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Implications of innovative options for transport on the level of the energy system

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Summary

There are several options to reduce greenhouse gas emissions from transport by 60% in the Netherlands, by 2050. In addition to efficiency improvement, new types of fuels, such as electricity, hydrogen and biofuels, also are important new energy carriers. Their introduction, however, has to be part of an integral systems innovation and their production will require certain adjustments. It also will offer opportunities, such as an improved balancing of the demand and supply of renewable electricity within a certain period of time (e.g. day or night). Some of the technical interactions within the energy system have been analysed using the E-design model. We find substantial additional emission reductions in the energy, industry, built environment and fuel production sector, in most cases of 2 to 5 Mt CO_2 eq (1% to 2% of current total emissions in the Netherlands). In addition, even higher reductions would be possible if carbon capture and storage (CCS) would be introduced in the production processes of biofuels. On a system level, the expected limited availability of sustainably produced biomass, which also affects transport, requires an integral vision on its preferred future applications.

Introduction

Europe has set a challenging climate policy target of reducing greenhouse gas emissions by 80% to 95% by 2050, compared with 1990 levels. This will require fundamental changes, especially to the energy system. The European Commission has published a climate road map showing the possibility of an 80% reduction within European borders (European Commission, 2011a). In order for this target to be achieved, all sectors would have to contribute, with the potential for emission reductions being greater in some sectors than in others. For the transport sector, the road map would result in a 60% emission reduction (European Commission, 2011b). This 60% reduction is the long-term target for the Netherlands, as was recently published in the Dutch Energy Agreement for Sustainable Growth (SER, 2013).

The presented European road map suggests there is an optimal package of options for realising the long-term European target. However, there are many different options to create a low-carbon energy system, but the uncertainties about the costs of these (technological) options are much too high to perform a cost optimisation. An explorative study has illustrated how an 80% emission reduction could be achieved in the Netherlands (PBL/ECN, 2011). Emission reductions per sector differ substantially and, in the Netherlands, emissions from transport are relatively hard to reduce.

Appendix 1 shows the results from an analysis of the Dutch energy system as a whole and the importance of individual technologies for the realisation of an 80% greenhouse gas emission reduction. It shows that electric and hydrogen transport technologies are some of the relatively important technologies, without which it would be much more difficult to reach the target. The only technology that is even more vital in this respect, is the production of hydrocarbons from biomass in combination with CCS, especially because of the negative emissions and the lack of clean alternatives for some applications. This option obviously is strongly related to biofuels for transport, as well.

For this study, we analysed some of the options to realise a 60% emission reduction in the transport sector in the Netherlands as the necessary contribution to an 80% reduction for the whole system. Dutch shares in global air traffic and shipping are not (yet) included in the Dutch emission reduction target (SER, 2013). An ambitious reduction target of 80% or more requires innovation of the entire energy system. This is more than a series of measures for every sector. The choice for a specific technology in transport has a strong impact on processes in the production chains of fuels and vehicles. This report illustrates and quantifies that impact. Our analysis mainly concerns the options for a future system rather than the various pathways to get there; nor have the behavioural changes been taken into account. This is followed by a discussion on the steps to be taken today to develop one of the more important options, namely that of electric driving.

For the Netherlands, calculations were carried out, using the E-Design model, and included interactions with neighbouring countries. The E-Design model, as a tool for backcasting, was developed by PBL Netherlands Environmental Assessment Agency and the Netherlands Energy Research Centre (ECN). The model supports the development of an energy system for 2050 designed to meet a specific target level for greenhouse gas emissions. It includes many technical options for all sectors and the interactions between the sectors. This paper briefly describes the model itself, our analysis assumptions and results, followed by a discussion on these results.

E-Design

The E-Design model has been developed by PBL and ECN as a tool for backcasting, focusing on the energy system for the Netherlands. It is a tool for the design and development of a future energy system.

The focus of the model is on the energy supply side of the energy system. The energy demand from the different sectors is a model input, although there is the option to define several levels of energy demand, based on existing analyses. In this respect, the importance to save energy can be included in the analysis. For the transport sector, efficiency improvements to vehicles and other means of transport are included (Office of Public Sector Information, 2007). Interactions with other European countries are included in the model, but institutional aspects and environmental policies are not. The target year of 2050 ensures a sufficient degree of freedom to design a new Dutch energy system, to some extent, independent of the present situation.

The user of the E-Design model determines and selects the technologies for the design of the energy system. The model calculates the greenhouse gas emissions and production costs, based on the system designed by the user. The design of a new energy system is a search that involves combining system options with various results, and the E-Design model guides the user by indicating the consequences of a particular design, enabling the user to adjust and calculate alternative options, in an iterative way.

The model enables the defining of a broad range of options for a future energy system. It includes the most important sectors: transport, built environment, industry and energy production including electricity, methane, liquid transport fuels and hydrogen. The model distinguishes 17 subsystems (Figure 1). The E-Design model divides the transport sector into three subsystems: 1) Passenger vehicles in an urban area, 2) light-duty vehicles, and 3) heavy-duty vehicles. All other transport modes are also taken into account but are not included in a subsystem. Furthermore, shipping and aviation are included in the biofuel option. Overall, the model includes over a hundred technical options, some widely used, some more innovative options that are currently in the phase of development, niche markets or early diffusion. The characteristics of these technologies, costs and efficiencies, by the year 2050 were assessed by experts. Based on literature and experience, experts of ECN and PBL estimated these values, including a range that includes both optimistic and pessimistic views.

The model ensures consistency in supply and demand for all specific energy carriers, and for electricity, because of the intermittency issue, even on an hourly base.

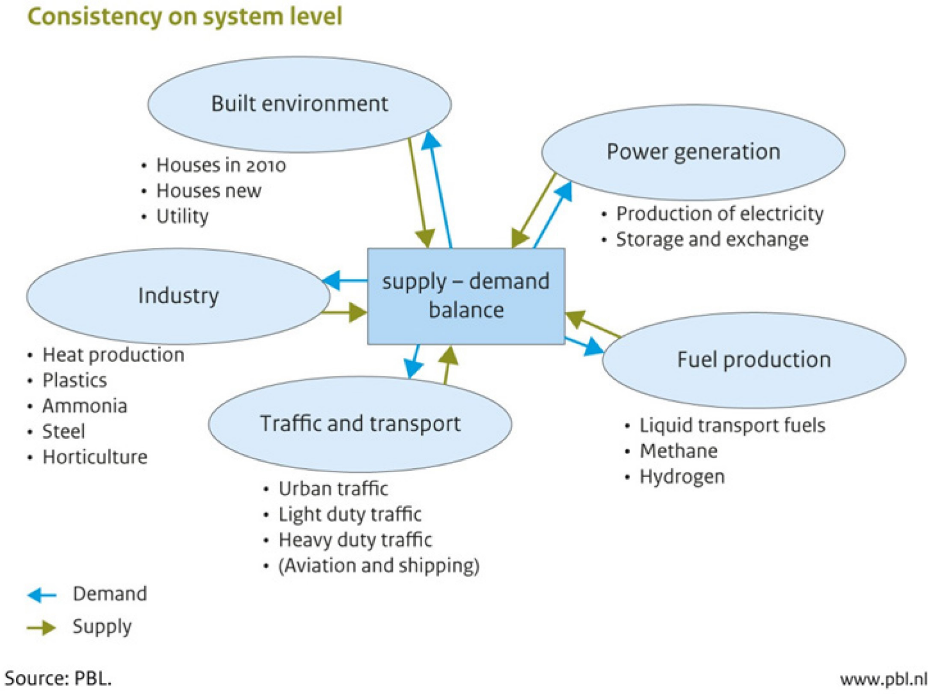

Figure 1 The E-Design model

In interactive sessions, the model may be used to design an energy system for 2050 that meets specific targets. The main target is the level of greenhouse gas emissions. However, restrictions may also be included, such as the supply of biomass, the storage capacity for CO_2, or for wind, solar, geothermal or nuclear energy. The main result from an interactive session consists of the user's ultimate design. Another output of the model is that of total production costs, based on expectations of price/performance ratios in 2050 and estimates of future prices for technology options. Because of the uncertainties on long-term costs, cost optimisation was not included in the model.

When designing a future energy system, the user defines the choice of technologies in the subsectors available in the model, in terms of a percentage for the contribution by each technology to the total output of the subsector (such as a percentage of electric or hybrid cars). Finally, the model calculates the consequences of the configuration designed by the user and reports the related greenhouse gas emissions, production costs for the energy system, and its total use of resources.
Table 1 shows, for example, the technical options for light-duty vehicles with the main assumptions on their future actual performance. This includes efficiency improvements in the national car fleet, for all types of cars examined in this study, based on business as usual improvement and current policy (CE, 2011).

Table 1 Technical options for transport and their characteristics in 2050

Emission factors (gram CO_2/km)	
Small urban car ICE	90 *
Average passenger car	
• Internal combustion engine	120 **
• Hybrid	110 **
• Plug-in hybrid	40
Heavy-duty vehicle	640
Electricity (kWh/km)	
Small electric urban car	0.05
Average passenger car	
• Plug-in hybrid	0.12
• Electric car	0.19
• Plug-in fuel cell	0.12
Hydrogen (MJ/km)	
Average passenger car	
• Fuel cell	0.94
• Plug-in fuel cell	0.33
Heavy-duty vehicle	11.0

*) actual emissions from the national average car fleet, not from test cycles
**) Average of whole national fleet including light-duty vehicles

Methodology

A 60% reduction target was the starting point for the calculations on transport.

For the Netherlands, this led to a reduction target of 85% for the four other sectors together (energy, industry, built environment and fuel production) to realise an overall emission reduction of 80% or 45 Mt CO_2 eq). With the help of E-Design, four quite different options were composed to realise this 85% reduction target for those other sectors, without taking the measures in the transport sector into account, with the exception of improvements in car efficiencies. Table 2 shows some of the main characteristics of these system options, which mainly differ in the type of power generation.

Table 2 Some of the main characteristics of system options

Variants of systems options (excluding transport)	Description of the main differences in characteristics
SO1	Large shares of nuclear power and natural gas with carbon capture and storage (CCS) in power generation
SO2	Large shares of offshore wind turbines and photovoltaics in power generation in combination with natural gas
SO3	Large shares of natural gas and coal, including biomass co-firing, both with carbon capture and storage, for power generation
SO4	Large share of natural gas, only partly with carbon capture and storage, for power generation More energy saving and other measures in industry and the built environment

Subsequently, to realise a 60% reduction, measures were added for the transport sectors (road transport, shipping, aviation) including those on biofuel, electric vehicles or fuel-cell cars on hydrogen and hybrid vehicles. These measures also affect the emission levels in other sectors in several ways. The E-Design model was used for calculating this impact on the emissions in the other sectors. Four different options for transport and transport fuels have been studied (see Table 3). The proportional contribution of specific technologies in other sectors would remain unchanged under the various options. In the Netherlands, the emission reduction percentage for transport would equal an absolute emission of 17 Mt CO_2 equivalent by 2050. These emissions include those from the international shipping and aviation sectors based on a per-capita distribution.

In the analysis, we assumed that electric light-duty vehicles are less suitable for long-distance travel (PBL, 2009). Thus, their contribution was limited to 50%, completed by another 50% in plug-in hybrids with fuel cells. Although fuel-cell passenger vehicles would enable long-distance travel, energy conversions in the hydrogen production chain would cause more energy loss than in case of electric vehicles.

To reach the transport sector target of 17 Mt CO_2 equivalent, biofuels are an important option. For our analysis, we chose biofuel production by gasification of biomass with the option of CCS (IEA, 2009, 2011a, 2012) or reuse of CO_2, followed by the synthesis of liquid fuel. It should be noted that there are promising alternatives, as well (e.g. advanced fermentation). Because the efficiency of gasification is limited and about 50% of the biomass is assumed to be needed as process energy, a relevant part of the carbon can be captured, leading to negative emissions for this process.

Table 3 Variants of future options for transport and the production of liquid transport fuels

Code	Description
Bio	• Transport vehicles on liquid fuel (100%) including heavy-duty vehicles • 62% share of biomass gasification in fuel production • Biomass gasification without CCS
Bio_CCS	• Transport vehicles on liquid fuel (100%) including heavy-duty vehicles • 62% share of biomass gasification in fuel production • Biomass gasification with CCS
El_Bio	• Electric and hydrogen propulsion (fuel cell) (both 50%) and heavy-duty vehicles on liquid fuel (50% on diesel and 50% on hydrogen) • 35% share of biomass gasification in fuel production • Biomass gasification without CCS
El_Bio_CCS	• Electric and hydrogen propulsion (fuel cell) (both 50%) and heavy-duty vehicles on liquid fuel (50% on diesel and 50% on hydrogen) • 35% share of biomass gasification in fuel production • Biomass gasification with CCS

For this analysis, we made assumptions on the economic activities of 2050 in the Netherlands. This view on the future was based on the Reference Projection (ECN/PBL, 2010), which was subsequently extrapolated to 2050 (PBL/ECN, 2011) (IEA, 2012). It includes an increase of 20% in light-duty road traffic and 32% in road freight traffic compared to 2010.

Table 4 Assumptions on transport activities in the Netherlands in 2050

Billion kilometres per subsector	
Urban transport	22
Passenger vehicles and light-duty transport	105
Heavy-duty transport	10
Liquid fuels (PJ)	
Shipping, aviation, and land transport modes not mentioned above	1758
Rail transport en other electromobilty (TWh)	2

Results

We calculated the impact of the various options that would realise an emission reduction in the transport sector of 60% on the emissions in the energy, industry, built environment and fuel production sectors (see Table 5). In general, the various options would result in an additional emission reduction in the other sectors (an overall emission level of less than 45 Mt CO_2 eq). The introduction of carbon capture and storage (CCS) in the production of biofuels by far would be the most important factor, because negative emissions for the overall energy system would be feasible that way. Without CCS, the additional emission reduction would be limited to between 2 and 5 Mt CO_2 eq. In case the emissions from the electricity sector would be relatively high (option SO4), electric and fuel-cell cars would deliver an additional reduction of between 0 and 4 Mt for the total energy system.

Table 5 Impact of measures to realise a 60% emission reduction in transport on a systems level

System variant	Transport variant	Total system emission Mt CO_2 eq/year	Biomass used PJ/year	CO_2 storage capacity Mt/year
SO1	Bio	41	1027	44
	Bio_CCS	-11	1055	95
	El_Bio	41	578	50
	El_Bio_CCS	24	587	67
SO2	Bio	41	934	35
	Bio_CCS	-11	961	86
	El_Bio	41	453	37
	El_Bio_CCS	24	462	54
SO3	Bio	41	1116	74
	Bio_CCS	-11	1146	125
	El_Bio	41	698	89
	El_Bio_CCS	24	708	106
SO4	Bio	41	1059	52
	Bio_CCS	-11	1088	103
	El_Bio	45	631	62
	El_Bio_CCS	27	641	79

The batteries in electric cars could serve as a storage facility for other power-use purposes (e.g. during spikes in supply or demand), especially in case of a high share of wind and solar electricity. We studied the impact based on the assumptions that the charging process is controlled for optimal balancing of electricity, the electricity in the batteries is not stored for more than one day, and that there are no other storage facilities and no additional interaction with other countries for balancing. A loss of wind and solar electricity of about 17% (as would be the case in system option SO2) was reduced by 1% to 2% by the introduction of the El_Bio variant. Although this would be a benefit for whole system of power generation, it also shows that balancing supply and demand would mainly be a problem over periods of more than 24 hours.

Discussion

The results from the analysis show that zero-emission cars powered by electricity and/or hydrogen may be a very important, not to say vital part of a low-carbon economy, not only because of the direct effect on transport emissions, also because of the positive impact on the energy system as a whole. Furthermore, the negative emissions related to biofuel production with CCS, with the highest potential under the Bio_CCS option, offer attractive prospects. However, the options differ strongly in the use of biomass and CO_2-storage capacity needed. The future availability of biomass and CO_2-storage capacity can only be estimated roughly, but will definitely not be unlimited. A strategy for the energy transition should include these limits and uncertainties.

Because of a limited national supply in the Netherlands (estimated at 200 PJ for 2050), most of the biomass will have to be imported. Estimates on the potential global supply in 2050 vary from an optimistic 400 EJ to a more realistic 100 to 200 EJ. Especially the assurance of sustainability is more doubtful in the first estimate. Table 6 presents an indication of the potential supply for the Netherlands, based on equal biomass shares, globally. However, countries with large amounts of biomass tend to use more, and this makes an equal distribution over the world rather unlikely. In this respect, the numbers in Table 6 may be somewhat optimistic for the Netherlands.

Table 6 Potential supply of biomass in 2050 for the Netherlands. (Dornburg *et al.*, 2010; IEA, 2007; IPCC, 2011; Van Vuuren *et al.*, 2010; WGBU, 2008)

Equal share	Share of the Netherlands in 2050	Potential supply for the Netherlands in 2050	
		Based on global supply of 150 EJ	Based on global supply of 400 EJ
Per capita	0.19%	285 PJ	760 PJ
Per unit of GNP	0.49%	735 PJ	1960 PJ

In case of a potential energy supply of about 700 PJ, only the transport variants that are based on maximising electric transport could be considered realistic. Around 1000 PJ of biomass would be needed for a 60% reduction in transport emissions that has to be realised only through the use of biofuels. In case of system option SO3 (about 18% co-firing of biomass in coal plants) in combination with maximising electric driving, would still require around 700 PJ of biomass.

The spectacular impact of CCS on emission levels in biofuel production requires large CO_2 storage capacity. However, again, this storage capacity would only be limited. We can distinguish between storage capacity under the Dutch area of the North Sea, below ground in the Netherlands (which was excluded because of current public resistance), and storage capacity in the rest of Europe. Table 7 presents a survey of the estimates. Dutch storage capacity is mainly located in (almost) empty gas fields (Slochteren field not included for 2050). European capacity is mainly located in a big aquifer in the Norwegian part of the North Sea. Some CO_2 is already being stored there. However, there is still uncertainty about the safety of storing huge amounts of CO_2 in such aquifers, because there is no experience with this CO_2 storage on that scale.

Table 7 Potential CO_2 storage capacity. (CO2Europipe, 2010; EBN/Gasunie, 2010)

Location	Storage capacity	
	Megatonne	Mt/year (available for 50 years)
Netherlands (North Sea)	1200	24
Netherlands (below ground)	1000	20
Equal share per capita of European capacity (EU27)	10366	207

It is clear that, for the Bio_CCS and El_Bio_CCS options, CO_2 has to be exported. For SO3 en SO4, even without CCS, biofuel production will require the export of CO_2 because CCS is implemented elsewhere in the energy system. It should be noted that the CCS capacity required in the transport variant El_Bio is higher than under the Bio option. The main reason for this is the fact that some methane gas is produced during the process of biomass gasification with CCS, and this gas is subsequently used for power generation, which increases under the El_Bio option. This, again, illustrates the interdependencies within the energy system.

The urgency to accelerate the transition towards electric driving

The results show that electric driving is an important option to realise emission reduction targets and restrict the dependency on CO_2 storage capacity and the import of sustainable biomass. The question is whether there will be enough time to realise this transition before 2050? The average lifetime of a car is less than 15 years, suggesting there is enough time to replace the current fleet of vehicles by electric vehicles before 2050. However, the shift to electric driving requires more than producing a new type of car (see Figure 2). Development and construction of a new energy system with sustainable and clean energy sources takes decades. Changes within the coming period will co-determine the system in 2050 (ECN/PBL, 2013; PBL, 2012; PBL/Stockholm University, 2009). Preparations, learning processes, partnerships and required procedures all are time consuming issues.

For electric driving to be commonplace by 2050, a significant number of electric cars already will have to be sold in the years from 2035 to 2040. Taking into account that the coming decade will be needed for the learning phase, during which time the public has to obtain more confidence in the performance of electric vehicles and the price of batteries has to decrease, the share of electric vehicles up to 2020 will be limited to a few per cent. Low-carbon transport requires full engagement and participation of all stakeholders to bring about changes in behaviour. This then leaves a period of 15 to 20 years for the actual transition.

The manufacturing of electric cars not only takes place in car factories. The extraction of raw materials (e.g. lithium for batteries) and a large battery production capacity also will be needed. Their development has to be in balance, to prevent large price fluctuations and associated disruption of the battery market. Furthermore, the infrastructure for charging those batteries has to be developed (European Commission, 2013). Again, such a development interacts with development in the production of electric vehicles. These interdependencies slow down the actual rate of change. Therefore, 15 to 20 years is a relatively short period and it is very urgent that the transition process be accelerated to the largest extent possible.

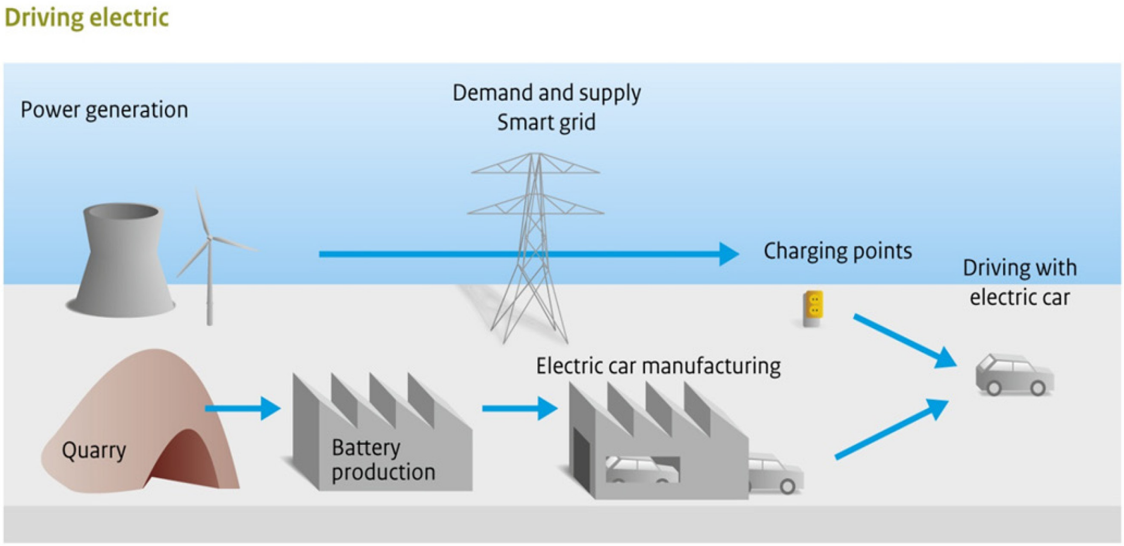

Figure 2: Schematic view of a new system for the realisation of electric driving

Different roadmaps, such as for electric and plug-in hybrid electric vehicles (IEA, 2011b, 2012), describe possible ways to go forward and which first steps to take. It should be realised that such first steps would be part of a learning process. The main target for the first ten years is to convince a sufficient number of drivers that electric vehicles are the most attractive option, batteries have a long life time and the system offers a large enough range. Experiences in practice and a scale up in production are needed as well as realistic plans for battery charging systems, to assure people of the availability of sufficient numbers of charging points nearby their homes.

However, another innovative option is available, although is still on a distant horizon. Liquid fuel or methane can be produced from (captured) CO_2 and H_2 (Frauenhofer, 2009). Especially if H_2 production could be based on an overproduction in renewable electricity, in the future, it may provide an integral solution. The costs for this option are still very uncertain, not only because of limited experience with this type of synthesis on a large scale, but particularly because the real costs are related to the design of the system as a whole and the availability of low-cost renewable electricity.

Conclusions

Low-carbon transport offers opportunities to also improve emission levels in other sectors. Additional emission reductions can be realized. Electrification fits well into a low-carbon system, optimising the use of the many technological options to produce clean electricity. The potential impact of biofuels on biomass demand and CO_2 storage capacity also shows that the energy transition requires an integral strategic approach. The results point to the potential decisive role of biomass combined with CCS, to achieve negative emissions. But the availability of sustainable biomass and safe and publicly accepted storage facilities for CO_2 is critical.

The large demand for biomass in the SO3 option is related to the co-firing of biomass in coal-fired power plants, showing that strategic priorities may have to be set for the use of biomass, even in the case of maximising electric transport. A good strategy for clean transport is strongly related to the role of biomass in general. This future role can be based on estimates on future sustainable supply. Using the most optimistic estimates may lead to disappointment, which would be especially painful if the alternatives for biofuels receive no support. Also the future role of CCS is related to the use of biofuels.

Appendix 1

Comparison of the importance of the availability of technologies for a clean economy by 2050. Source: PBL/ECN. 2011

Technology	**Relative importance in the Netherlands**	**Explanation**
Wind onshore	Limited	The technology fits in closely with the vision of the future, but the potential for the Netherlands is thought to be limited; therefore, not using this option can be compensated for by other technologies.
Wind offshore	Large	The technology fits in closely with the vision of the future and has a large potential. Not using this option will require an increase in import of clean energy or a larger share of nuclear energy.
Solar PV	Limited	The limited use of this technology fits in well with the vision of the future. However, it has its limitations (more so than wind) with regard to matching supply and demand.
Nuclear energy	Large	The technology fits in closely with the vision of the future and has a large potential. Not using this option can be compensated for by wind and solar energy (supplementary solutions for matching supply and demand will then also be required)
Gas-fired power plant with CCS	Limited	This will become much more important if no pan-European electricity grid will be built with a large exchange capacity. Gas-fired power plants are important in providing a flexible supply.
Coal-fired power plant with indirect co-firing of biomass and CCS	Very limited	Although this is a form of electricity generation with low, sometimes even negative, emission levels, there are also clean alternatives, and many variants at the system level in which better use can be made of biomass and CO_2 capacity for the production of fuels or green gas.
Heat from geothermal energy	Limited	The technology fits in closely with the vision of the future, but the potential for the Netherlands is limited; therefore, not using this option can be

		compensated for by other technologies.
Solar heating	Limited	The technology fits in closely with the vision of the future, but the potential for the Netherlands is extremely limited, as supply is mainly available in the summer and additional technology will be required in the winter.
Electrical heat pumps	Large	This technology plays an important role in the electrification of industry, horticulture and buildings, helping to increase the amount of clean electricity used.
Micro CHP with hydrogen	Limited	Hydrogen can be produced by using electricity, but the energy losses are high if this hydrogen is subsequently used to generate electricity. It would only be useful if hydrogen was used as a storage medium (a less obvious choice) or if it would be produced from biomass.
Micro CHP with methane	Very limited	Decentralised electricity generation that makes use of natural gas does not result in emission reductions if the centralised electricity generation system produces no, or very little, emissions. Local application with biogas may be a useful supplement.
Biomass gasification for fuels (+CCS)	Very large	The production of biofuels (green gas, transport biofuels) is crucial for sources for which there are few clean alternatives. It also has the advantage that biomass gasification with the capture of CO_2 released during the process has negative emissions.
Electric cars	Large	This type of vehicle may make an important contribution to electrification and therefore to the role of clean electricity, partly due to the flexibility provided by battery charging.
Hydrogen cars	Large	These vehicles could provide an alternative to electric vehicles but may be more useful as an additional option for long distance road traffic and transport.
CCS of industrial emissions	Large	For many processes there are no alternatives, or the alternatives are shrouded in uncertainty.

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