn tons of biomass. As a comparison, current world trade in wood pellets is 11 mn ton and current storage capacity in Rotterdam harbor is 200,000 tons. See exhibit 42. Furthermore, if biomass has to be transported as it is currently –from overseas (e.g., North America, Canada) – the CO_2e emissions from transport might be higher than that of coal or gas, thereby partly negating the CO_2e benefits of biomass versus coal and gas.

Exhibit 42

Currently, NL is dependent on overseas import of white pellets and responsible for 42% of EU white pellet imports

Production and import of white pellets
Ktonne (TWh electricity), 2009



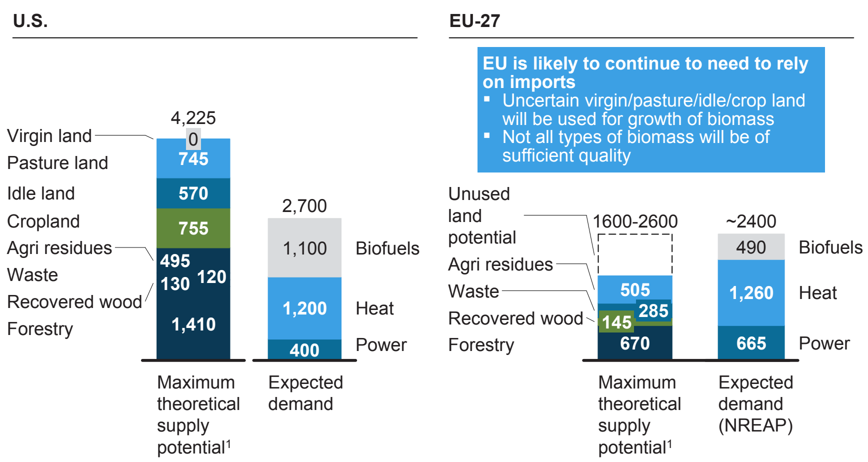
Implementing the NREAP (12 TWh electricity) would require ~5-10 Mt of imported white pallets (assuming 50%-100% use of white pellets in electricity production from biomass). To compare: current worldwide trade in white pellets is ~11 Mt and 2007 storage capacity in Rotterdam harbor was 0.2 Mt

SOURCE: Pellets Atlas 2009

Exhibit 43

EU is expected to continue to rely on imports as not all local biomass supply is expected to be mobilized by 2020

Supply mobilization potential in 2020[1], TWh, primary energy



1 Supply potential after all other demands for land and biomass have been met (food, feed, forestry products, A/R, and REDD)
SOURCE: NREAP

D

Appendix D: Netherlands as a flexible energy provicer

This appendix explores the Netherlands' opportunity to become a gas-to-power hub. In this option, the Netherlands would export flexible power produced from gas within its own country. This option is only attractive if it is more profitable and abatement-friendly than shipping the gas to these countries and turning it into power over there. It is not just a question of shipping costs of gas versus power, but also of societal acceptance of gas plants, gas availability, CCS availability, and regulations.

Based on the following points, it appears that the Netherlands could be well placed to become a gas-to-power hub for neighboring countries. However, further detailed study is required to fully establish what circumstances would make "Netherlands as a flexible power hub" an attractive proposition.

Potential reasons that the Netherlands could prosper in this role include:

- The Netherlands has a plentiful gas supply. Large indigenous production, easy access to pipelines and LNG regas capacity ensure a secure, diverse gas reservoir
- The Netherlands can secure clean gas-fired power because of its good CCS position. There is 2.2 GtCO2 on- and near-shore storage potential and the public and private sector support CCS, especially when compared to some other European countries

The Netherlands has a strong interconnected power transmission network. In 2010, its available capacity (on yearly average) was 4 GW to Germany and 2.3 GW to Belgium. All sensitivities modeled in this study only partially use this capacity. Transmission capacity is slated to grow over the next ten years to the UK, Germany, Norway, and Denmark

The amount of gas-fired production that the Netherlands could "in source" from its neighbors will depend on the amount needed in these neighboring countries and the available gas and power transmission capacity available in the Netherlands. In the options modeled in this study, neighboring countries need about 38 GW total of new gas capacity in the next 20 years (Exhibit 45 below). On a yearly average basis, power transmission capacity to the Dutch neighbors would support up to 7 GW of additional gas-fired capacity in the Netherlands. However, available peak capacity is likely to be less. The same holds true for the gas transport capacity. In a "worst case" sensitivity where the entire 7 GW capacity would have to be added to both the Dutch power and the Dutch gas system, it would be expensed in full on these plants, which would lead to additional costs of €6/MWh over the lifetime of these plants. This is about 10% of the expected LCOE of gas-fired power production. These costs could potentially be justified by better CCS and regulatory conditions in the Netherlands than in the neighboring countries.

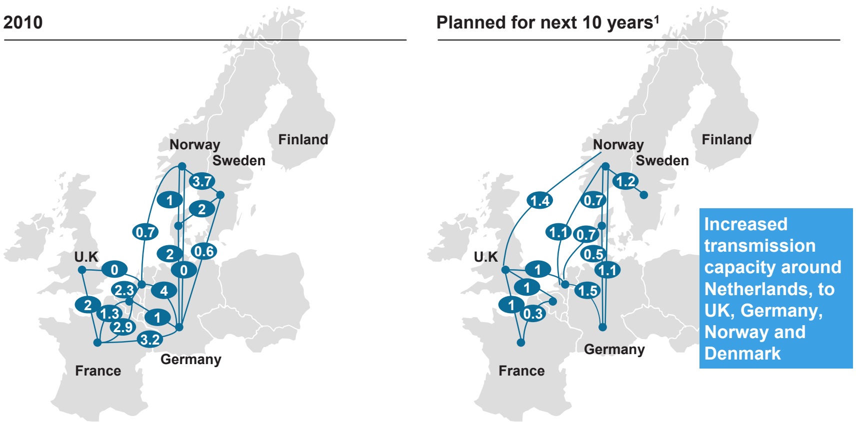
Construction of 7 GW of gas plants would raise Dutch gas demand around 8 BCM compared to 2030 levels in abatement pathways.

Exhibit 44

The Netherlands is well-connected to the rest of Europe and capacity will grow in the future

Net transfer capacities in Europe, GW, current, and future

Transmission capacity, GW



1 Only plans where actual capacity was mentioned included – in case of range, mid point was taken; capacity within countries excluded

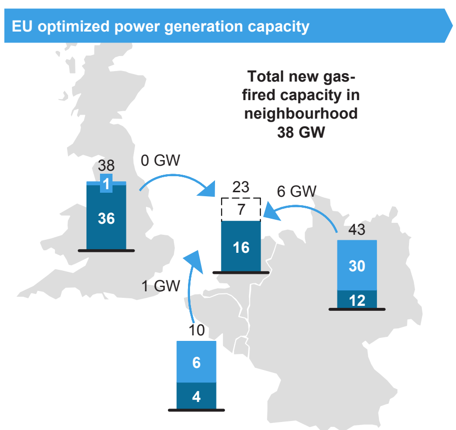
SOURCE: ENTSO-E

Exhibit 45

Up to 7GW of gas-fired capacity could be moved to the Netherlands

Capacity in GW, 2030

Moved capacity
New capacity 2020-2030
Stock capacity build before 2020



Becoming a hub would imply

- Total gas-fired capacity of 23 GW
- Total gas-fired production of 118 TWh
- Total gas demand in power generation of 22 bcm (without hub 14 bcm)
- Total additional power export of 35 TWh to Germany and 10 TWh to Belgium
- Total cumulative CCS storage capacity of 1.1 $GTCO_2$ (of which 0.8 GTCO2 from gas)
- 15 new gas plants[1]

1 Assuming average plant size of 440 MW

SOURCE: ENTSO-E

E

Appendix E: Carbon capture and storage

Carbon capture & storage (CCS) is an abatement technology that can capture CO2e streams from large point emitters and store these in depleted gas/oil fields or aquifers.

In industry, CCS will be critical to meet the CO2 reduction targets. In the power sector, CCS is needed in almost all abatement options.

CCS is critical in industry because other abatement options are not enough to reduce emissions to the targeted 2050 level; without it, Europe might see a large-scale relocation of industry to regions with less ambitious CO2 regulations. CCS could be used in two ways. First, direct CO2 emissions from industrial plants could be captured and stored. Second, CCS could produce CO2-free hydrogen from natural gas, and industrial plants could subsequently use the hydrogen to produce CO2-free heat.

In the power sector having "dispatchable" generation sources that can balance the intermittent supply from RES will be essential to balance the power grid. Gas and coal plants equipped with CCS could provide this service. The option to rely fully on renewables could be constrained because of their intermittent nature, which could lead to an insufficiently stable power system. Nuclear faces increased societal pressure.

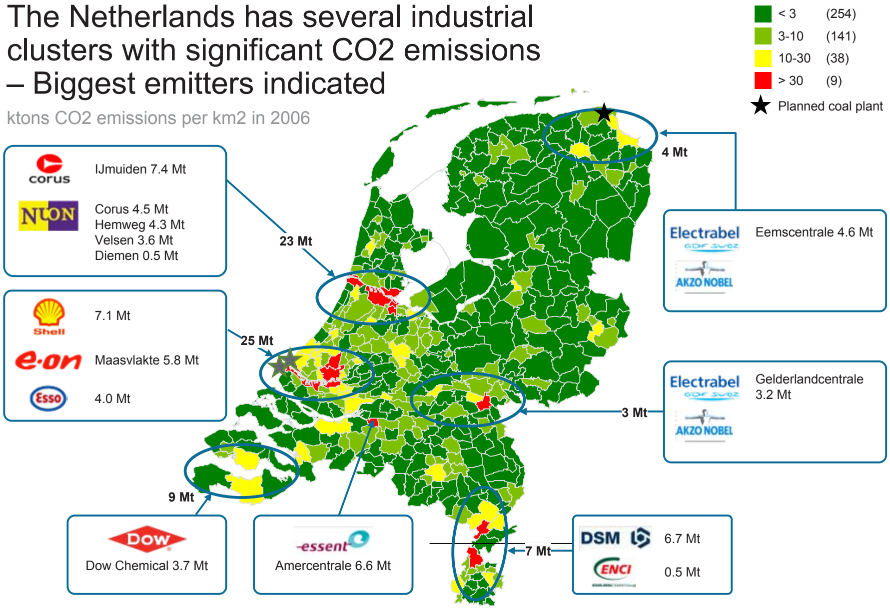
By 2030, current projections suggest that CCS would have lower costs in the power sector than technologies like wind off-shore and dedicated biomass plants. A series of demonstration projects could further reduce CCS's costs to levels around €40-55/ton of CO2e abated in 2030. At the moment, the ramp up of demonstration projects is significantly behind schedule. To catch up, companies would need real economic incentives to engage in CCS for the long term. Current CCS policies in Europe and the Netherlands are not yet fully developed.

CCS market potential in the Netherlands is high compared to other regions in Europe. This is due to the presence of a few industrial clusters that would lend themselves relatively well to large-scale CO2 capture and transport (Exhibit 46). The Netherland also has a wide range of suitable storage locations, amounting to a total volume of 2.2 GTCO2e (Exhibit 47).

Exhibit 46

The Netherlands has several industrial clusters with significant CO2 emissions – Biggest emitters indicated

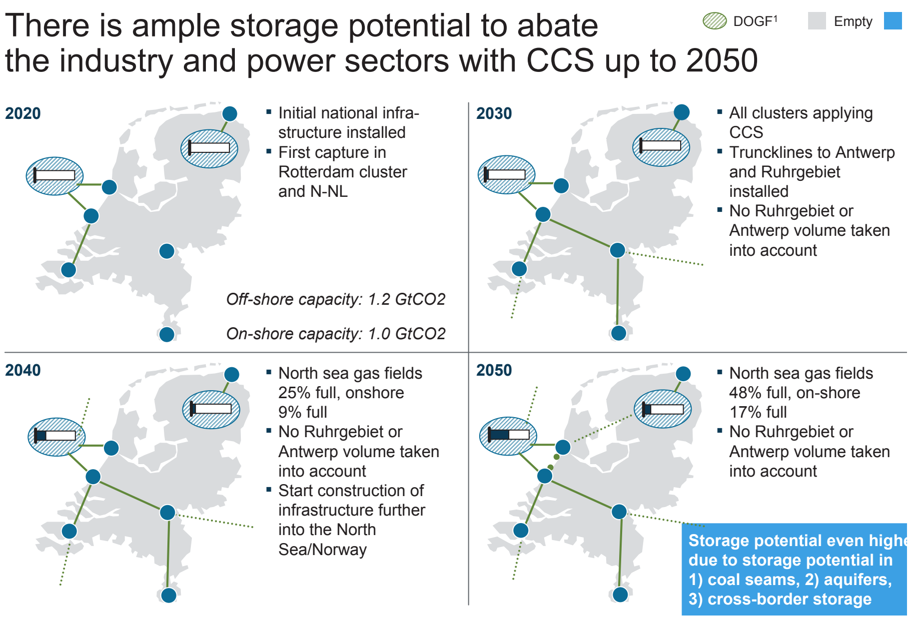
ktons CO2 emissions per km2 in 2006



SOURCE: Emissieregistratie.nl; Bellona.org

Exhibit 47

There is ample storage potential to abate the industry and power sectors with CCS up to 2050



1 Depleted oil and gas fields
Note: storage capacity in coal seams is not yet very well understood and could be much lower than assumed
SOURCE: EBN/Gasunie report CO2 transport and storage strategy

Appendix F: Lower coal build out sensitivity

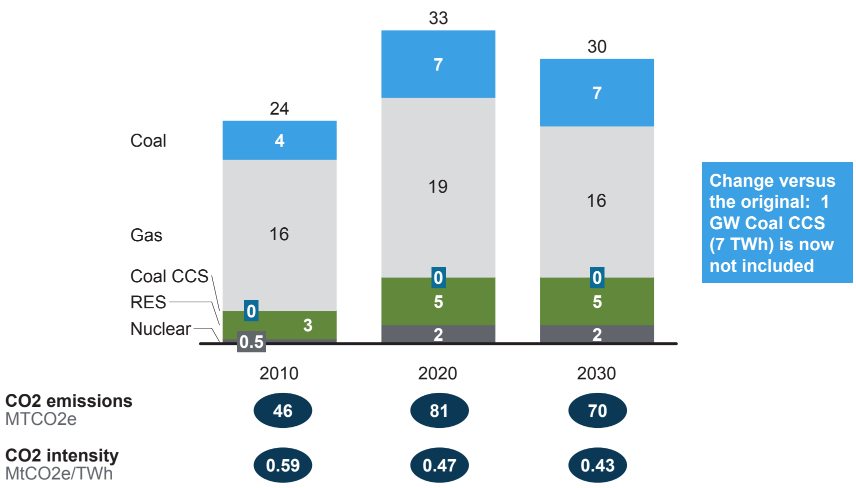
The build-out of coal plants in the Netherlands the coming 5 years is not entirely certain. This sensitivity looks into the effect if 3 new coal plants will be built, instead of the 4 assumed in this study. None of the three remaining new coal plants is assumed to have CCS in the BAU. The effect of this sensitivity would be limited to the power sector, the other sectors would not be affected.

The adapted Business as Usual power mix is shown in exhibit 48 below. The only change compared to the BAU shown in chapter 1 is a reduction of coal fired capacity with 1GW. Optimization on European level showed that the "missing" 1GW will be compensated outside the Netherlands, mainly through RES. This would result in a 7TWh lower power export from the Netherlands.

Exhibit 48

Power generation capacity in business as usual (adjusted)

GW



SOURCE: ECN; NREAP

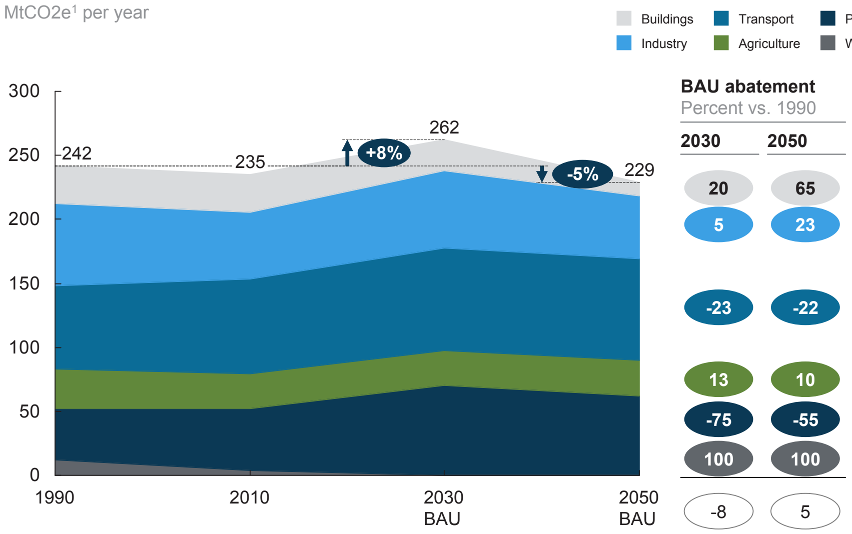
The CO_2e emissions from the Dutch power sector would decrease compared to the "original" BAU, following from the 7TWh lower coal-fired production. See exhibit 49.

The effect of the potential different coal build-out on the power pathway ("EU Target") and sensitivities shared in chapter 2 is limited for most. Exhibit 50 below gives the 1GW-adjusted power production mix for the BAU and the EU Target pathway. The exhibit shows that there is no difference in the capacity and production mix between the "original" EU Target pathway and the "new" EU Target pathway other than the 1GW coal capacity and its associated production of 7TWh. RES build out remain the same (driven by NREAP), and so do the other capacities and production.

Exhibit 49

CO2 emissions in Business as Usual (adjusted)

MtCO2e[1] per year



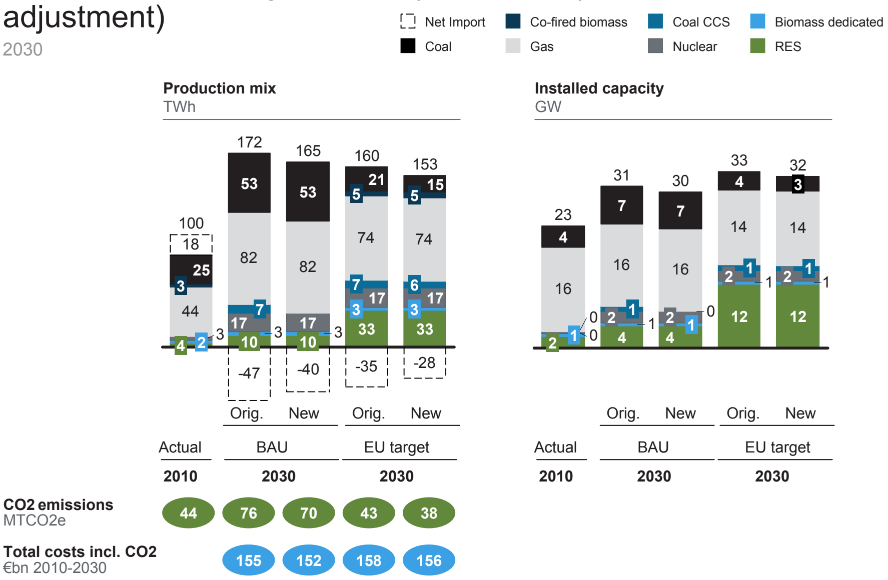
1 Includes CO2, CH4, N2O, HFKs, PFKs, SF6

SOURCE: ECN

Exhibit 50

Power mix: EU Target pathway and BAU (comparison after adjustment)

2030

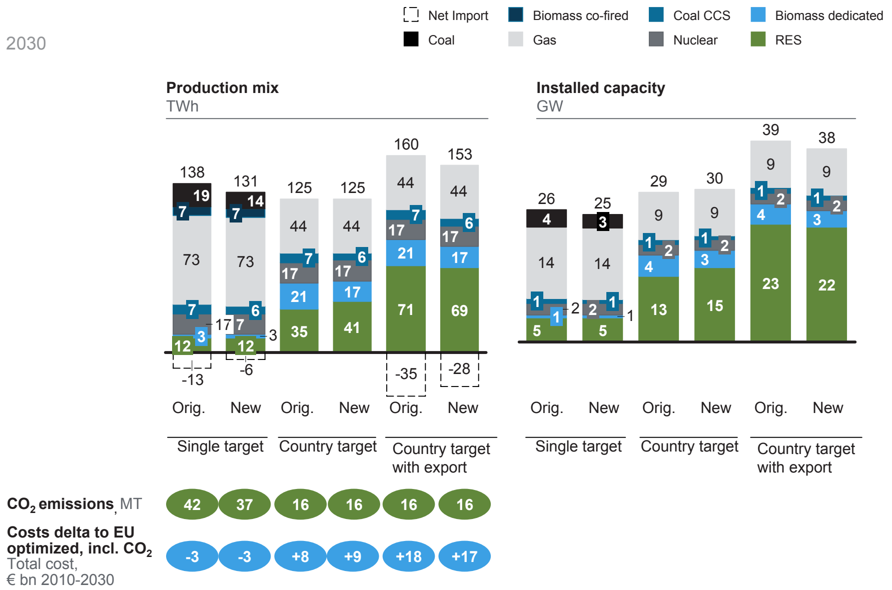


Adapted BAU costs will be less than the original BAU, as it assumes lower build out with correspondingly lower costs. The “EU Target - new” pathway costs would be around EUR 156 bn over the period, excluding costs and revenues from exports.

For the power sensitivities, the impact of the 1GW lower coal build out is mostly limited. See exhibit 51 and descriptions below.

Exhibit 51

Power mix for sensitivities (comparison after adjustment)



- The “Country target with Export” sensitivity would change in the following way. It will have 1GW less dedicated biomass capacity, as this capacity would come mostly from conversion of coal plants built in 2010-2015 of which there would be 1GW less in this sensitivity. The production effect of this 1GW lower capacity is 5TWh (this is 2TWh less than the 7TWh reduction from the dedicated coal plant in the EU pathway, as a coal plant converted to dedicated biomass plants is assumed to produce about one third less power). As this sensitivity assumes the same total power production as the EU Target pathway while meeting the incountry 60% abatement target, the required additional no-carbon production increase is 2TWh less. This translates in either 2TWh less offshore wind or 2TWh less gas-CCS depending on the option within this sensitivity (see section 2.3.3 and Appendix A for more details). The absolute costs of this pathway will be EUR 2 bn less compared to the original. Because of the cost change of the pathway the cost difference with the EU pathway changes to EUR 17 bn.

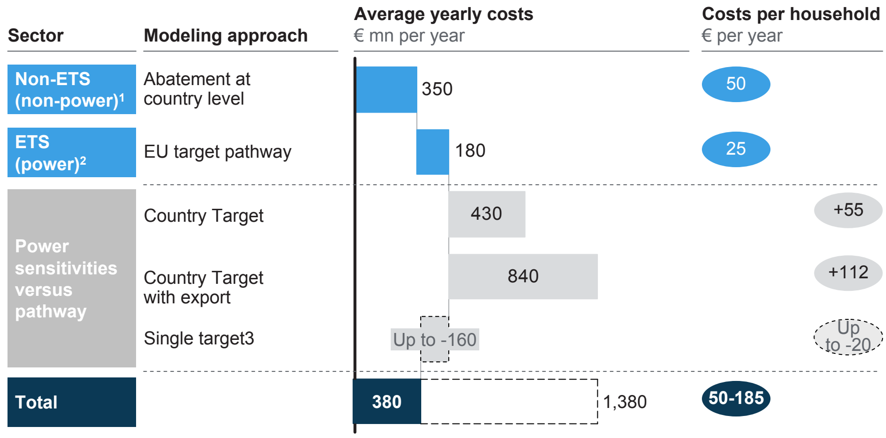
- The “Single target” sensitivity change is limited to 1GW less coal and a correspondingly lower coal-fired production of 7TWh. The “missing” 1GW of coal will be replaced by RES in other countries following the logic of cost-optimization on EU level. Absolute costs will be EUR 2 bn less compared to the original. The cost difference with the EU pathway remains EUR 3 bn.
- The “Country target” sensitivity changes significantly. In this sensitivity, the Dutch power sector needs to produce 125TWh of power with a strict ceiling of 16Mt CO2e. The original pathway has 3.5 GW of dedicated biomass from coal conversion; this will now be reduced to 2.7 GW as there is less coal to convert. As a consequence, the Netherlands needs to produce 7TWh of “clean” power in an alternative way. With the cost assumptions in this study this leads to an additional 2 GW of off-shore wind. From a total societal perspective, total cumulative costs will be lower by EUR 2 bn compared to the original, as building off-shore wind is cheaper than building coal and then converting it into dedicated biomass. On a relative basis though, the cost difference between the pathway and this sensitivity increases with EUR 1 bn as the pathway costs decrease (less coal being built) while there are additional costs for the build-out of wind offshore to meet demand.

An overview of costs is given in exhibit 52 below

Exhibit 52

Abatement costs versus BAU
– including costs of CO2 (adjusted)

2010–30



1 Industry sector, even though part of the EU ETS, has been modeled with a domestic perspective in this study and is included in the non-ETS category here, costs including CO2 only consider costs for ETS sectors (industry and power)
2 Costs of the power system are based on consumption, costs of exported power are excluded in these figures
3 Costs depend on incentives NL may have to pay to other countries to build the RES capacity instead and/or to develop alternative abatement options

Impact on gas demand

As gas-fired production does not change compared to the original, there is no impact on gas demand.