August 2024

Wide cost differences in climate policy choices

Analysis of cost differences between a fossil-free and CO2-neutral Netherlands in 2050

This report was written by PZ Energy Research & Strategy and Quo Mare.

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Introduction

On December 12, 2015, an international climate treaty was concluded at the *Conference of the Parties* (COP21) in Paris: the Paris Climate Agreement. With that treaty, 195 countries agreed to limit global warming to well below two degrees Celsius, with efforts aimed at one and a half degrees. Although energy and climate policies were being implemented by many countries even before that, the energy transition gained momentum after the treaty was signed.

When making climate policies, it is crucial to keep in mind the end goal of these policies - limiting global temperature rise. Indeed, many policies are currently driven by alternative or indirect goals that do not necessarily promote efficiency and effectiveness toward meeting the actual goal. One of the trade-offs that can have a major impact on the level of investment for meeting those goals is the choice of whether to eliminate fossil fuels entirely, or whether to focus primarily on making the energy mix emission-neutral (usually summarized as reducing greenhouse gas emissions, often referred to as CO2 equivalent[1]).

In Europe, climate targets have been set by the European Commission (EC). These targets must be met proportionately by individual member states. Each member state therefore also has national policies that, aided by the frameworks set from Europe, must ensure sufficient and timely reduction of CO2 emissions. The energy transition is therefore also an economic challenge. After all, you are replacing a highly efficient, and therefore cheap, energy mix for another, often less reliable and/or more expensive mix with a higher space requirement. Therefore, the goal is to achieve the transition to an economy with no emissions toward the atmosphere and at the lowest possible cost. How high these costs will be depends on policy choices that may or may not exclude certain technologies.

There is no time for pickiness, but...

The Netherlands seems to be leading the way in setting even more ambitious climate goals than already prescribed by the EC. Looking at cost effectiveness, the question can be asked to what extent it is desirable to be (too) far ahead of the rest of the world. There is also another consideration to be made, namely that of technology choices.

The Netherlands Environmental Assessment Agency (PBL) showed in a recent study[2] that delaying or ruling out options in advance will make climate neutrality in the Netherlands in 2050 almost or even completely impossible. The luxury of choosing between energy sources and technologies is no longer available, according to PBL. This seems at odds with the recent citizen initiative[3] , introduced by Triodos Bank and a broad group of organizations and companies. This initiative is precisely committed to an international treaty that completely stops the use of coal, oil and gas. It is true that climate goals can also be achieved by excluding certain technologies or energy sources. But that would be at the expense of the affordability and/or reliability of the energy system. In addition, part of the CO2 emissions will be moved outside Europe. Something that is good for achieving our own goals, but rather counterproductive for combating global climate change - and thus the ultimate goal.

In this report, compiled by PZ Energy Research & Strategy and Quo Mare, we compare two scenarios for the transition to an energy system in 2050 that fits within the set goals. We then highlight the differences. Two transformation scenarios are presented: the Net-Zero - or CO2-neutral - scenario and the fossil-free scenario. In the fossil-free scenario, coal, oil and gas will no longer be used at all and only emissions from the agricultural sector need to be offset. In a carbon-neutral society, CO2 emissions from the extraction, transportation, conversion and consumption of these fossil energy

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[1] Unless explicitly stated, CO2 in this report refers to CO2 equivalent

[2] PBL (April 2024), https://www.pbl.nl/actueel/nieuws/ook-controversiele-opties-nodig-voor-klimaatneutraal-nederland-in-2050

[3] Triodos Bank (July 2024), Farewell to fossil - Farewell to fossil

sources can be offset with negative emissions, or captured through *Carbon Capture and Storage* (CCS).

Depending on policy choices, there could be large cost differences between the different scenarios. Scenarios that both result in achieving the ultimate goal: ending greenhouse gas emissions toward the atmosphere by 2050 in order to limit global temperature rise to no more than two degrees Celsius, and as close as possible toward one and a half degrees.

The model calculation underlying this report assumes only direct costs and revenues. This excludes from this quantitative analysis any indirect costs and revenues associated with a particular energy system. If these were to be considered, the annual cost differences between the scenarios would increase even further.

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Current situation

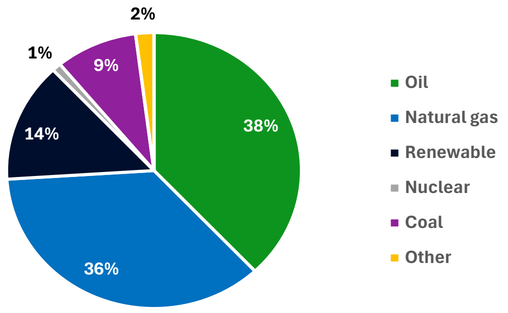
Before looking at scenarios for a future energy system in 2050, we first provide insight into the current situation. Thus, we set out the current energy mix of the Netherlands and describe the implemented and intended climate policies that should lead to the future energy mix.

Current energy mix

To move from the current situation to a CO2-neutral or fossil-free society, the energy mix of the Netherlands must change significantly. The most recent data from CBS refers to 2022. In 2022, a total of 2,712 PJ of energy was consumed in the Netherlands. This does not include 15 PJ of electricity exports. Most of this was oil (38%) and natural gas (36%). The share of renewable energy has increased since 2021, from 10% to 14% in 2022.

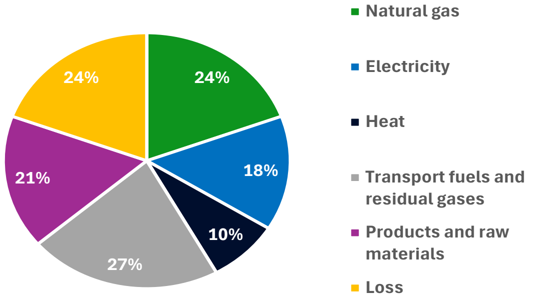
Primary energy consumption 2022 (2,712 PJ)

%



Final energy consumption 2022 (2,064 PJ)

%



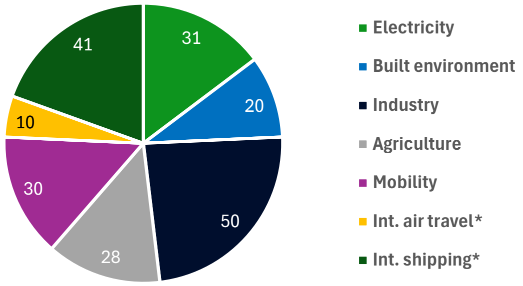
Source: CBS, EBN

Source: CBS, EBN

In final consumption, the distribution is spread among electricity, natural gas, heat, transportation fuels and residual gases, and products and raw materials. Furthermore, 24% of energy is lost through conversion, own use and distribution. This brings total final consumption to 2,064 PJ. Natural gas consumption in 2022 is down from 40 billion cubic meters (bcm) to 31 billion bcm (1,090 PJ) compared to 2021.

CO2 emissions in 2022

Mton



Source: CBS, EBN (* = refueled in the Netherlands)

This decrease is due to the replacement of natural gas in power plants by wind and solar, diversion and conversion by industry, savings in the built environment, diversion and conversion by greenhouse farming and a mild winter. The main driver for this sudden sharp decline in the use of natural gas has mainly to do with increased energy prices. The increase in the energy tax on gas also has a negative effect on consumption.

Furthermore, the ratio of CO2 emissions of different sectors can be seen in the figure above. It shows that industry has the largest share of CO2 emissions with 50 Mton. This is followed in the Netherlands by mobility and electricity with 30 Mton and 31 Mton, respectively.

Exports in the Dutch economy

Exports of fossil raw materials and fuels and chemicals refined from them are an important lynchpin of the Dutch economy. Thus, annual Dutch exports of oil and products refined from oil are stable well above 100 Mton[4] , with an exception for 2020 due to the Covid pandemic. This includes products from the Dutch refineries and chemical industry as well as re-exports.

In value terms, the petroleum industry exported EUR 1 billion in 2021. The chemical industry - for which oil and gas are often the basic products - accounted for exports of nearly EUR 11 billion. In addition, the Netherlands exported nearly EUR 2 billion worth of base metals and EUR 3.5 billion worth of metal products. Plastics production also made a significant contribution to the Dutch trade balance at EUR 2.2 billion. Total industrial exports were over EUR 61 billion in 2021. The export value of fossil-based sectors make a significant contribution to this. [5]

Current climate policy toward 2030

Current Dutch climate policy has its roots in the 2013 Energy Agreement. This agreement, concluded during the Rutte II administration, set the Netherlands the goal of generating 14% renewable energy by 2020 and achieving annual energy savings of 1.5%. The global Paris Climate Agreement raised the bar for national climate policy even higher. Thus, the next cabinet (Rutte III) set to work on a further development of the formed Energy Agreement. The result was the formation of the Climate Agreement in 2019. The main goal of this agreement was to reduce CO2 emissions by 49% in 2030 compared to 1990.

With the establishment of the Climate Agreement, the Climate Act was also passed in 2019. In addition to providing a legal basis for the Climate Agreement, this Climate Act also requires the government to prepare an annual Climate and Energy Outlook (KEV). The KEV prepared by PBL is the main monitor that evaluates the progress of the national climate policy. Thus, based on this evaluation, the government can annually adjust the policy to achieve the target emission reduction.

Finally, the national targets from the 2019 Climate Accord were increased again in 2022. This followed the European Climate Law passed in 2021. This European law mandates a 55% emissions reduction for the EU by 2030. The Rutte IV cabinet then committed in the coalition agreement to also set the national target for 2030 at 55% emission reduction with a goal of 60%. An emission reduction of 55% corresponds to a remaining emission level of 103 Mton in 2030.

The most recent KEV, published on Oct. 26, 2023, shows that with current adopted and planned policies, we are heading for a 46% to 57% emission reduction. Thus, this KEV was also the first edition in which the 2030 target is within the range to be met. At the same time, the range is relatively wide due to various factors such as weather, energy prices and policies in surrounding countries.

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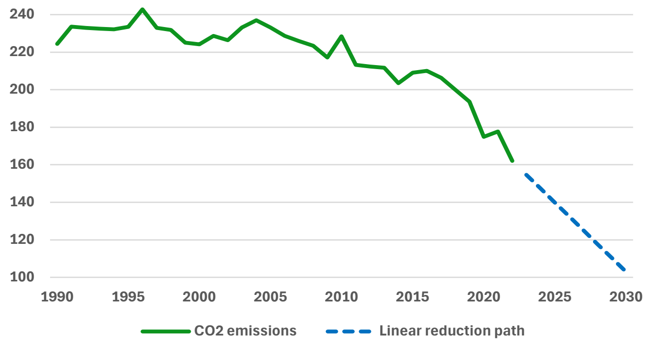
[4] Eurostat (2024), https://ec.europa.eu/eurostat/databrowser

[5] CBS (2023), https://longreads.cbs.nl/nederland-handelsland-2023/nederlandse-verdiensten-aan-de-export/

CO2 equivalent emissions NL and required reduction for 2030 target

Mton



Source: Our World in Data, PZ ERS

A key feature of Dutch climate policy is its sectoral approach. Thus, the emission reduction task is divided by sector. These sectors are (1) electricity, (2) built environment, (3) industry, (4) mobility, and (5) agriculture and land use. Thus, the emissions reduction targets actually vary by sector. The table below shows the reduction targets and residual emissions for 2030 by sector.

2030 reduction targets by sector

Sector	Targeted emission reductions	Emissions in 1990 (in Mt)	Indicative residual emissions (in Mt)
Electricity	77%	56	13,0
Built environment	58%	31	13,2
Industry	59%	71	29,1
Mobility	16%	25	21,0
Agriculture and Land Use	38%	32	19,7

Source: KEV 2023

In order to achieve the set goals, many policy choices have been made over the years by various cabinets. An overview of all climate policy measures taken is beyond the scope of this report. Instead, we focus on climate policy in the industrial sector, in line with the model's focus on that sector.

Policy choices determine direction

A cornerstone of Dutch climate policy is the Stimulation of Sustainable Energy Production and Climate Transition (SDE++). This subsidy scheme was created to allow low-carbon technologies to compete with fossil alternatives using subsidies. The scheme disburses money to a variety of techniques. The list of techniques has been growing over the years. Initially, techniques such as wind power and solar PV mainly made up the list. Consequently, the rollout of production capacity of these techniques has prospered partly because of this subsidy policy. Some 50% of electricity production is now renewable and this percentage will continue to grow significantly in the coming years, in part due to the plans for offshore wind power.

In addition to the commitment to electricity from solar and wind, the electricity sector has also chosen to phase out coal-fired power plants. Coal may no longer be used to generate electricity by 2030. At the same time, it has been agreed to keep the Borssele nuclear power plant open longer, preparations are underway for the construction of two new nuclear power plants, and since the new administration, there is an intention to build two more nuclear power plants. Although the actual production of these plants is still at least ten years away, they will become an important part of the future electricity system in the Netherlands.

The electricity sector accounts for "only" 18% of final energy demand. The challenge therefore lies primarily in making the remaining 82% of our energy consumption more sustainable. The industry sector is the largest part of this. *Carbon capture and storage* (CCS) plays an important role in making that sector more sustainable. It is therefore not surprising that most of the total subsidy budget of the SDE++ is now reserved for CCS. Besides CCS, the EU ETS and, for the Netherlands in particular, the national minimum CO2 price play an important role in reducing greenhouse gas emissions from industry.

With the decrease in the number of available emission rights within the ETS and the annual stepwise increase in the minimum CO2 price, Dutch entities are assured that emissions will become more expensive. Sustainability will therefore pay off. In the industrial sector, cautious efforts are being made to use hydrogen to replace current fossil molecules. For example, 42% green hydrogen should be used in industry by 2030 and a goal of eight gigawatts of electrolysis capacity by 2032 has been set.

Through the climate policies that have been adopted, we as a country have embarked on a path toward a new energy system. Far from all final policy choices have been made, but we can already look ahead to the future energy system.

Future energy mix

CO2 neutral versus fossil free

In order to get a better picture of this possible future energy system, we have assumed two scenarios, or two transition paths, in this study with the goal of achieving the (Dutch) climate goals for 2050. These two scenarios are a CO2-neutral energy system and a fossil-free energy system in 2050.

In a carbon-neutral society, CO2 emissions from the extraction, transportation, conversion and consumption of fossil fuels can be captured through CCS, or offset with negative emissions. In other words, fossil fuels (oil and gas) can still be used in 2050 as long as CO2 emissions are net zero (captured or offset). This therefore allows some of the fossil fuels to continue to play a role in the energy mix, assuming - due to the ban on burning coal in power plants by 2030 - that coal will no longer play a role in the electricity mix from 2030.

In the fossil-free scenario, coal, oil and gas will no longer be used at all by 2050. However, molecules will still be needed to produce all kinds of materials. There will therefore be a greater role for renewable carbon (such as biomass and hydrogen) and renewable energy. So this is not just about decarbonization - the reduction of CO2 emissions combined with capture - of the energy mix, but complete recarbonization - the replacement of CO2 emitting methods with CO2 neutral solutions.

In both scenarios, 18 Mton of CO2 equivalent emissions will still need to be offset due to methane and nitrous oxide emissions from the agricultural sector. In both scenarios, the size of this sector is assumed to remain the same. To offset these emissions, negative emissions must be identified in both scenarios. The most likely option for this is biomass gasification combined with CCS (BECCS), which produces negative CO2 emissions and thus offsets emissions from the agricultural sector.

The investment assumptions assume the willingness to invest at the highest margins and/or lowest costs on a net present value basis over the entire term to 2060. As a result, the model calculates that investments are made in those technologies that yield the most, or cost the least. And then at that time when the present value - or present value of the future investment - of those costs are lowest. As a result, most of the costs fall toward the end of the investment horizon (2045-2050), when policy goals become so close that sustainable investments can no longer be postponed.

Large proportion of scenarios have overlap

A significant portion of these transition paths are the same in both scenarios. Simply because investments and decision-making take place on the basis of the economically feasible and most affordable alternatives. For example, a significant share of the replacement of fossil fuels for electricity generation will be met by investments in solar and wind energy. At the same time, the transition to the consumption of low-temperature heat (excluding industry) will be achieved through the development of district heating networks and the installation of heat pumps. These investments in renewable electricity and heat generation are expected to be able to reduce some 76 Mton of CO2 emissions over the next 26 years, mainly in the built environment, agriculture and energy sectors.

Some 50 Mton of CO2 equivalent needs to be reduced in industry. Much of this comes from the high-temperature heat required in industrial processes in refineries, for example. In addition, emissions are released when making steel or producing fertilizer. It is expected that some 28 Mton of this can be reduced through the use of hydrogen and electrification of processes.

The remaining task is to reduce the remaining CO2 emissions from industry (22 Mton), supplemented by the Dutch scope-3 emissions of kerosene and gasoil from the air and shipping sector of about 14 Mton. Finally, the remaining 18 Mton CO2 equivalent emissions by the agricultural sector are added. This brings the total remaining CO2 emissions to about 54 Mton CO2 per year. The two scenarios show different interpretations on behalf of these remaining emissions in order to reach the final target in 2050.

Technologies in the energy system of the future

The last mile is the longest

To achieve the above sustainability of the Dutch energy system, several techniques can be used. In this chapter, the production techniques of renewable hydrocarbons and blue or green hydrogen are briefly outlined. The options for these are hydrocarbons from fossil sources combined with CCS or renewable carbon production, with or without CCS to achieve negative emissions. Their use varies depending on cost and scenario.

Finally, the chapter discusses the most obvious sustainability options for the steel and fertilizer industries. To achieve net zero CO2 emissions by 2050, it is necessary to replace these hydrocarbons as well for an alternative with net zero emissions, whether or not in a fossil-free manner. Moreover, additional hydrogen must be produced to make the heavy transport sector more sustainable and meet the heat demand of the steel and fertilizer plants and the chemical industry. This puts the future demand for hydrogen at 5 Mton or more in many scenarios at full sustainability.

Deployment of renewable coal hydrogen

In both the fossil-free and CO2-neutral scenarios, renewable hydrocarbons are indispensable. *Biomass to Liquids (BTL)* is an example of a process in which biomass is converted to liquid fuels, for example biodiesel. In the BTL process, Fischer-Tropsch (FT) synthesis plays an important role. This is a chemical process in which liquid hydrocarbons can be produced from synthesis gas, in this case using biomass as a carbon source. This can also be used to produce *Sustainable Aviation Fuel (SAF)*, although it is also possible through other techniques such as *Hydrotreated Vegetable Oil (HVO)*.

Waste to Liquids (WTL) is the same process as BTL (first gasification and then FT synthesis), but using the organic fraction of municipal waste (MSW) as input. The extracted biogenic fraction of municipal waste is also referred to as *Refuse Derived Fuel (RDF)*. Another method of upgrading waste (especially plastics) to renewable hydrocarbons is chemical recycling. Pyrolysis of plastics is one of the options. Pyrolysis oil is produced from waste plastics, which can be used as feedstock for naphtha crackers. This involves heating plastic without oxygen to 300-600 degrees Celsius, which breaks down the waste plastic into smaller naphtha-like molecules, the pyrolysis oil. In addition to pyrolysis oil, gas and solid residue are also made, which can be used as fuel for heat or electricity production, with CO2 capture, of course.

To provide inputs to the above processes, a number of raw materials of non-fossil origin are required. As mentioned, plastic waste is converted into pyrolysis oil to be used as cracker feed. In addition, woody biomass (lignocellulose) and offal/finished frying fat (lipids) provide the feedstock for the production of renewable fuels to reduce scope-3 emissions from kerosene and gas oil in aviation and shipping. The other available inputs, such as wood pellets (e.g., reprocessed wood residues from forests) and biogenic waste streams from fermentation processes can be used for electricity production. Here, CO2 emissions - like biogenic emissions in the aforementioned sustainable processes - can be captured, resulting in negative emissions.

Carbon Capture and Storage (CCS)

In a CO2-neutral society, CCS is indispensable to capture emissions from the fossil fuels required. With CCS, CO2 emissions released from burning fossil fuels are captured and stored in underground reservoirs (empty gas and oil fields or salt caverns). There are various methods for this, where the CO2 can be captured both before and after the combustion process. In this way, CO2 emissions do not enter the atmosphere. CCS is a cost-effective technique for making processes more sustainable where it is costly to replace fossil energy inputs with renewable sources. This applies both to the direct combustion of oil, gas and coal in the production process and, for example, to the production of blue hydrogen.

CCS will be used in the net-zero scenario to directly capture and store CO2 released from the burning of fossil fuels. In this way, CO2 emissions to the atmosphere are prevented. In the net-zero scenario, CCS will also be used in hydrogen production. In addition, CCS can be used in the fossil-free scenario to achieve negative CO2 emissions. This means capturing CO2 from biomass conversion or combustion (BECSS). This capture then offsets CO2 emissions elsewhere. In practice, this will be able to offset methane and nitrous oxide emissions from the agricultural sector.

There are currently two CCS projects under development in the Netherlands, Porthos and Aramis. When both are fully operational, the total storage capacity in the Netherlands will be 27.5 Mton CO2 per year. In addition, CO2 storage capacity abroad is also expected to be used, particularly in Norway (such as the Northern Lights project). Besides Porthos and Aramis, no CCS projects are planned in the Netherlands, but expansion is still possible. This makes the development of CCS capacity from 2035 onwards difficult to estimate. However, it is certain that there are enough empty gas fields available. In addition, it is plausible that the EU ETS price will continue to rise, providing a good business case for future projects. The main risk for future capacity expansion is lack of public support for CO2 capture and storage.

Green and blue hydrogen

Hydrogen production in 2050 will follow four possible production methods. Electrolysis technology produces green hydrogen without emissions, provided that renewable electricity is used. In the electrolysis process, electricity splits water into hydrogen and oxygen. Thus, this production method is also suitable for the fossil-free scenario.

One speaks of blue hydrogen when natural gas is used in the production process, combined with CCS. Blue hydrogen can only be used in the CO2-neutral scenario. Common techniques for this are *Steam Methane Reforming (SMR)* and *Autothermal Reforming (ATR).* For both techniques, natural gas is the most common input, but other hydrocarbon sources can also be used, such as biogas. ATR is generally more energy efficient than SMR (no external energy source required), but also more complex (requires pure oxygen). In addition, CCS is easier to integrate into the ATR process. Although SMR technology is currently still dominant, this means that - with the increasing emphasis on sustainable hydrogen production - the ATR process will most likely become the most common production technology in the future.

Finally, there is the method using biomass gasification, which can also be used in the fossil-free scenario. Combined with CCS, this can even provide negative emissions. First, biomass is converted into synthesis gas with the help of oxygen. This is a mixture of carbon monoxide (CO) and hydrogen. Next, CO is converted with steam (H2O) into hydrogen and CO2 through the so-called water-gas-shift (WGS) reaction. Then, using the Pressure Swing-Absorption (PSA) process, the CO2 is separated from the H2 and the CO2 can then be stored.

Steel and fertilizer industry and refineries

With annual CO2 emissions of 6 Mton each, the steel and fertilizer industries are among the most polluting sectors in the current Dutch economy. Making both sectors more sustainable will require a large amount of green or blue hydrogen. In addition, further sustainability in the fertilizer industry will require investments in the *Air Separation Unit* (ASU). Integrating these plants with CCS is an important step in this, along with powering ASUs with renewable electricity.

These investments can be circumvented by importing all ammonia as a raw material for fertilizer production, rather than producing it yourself. In practice, sustainability in the steel industry means a switch from coal-fired blast furnaces to electric arc furnaces or blast furnaces with *Direct Reduced Iron* (DRI), through hydrogen. DRI makes the steel production process more energy efficient, which together with the use of green or blue hydrogen and CCS can make steel production CO2 neutral.

The production of transportation fuels and chemicals in refineries and naphtha crackers currently emits about 22 Mton of CO2 per year. Electric steam crackers are an important technology to reduce these emissions. Whereas the high temperatures in the cracking process in conventional crackers are achieved by burning natural gas, this process can be made more sustainable by using electric heating elements. However, this technology is still in its infancy and is not expected to be commercially applied on an industrial scale until after 2040.

Method quantitative analysis TDES

This section outlines the methodological choices made for the model calculation underlying this theme report. We limit ourselves to the most crucial inputs to the model. We describe the functionality and operation of the underlying model, the data used, and finally discuss the most relevant general assumptions made.

The model includes a number of policies. The most comprehensive and influential policy is the EU ETS. The EU ETS will eliminate scope 1 and 2 emissions in the relevant sectors by 2050.

In addition to the regular EU ETS, the model also takes into account the introduction of ETS II. This becomes applicable to all sectors and households in the model from 2026. For this second ETS, the market price is increased linearly from 0 at the start of the system up to and including the same price assumed for the current EU ETS in 2034 (EUR 166/ton). In addition to the EU ETS, the effect of the *Carbon Border Adjustment Mechanism* (CBAM) is also included in the model. The CBAM affects imports of fossil hydrogen and ammonia from outside Europe. In addition, it is assumed that the scope of CBAM will be extended to other refinery products, such as motor gasoline. The phased introduction of CBAM between 2026 and 2034 is also included in the model.

TDES: Transition of Dutch Energy System

This theme report is based on the quantitative calculations of TDES: a techno-economic optimization model designed by Quo Mare. The purpose of the model is to find the most cost-effective way to change the Dutch energy system anno 2022 to a CO2-neutral or fossil-free energy system in 2050. The model produces output for each year between 2020 and 2050.

The model covers the entire Dutch energy system, but focuses on the industry sector in terms of level of detail. A variety of boundary conditions are given to the model, such as different policy measures, feedstock availability and demand for end products. In addition, a number of assumptions are made about the development of variables such as feedstock prices. These are mainly based on the report: "The energy system of the future: the II3050 scenarios" by Netbeheer Nederland.

The model serves as a tool to calculate the cost optimization of a regulatory framework. That is, the model now assumes the established and intended climate policies of the Dutch government. Thus, the model is also able to calculate potential policy changes and compare them with the baseline scenario of the current policy.

In addition to this overarching European industrial policy, two more national policies are included in the model. First, the ban on the use of coal for power generation by 2030 has been taken into account. In addition, scope 3 emissions are limited by the model to net zero in 2050. This is achieved through a linear decrease in fossil fuel exports from 2035 through 2050.

Regarding the economic supply and demand for products and (thus) energy, the model assumes that demand for goods and services depends on economic feasibility. In other words, total production and export demand in 2050 is determined by whether production makes economic sense, or whether import is a more logical option. Thus, differences may arise (for example, based on policy choices made or commodity prices) in how demand for goods and services is met in terms of energy inputs. As a result, energy demand in the mobility and industrial sectors is variable. Energy demand in the built environment and agriculture is assumed constant.

Finally, a number of other assumptions were made that provide relevant insight into how the model works. For example, while the model broadly includes the cost of the energy infrastructure needed, it does not make specific assumptions about associated location or companies. In addition, technologies that are still too much in their infancy are not included in the model. Cost reductions of new technologies through technological development and economies of scale are also not included in the model. Thus, the CAPEX costs of electrolyzers are assumed constant. Also, the model assumes a "Homo Economicus" approach. That is, the model bases the choices made purely on a financial-economic consideration.

The different scenarios ultimately lead to different energy systems in 2050 and, on the path to them, to different investment costs. The modeling underlying this report assumes direct investment costs. This excludes from this quantitative analysis any indirect costs and revenues associated with a particular energy system. An example of this would be the loss of a significant proportion of products that are currently still made in Dutch refineries, but probably no longer will be after the transition. Think of building materials for antibiotics, fertilizers and plastics. Something we cannot do without after 2050 either, and thus become import dependent. At the same time, new industries will emerge, which in turn can make a positive contribution to the Dutch economy.

Results

This chapter explains the results of the TDES model calculation. Successively, the results are discussed with respect to two key technologies, namely CCS and hydrogen production via electrolysis. Then the differences in investment costs and annual cost differences between the two scenarios are explained.

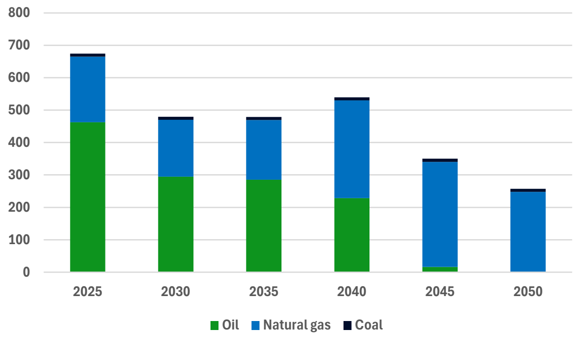
Key role for CCS and hydrogen

In the period between now and 2040, both scenarios see a gradual increase in the sustainability of the Dutch energy system. One of the major drivers behind this is the EU ETS. This makes, for example, the use of coal for electricity production in both scenarios economically uneconomic even before 2025.

Starting in 2045, large differences are visible between the two scenarios in fossil resource consumption. The graphs below show the inputs to coal (for use in steel production), crude oil and natural gas in the energy systems of the future by scenario.

Input fossil in energy system, CO2 neutral scenario

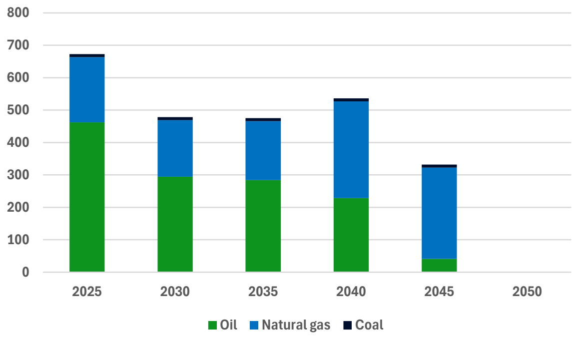
TWh



Source: Quo Mare

Input fossil into energy system, fossil-free scenario

TWh



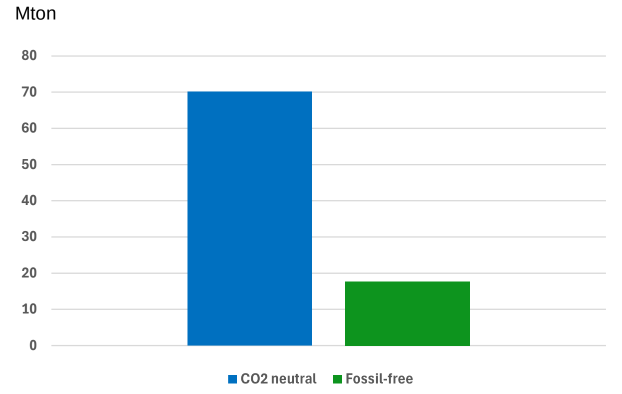
Source: Quo Mare

Because a carbon-neutral scenario avoids emissions to the atmosphere, the emissions associated with fossil fuel combustion must be captured. As a result, one of the biggest differences between the two scenarios is the extent of CCS use. Because the differences in fossil fuel use only begin to occur starting in 2045, the differences in CCS are also only significant toward 2050, as shown in the graph on the next page.

In the fossil-free scenario, the capture and storage of nearly 18 Mton of CO2 is still necessary. Thus, these emissions cannot be avoided even without the consumption of fossil fuels. Although fossil fuels are no longer burned in this scenario, livestock still produce a significant amount of methane and nitrous oxide emissions. These emissions are offset by CO2 capture in biogenic material combustion (BECCS), which produces negative emissions. The agricultural sector emits the same amount of greenhouse gases in the CO2-neutral scenario.

On top of this, in the CO2-neutral scenario, over 50 Mton of CO2 is captured as a result of fossil fuel combustion, which the model assumes will result in additional scaling up of CCS capacity after the development of Porthos and Aramis. Indeed, large-scale capture of these emissions is more cost-effective than phasing out fossil fuel inputs. This brings the total CO2 capture in the CO2 neutral scenario to over 70 Mton CO2 in 2050. This CO2 capture takes place entirely in hydrogen production via the *ATR process* and in bioenergy combustion.

Difference in use of CCS in 2050.



Source: Quo Mare

In making the Dutch energy system more sustainable, hydrogen plays a key role in both scenarios. In the CO2-neutral scenario, this need is largely met by the production of blue hydrogen through the ATR process, totaling 7.7 Mton. To this is added a small amount of green hydrogen production from electrolysers (0.8 Mton) and imports (1.2 Mton).

In contrast, in the fossil-free scenario, blue hydrogen is not an option, and thus will require heavy investment in electrolysis capacity. This brings green hydrogen production to 1.5 Mton by 2050. Since potential electrolysis capacity is not sufficient to meet hydrogen demand, 3.5 Mton of green hydrogen will also be imported in this scenario.

Differences in investment costs

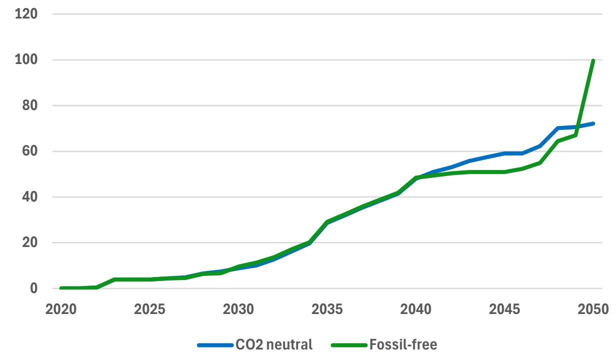
The model calculation shows that investment costs in the CO2-neutral scenario up to 2050 total EUR 72.1 billion. A fossil-free energy system in 2050 would require investments totaling EUR 99.7 billion. While the investment costs up to 2045 are comparable, the differences between the scenarios increase sharply in the last five years. This is due to the fact that investments in sustainability technologies are also made primarily in the last five years. For example, the total difference in investment costs in 2050 is as much as EUR 27.6 billion.

The difference in investment costs between the two scenarios is particularly reflected in investments in the renewable hydrocarbon industry, hydrogen production and the steel industry. In the carbon neutral scenario, the pressure on renewable carbon pathways is lower because fuels are still produced from fossil sources (natural gas), combined with CCS. As a result, investments are only made in cost-effective renewable production routes, bringing the investment costs for these to a total of EUR 10.1 billion.

In the fossil-free scenario, renewable hydrocarbons must cover all final demand, which also means investment in more expensive processes, pushing up the cost for this to EUR 16.4 billion. In addition to higher investment costs, this also results in the loss of exports. Maintaining exports would mean investing in capital-intensive processes such as *Power-to-Methanol*, based on syngas production from captured biogenic CO2 with green hydrogen, which involves a substantial cost and thus does not provide a profitable export product.

Timeline for investment costs in both scenarios (cumulative)

Billion euros



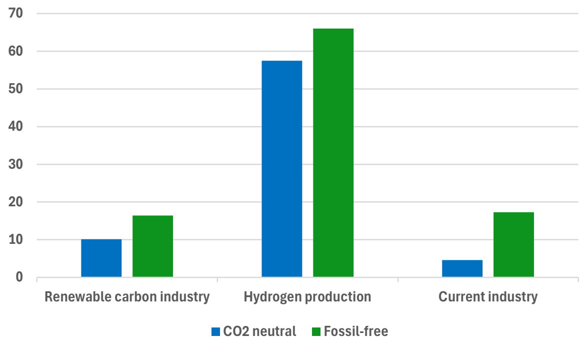
Source: Quo Mare

Regarding hydrogen production, the total investment cost is modeled at EUR 57.5 billion in the CO2-neutral scenario, where it is EUR 66 billion in the fossil-free scenario. This is mainly due to the investments in electrolysis capacity. These are at EUR 13.3 billion in the CO2-neutral scenario, while they are at EUR 30.1 billion in the fossil-free scenario. With this additional investment of EUR 17 billion, green hydrogen production in 2050 grows from 0.8 Mton to 1.5 Mton. This is not nearly enough to meet Dutch demand for green hydrogen in the fossil-free scenario. This creates an import requirement of 3.5 Mton of green hydrogen per year starting in 2050.

In the CO2-neutral scenario, hydrogen production costs also increase due to the additional production of blue hydrogen (ATR process with CCS). Investment costs in the ATR process are EUR 8.5 billion higher in the CO2-neutral scenario as a result. However, this is less than the investments in green hydrogen in the fossil-free scenario, which explains the difference in costs in terms of hydrogen production between the two scenarios.

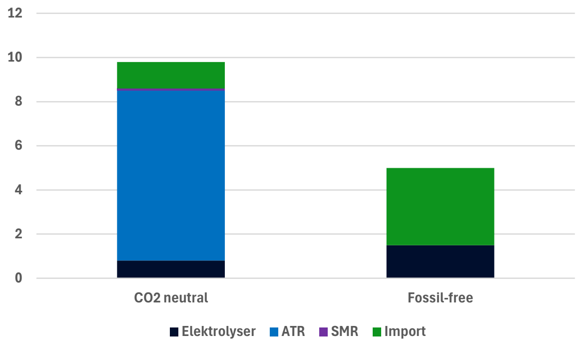
Investment costs until 2050 by category

Billion euros



Hydrogen demand fulfillment by scenario

Mton



Source: Quo Mare

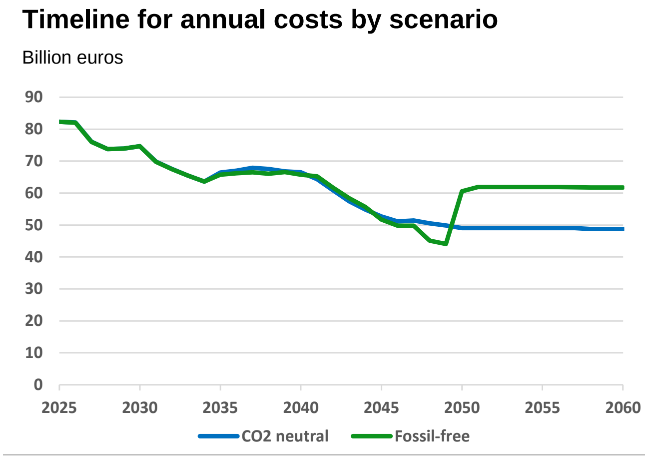
Source: Quo Mare

Finally, current industry, where fertilizer production, the steel industry and refineries in the Netherlands are currently the largest emitters. In total, investment costs rise to EUR 17.3 billion in the fossil-free scenario, well above the EUR 4.6 billion in the CO2-neutral scenario. This is mainly due to the substantial investments in the steel industry required to make the sector fossil-free. In contrast, there is no investment in the DRI process in the CO2-neutral scenario. This is because the use of coal in combination with CCS is the most profitable in this case.

Enabling exports in both the CO2-neutral and fossil-free scenarios requires large annual investments. In both cases, the question is whether this is economically feasible, and whether the Netherlands would then remain an exporter of, for example, many refined products, or whether it would mainly be production for own consumption. For fossil-free, those investments are considerably higher than for CO2-neutral, and thus export seems virtually impossible in the fossil-free scenario. In both scenarios, investments in the fertilizer industry drop to zero, restricting fertilizer exports from 2050 and making the Netherlands completely dependent on imports. Also, in both scenarios a similar amount is invested in electrifying steam crackers for the production of basic chemicals, such as ethylene, propylene and aromatics (benzene, toluene, xylene)

Differences annual costs

In addition to the fact that there are differences in the amount of investment costs, there are also significant differences in the annual costs per scenario. As can be seen in the graph below, it is striking that, as with the investment costs, the major differences only really become apparent from 2045 onwards. By choosing to let the model calculate what the economic consequences would be of certain policy choices, and contrasting these with the - economically - most favorable time to invest, we see that the cost trend of the two scenarios is almost the same for the next 20 years.



Source: Quo Mare

Only after those 20 years do the differences in annual costs become apparent. These costs consist of operational costs, transportation costs, the (purchase) costs of the raw material and fixed operational costs of ongoing projects. The depreciation costs of the aforementioned investments can be amortized over several years. We do not include these costs in the chart above to avoid double counting with respect to our analysis on differences in investment costs.

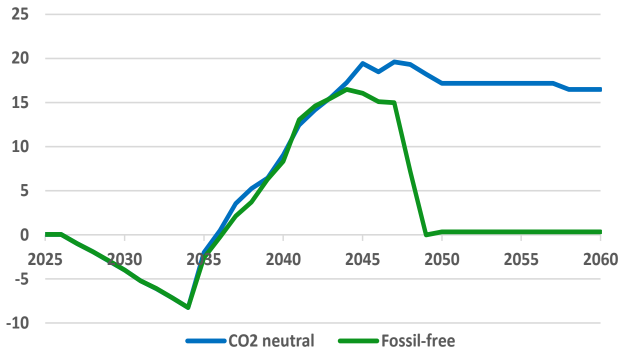
In the CO2-neutral scenario, the costs of Dutch industry stabilize around EUR 50 billion per year starting in the late 2040s. In contrast, in the fossil-free scenario, costs rise to over EUR 61 billion per year. The main reason for this is the purchase of green hydrogen. Since the Netherlands is about 70% dependent on green hydrogen imports in this scenario, the annual bill, with a cost difference rising from EUR 11.5 billion in 2050 to EUR 13 billion in 2060, will be significant.

Incidentally, the other cost differences are also significant. Here the annual transport/infrastructure costs are almost EUR 2.3 billion higher in a CO2-neutral scenario. Yet this is dwarfed by the complete cost picture.

By choosing certain investment costs - leading to differences in annual costs - by extension there are also annual differences in revenues. Whereas the Netherlands currently exports many refined products, in the CO2-neutral scenario these exports will shift to the export of mainly surplus hydrogen and/or green electricity. This provides an added value of over EUR 17 billion per year. In contrast, in a fossil-free scenario, the Netherlands is import-dependent and revenues will be only a few hundred million euros.

Timeline for annual (hydrogen) returns

Billion euros



Source: Quo Mare

Conclusion: choices cost money

When making climate policies, it is crucial to keep in mind the end goal of these policies - limiting global temperature rise. Many policies are currently driven by alternative or indirect goals that do not necessarily promote efficiency and effectiveness toward meeting the actual goal. One of the trade-offs that can have a major impact on the level of investment for meeting those goals is the choice of whether to eliminate fossil fuels altogether, or to make the energy mix emission-neutral to meet the Paris climate goals.

Many times the means to this end becomes an end in itself. One means of reducing CO2 emissions, and thus achieving the climate goal, is to stop using fossil fuels. Yet eliminating fossil fuels is not the initial goal of our climate policy. By obfuscating the goals, the energy transition may turn out to be considerably more expensive than is actually necessary. Most of this cost disadvantage will fall on the business community. They must largely bring about the energy transition in our country, while at the same time operating in an international playing field. This also means that extra costs incurred will be passed on as much as possible and thus indirectly to the consumer, read citizen, or voter.

Each member state of the European Union has its own goals, which are fleshed out by national policies. These policies are supported by the frameworks set by the European Commission (EC). Under Rutte IV, the Netherlands had set more ambitious goals than those imposed from Brussels. Opting for a frontrunner role fits the desire to be progressive and tone-setting compared to surrounding countries. That at the same time various methods were excluded, discouraged or delayed, leads to a transition path that seems fairly fixed for the coming years. Still, there are many choices to be made, especially for the period 2030-2050. The Schoof I administration will be at the forefront of these important choices.

That the making of certain choices by national governments leads to different economic consequences is inevitable. The moment governments make choices of techniques or methods that deploy certain means to achieve goals, it may be for strategic and/or ideological reasons. Especially at a time when geopolitical tensions are flaring up, and when cheap raw materials from certain countries are no longer desirable as a result of sanctions, this may be a plausible choice. Yet it is also good to look at economic consequences of our policies and to understand the cost differences between different transition paths. Not necessarily to make a value judgment about the policy, but rather to be able to have an open and honest debate about the costs of the transition, and - by extension - the consequences for Dutch industry.

One goal, two scenarios

In this report, we have contrasted two possible scenarios to clarify the differences in investment costs and annual direct costs and revenues. These two scenarios are: CO2 neutral and fossil free. In a CO2-neutral society, CO2 emissions from the extraction, transportation, conversion and consumption of fossil fuels can be captured through CCS, or offset with negative emissions. In other words, fossil fuels (oil and gas) can still be used in 2050 as long as CO2 emissions to air are avoided.

Under the fossil-free scenario, coal, oil and gas will no longer be used by 2050. Therefore, there will be a greater role for renewable carbon and renewable energy. Furthermore, some CO2 equivalent emissions will still need to be offset due to methane and nitrous oxide emissions from the agricultural sector.

For both scenarios, the electricity sector will no longer require fossil fuels over time. The biggest challenge lies in the remaining 82% of our current energy consumption. In the case of steering for purely economic considerations, the model calculations show that a large part of the current refining capacity will no longer be used in these two scenarios. A good portion of the current exports of refined products will then be discontinued. Obviously, other choices can still be made from strategic considerations.

A significant part of these transition paths are the same in both scenarios. Simply because investments and decision-making take place on the basis of the economically feasible and most affordable alternatives. The total remaining - as yet to be determined - CO2 emissions amount to about 54 Mton CO2 per year. The two scenarios show different ways of reducing these remaining emissions in order to reach the final target in 2050.

Fossil-free requires more investment than CO2-neutral, ...

In the period between now and 2040, both scenarios see the Dutch energy system gradually becoming more sustainable. One of the major drivers behind this is the EU ETS. From 2045 onwards, large differences are visible in the consumption of fossil resources in view of the different targets for 2050 in the two scenarios.

The difference in investment costs between the two scenarios is particularly reflected in investments in the renewable hydrocarbon industry and hydrogen production. Because a carbon-neutral scenario avoids emissions to the atmosphere, the emissions associated with fossil fuel combustion must be captured. This results in the degree of CCS use being one of the biggest differences between the two scenarios.

In the CO2-neutral scenario, imported naphtha, combined with CCS, along with some renewable carbon sources (such as pyrolysis oil) are inputs for the production of basic chemicals (such as ethylene, propylene and aromatics). This is not the case in the fossil-free scenario. In this scenario, only renewable carbon sources, including biogenic CO2, are used to make these basic chemicals. This requires more expensive synthesis gas-based processes, pushing up costs. The difference is EUR 6.4 billion in increased investment.

Finally, the sustainability of current industry, where fertilizer production and the steel industry are the largest emitters in the Netherlands. In total, investment costs here rise to EUR 17.3 billion in the fossil-free scenario, well above the EUR 4.6 billion in the CO2-neutral scenario. The difference between the scenarios is thus EUR 12.7 billion.

... import dependence on green hydrogen increases, ...

In the fossil-free scenario, import dependence on hydrogen increases sharply. Whereas in the CO2-neutral scenario blue hydrogen produced in the Netherlands can be used, in a fossil-free scenario this is largely replaced by imports of green hydrogen. This replaces part of the import of the much cheaper natural gas. Both fall under the indirect costs section.

In the CO2-neutral scenario, 0.8 Mton of green hydrogen in domestic production is combined with 7.7 Mton of blue hydrogen. In the fossil-free scenario, the cost increases by EUR 8.5 billion. This produces 0.7 Mton of additional green hydrogen, but at the same time makes the Netherlands about 70% dependent on imports of the green hydrogen needed. The much-heard argument that with (green) hydrogen we would be no longer, or less, dependent on imports therefore does not hold.

The model calculation thus shows that investment costs in the CO2-neutral scenario up to 2050 total EUR 72.1 billion. By contrast, a fossil-free energy system involves investments totaling EUR 99.7 billion. That makes this scenario a total of EUR 27.6 billion more expensive through 2050.

... and annual costs are also significantly higher

Another major difference between the two scenarios relates to annual costs for industry. Whereas in a CO2-neutral scenario the costs will stabilize around EUR 50 billion per year from 2045 onwards, they will be significantly higher in a fossil-free scenario from 2050 onwards. Due to the import dependence on green hydrogen, annual costs will rise to over EUR 61 billion per year. This cost difference of EUR

11.5 billion in 2050, rising to nearly EUR 13 billion in 2060, will be borne by Dutch industry. And, after being passed on, will therefore largely be borne by the Dutch citizen/voter.

By choosing certain investment costs - which lead to differences in annual costs - by extension, there are also annual differences in revenues. In addition to higher costs due to the import of green hydrogen in the fossil-free scenario, export revenues will be limited. In contrast, in a carbon-neutral scenario, surplus hydrogen produced will be able to be traded on the world market, which is estimated to generate revenues of about EUR 17 billion per year.

In terms of economic cost-benefit analysis, a CO2-neutral scenario thus works out much more favorable in net terms (costs minus benefits) than the fossil-free scenario. With a net difference of nearly EUR 30 billion per year, the costs plus benefits in a fossil-free scenario are significantly higher than in a CO2-neutral scenario from 2050.

The different scenarios ultimately lead to different energy systems in 2050 and, on the path to them, to different investment costs and returns. At the same time, both scenarios achieve the same ultimate goal: no emission of CO2 into the atmosphere. The modeling underlying this report assumes only direct costs and revenues. Thus, any indirect costs and revenues associated with a particular energy system are left out of this quantitative analysis. If these were taken into account, the annual cost differences between the scenarios would increase even further.

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List of abbreviations

ACU	Ammonia Cracking Unit
ATJ	Alcohol to Jet
ASU	Air Separation Unit
ATR	Autothermal Reforming
BCM	Billion Cubic Meter
BECCS	Bioenergy with Carbon Capture and Storage
BTL	Biomass to Liquids
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
DRI	Direct Reduced Iron
EU ETS	European Union Emissions Trading System
FT	Fischer-Tropsch
HDV	Heavy Duty Vehicle
HTH	High Temperature Heating
HVO	Hydrotreated Vegetable Oil
KEV	Climate and Energy Outlook.
MTO	Methanol to Olefins
MTG	Methanol to Gasoline
MSW	Municipal Solid Waste
PBL	Netherlands Environmental Assessment Agency
PJ	Petajoule
PO	Polyolefin
PSA	Pressure Swing-Absorption
PTL	Power to Liquids
PTM	Power to Methanol
RDF	Refuse Derived Fuel
SAF	Sustainable Aviation Fuel
SDE++	Stimulation of sustainable energy production and climate transition
SMR	Steam Methane Reforming
TDES	Transformation of the Dutch Energy System.
WGS	Water Gas Shift
WTL	Waste to Liquids

List of chemical compounds

CO	Carbon Monoxide
CO2	Carbon Dioxide
CO2-eq	Carbon dioxide equivalent
H2	Hydrogen
H20	Water
NH3	Ammonia

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