Effects of Climate Policies on Emissions of Air Pollutants in the Netherlands

Policy Studies

Netherlands Environmental Assessment Agency

ECN
Energy research Centre of the Netherlands

Effects of Climate Policies on Emissions of Air Pollutants in the Netherlands

First Results of the Dutch Policy Research Programme on Air and Climate (Beleidsgericht Onderzoeksprogramma Lucht en Klimaat [BOLK])

In cooperation with:
- CE Delft
- Ecofys
- Netherlands Organisation for Applied Scientific Research (TNO)
- Copernicus Institute, University of Utrecht (UU)

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Rapport in het kort

Effecten klimaatbeleid op luchtkwaliteit gunstig maar nog wel onzeker
De maatregelen uit het Nederlandse klimaatprogramma 'Schoon en Zuinig' hebben als doel de vermindering van de uitstoot van broeikasgassen. Sommige van deze maatregelen, zoals energiebesparing en inzet van meer windenergie, leiden ook tot de vermindering van de uitstoot van luchtverontreinigende stoffen. Van een aantal andere belangrijke klimaatmaatregelen is het effect op de uitstoot van luchtverontreinigende stoffen echter nog onzeker of onbekend. Om deze onzekerheden te kwantificeren zijn in 2008 onderzoeken uitgevoerd als onderdeel van het Beleidsgerichte Onderzoeksprogramma Lucht en Klimaat (BOLK)

De onderzoeken hebben aangetoond dat de klimaatmaatregelen gericht op het vergroten van de inzet van biobrandstoffen en biomassa en de afvang en opslag van koolstofdioxide niet hoeven te leiden tot een daling van de uitstoot van luchtverontreinigende stoffen. In sommige gevallen kan de uitstoot van bepaalde vormen van luchtverontreiniging zelfs toenemen. Het netto-effect van alle maatregelen uit het Nederlandse klimaatprogramma is echter gunstig voor de luchtkwaliteit. Wel blijven de onzekerheden in deze effecten vooralsnog groot.

De in BOLK opgedane kennis over specifieke klimaatmaatregelen kan bijdragen aan het op efficiënte wijze vormgeven van het toekomstige Nederlandse klimaat- en luchtbeleid. Mogelijk is de kennis ook interessant voor andere landen die dergelijke maatregelen invoeren of overwegen.

Content

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Summary

- In general, measures to abate greenhouse gas emissions, will also reduce other air polluting emissions (especially sulphur dioxide and nitrogen oxides). Climate measures in the Netherlands could reduce the additional costs of meeting the indicated national emission ceilings for air pollutants in 2020, by up to 50% (or 150 million euros). These cost reductions are relatively small, compared to the total of the indicated costs of the additional Dutch climate measures (about 3-9 billion euros).
- The effect of national and EU climate and energy policies on the reduction in domestic greenhouse gas emissions is uncertain. This is due to uncertainties about the future CO_2 price, which, among other things, will determine the extent to which CO_2 credits will be purchased abroad. Other uncertainties concern the effects of specific climate measures. Moreover, Dutch electricity export might even increase further under the EU climate and energy policies, due to the competitiveness of Dutch coal-fired power plants.
- When a large proportion of the climate targets for the Dutch industry would be met through the purchasing of CO_2 credits abroad, co-benefits would also occur abroad, in the form of lower sulphur and nitrogen emissions. Thus, cost savings from the reduction of these domestic air pollutants would be considerably less.
- Some CO_2 abatement measures will not necessarily reduce other air polluting emissions, for instance, the application of biofuels and biomass, and carbon capture and storage (CCS).
- The blending of biofuels in diesel or petrol creates a risk for increased emissions of air pollutants. This risk is the lowest for mixtures with less than 5 to 10% in biofuels. Using blends with higher amounts of biofuels requires specially adapted vehicles, to avoid increased air pollution. The legislation on European reference fuels, to be used in approval tests for new vehicles, should include the required blends of biofuels that meet the European biofuels targets.
- Instead of converting biomass into biofuels, it could be used more efficiently for the production of hydrogen or electricity. In addition, the air quality benefits from these green energy carriers could be larger if they would be allowed to contribute to the renewable energy target for road transport.
- Emissions resulting from the cultivation, transport and refining of biofuels, are generally higher than those generated by the production of fossil fuels (except for sulphur dioxide). This can be important since the production cycle emissions from biofuels can be larger than the emissions during its end use in road transport.
- Co-firing biomass in large coal-fired power plants will have a positive effect on air pollution. Biomass generally contains lower amounts of sulphur than coal, and changes in fuel quality and combustion can be dealt with by advanced flue-gas cleaning equipment. However, a growing number of small and medium-sized biomass, biofuel and biogas installations may increase air pollution, when emission limits for these installations remain less stringent, compared to those for larger-sized installations.
- Currently available post-combustion carbon capture and storage techniques can lead to a decrease in SO_2 emissions, but may lead to an increase in NH_3 and NO_x emissions, if no additional measures are taken. In case of a high CO_2 price, such techniques might be applied in the Netherlands, by 2020. Emerging pre-combustion CCS techniques and oxy-fuel techniques will probably deliver a better environmental performance, but they may not become available before 2025.

Addressing the effects of climate policies on air pollution

Greenhouse gases (GHG) and air pollutants share a number of common sources, such as energy conversion and agricultural activity. It is well recognised that climate change mitigation measures are generally beneficial to air quality, as well as for reducing greenhouse gases (GHG). In recent years, this synergy between air and climate policies has received more attention, following the adoption of more ambitious climate targets set by the European Union and the Dutch Government (see Chapter 1). Policies have been proposed by the European Commission (EC, 2008a,b,c,d,e) and the Dutch Government (Dutch Climate Programme 'Clean and Efficient') to address these targets.

Some climate measures have similar and well-known effects on emissions of air pollutants and GHGs. An example is energy saving. This causes a reduction in energy demand for among other things, conventional fossil-fuelled power plants. And conventional power plants emit well-known quantifiable amounts of both GHGs and air pollutants.

However the effects of some important climate measures on levels of air polluting emissions are less obvious. Particularly uncertain are the effects on the levels of air pollutants from 1) the use of biofuels in road transport; 2) the use of biomass, biofuels and biogas in stationary installations; 3) the emissions resulting from the chain of cultivation, transport and processing of biofuels and biomass, and 4) the application of various types of CO_2 capture and storage (CCS). To identify possible effects in more detail and – where possible – fill in the knowledge gaps on the climate measures, a research programme on air and climate has been established in the Netherlands, called '*Beleidsgericht Onderzoeksprogramma Lucht en Klimaat*' (BOLK).

This report integrates the results of four dedicated studies on climate measures, carried out in the first phase of the BOLK programme, together with an earlier assessment of the effects of the Dutch climate programme on national levels of air polluting emissions (Daniels *et al*., 2008). Below, this updated assessment is summarised followed by highlights from the main results of the four dedicated studies:
- the effects of biofuels in vehicles (Verbeek *et al*., 2008)
- the effects of biomass in stationary installations (Boersma *et al*., 2008)
- emissions resulting from cultivation, transport and refining of biofuels (Koper *et al*., 2008)
- effects of CO_2 capture and storage on air pollution (Harmelen *et al*., 2008)

Updated integrated assessment of the effects of the Dutch climate programme on air pollution

The results of the first phase of the BOLK research programme confirm that the Dutch climate programme 'Clean and Efficient', together with the measures proposed in the EU climate programme, create a reduction in GHGs and most of the priority air polluting emissions in the Netherlands (Figure S1). Clearly, there is a large range in terms of projected emission reductions. This is due to the uncertainty about the future price of CO_2 in the EU Emissions Trading Scheme (EU ETS), the effects of individual climate and energy measures and the export of electricity. The lower end of the range assumes a European CO_2 price of 20 euros/tonne and assumes export of electricity (about 25% of projected Dutch production in 2020). The higher end assumes a CO_2 price of 50 euros/tonne and no net export of electricity. The analysis shows that additional measures will be needed to meet the targets, as current Dutch climate targets and the indicated national emission ceilings for priority air pollutants are outside of these ranges.

Important measures for reducing GHG emissions in the Netherlands include energy saving, mainly through European directives on more efficient electrical appliances, more efficient passenger cars, and insulation of houses and buildings; the use of biofuels in road transport; road pricing; subsidising renewable energy, such as wind and solar energy; and stimulation of the use of combined heat and power (CHP) including CHP-using biogas from co-fermentation of manure and CCS. It is expected that these measures will lead to additional decommissioning of existing coal- and gas-fired power plants. Also, if the CO_2 price in the ETS is sufficiently high, capture and storage of up to 10 Mt of CO_2 ($MtCO_2$) is assumed to be realised, by 2020.

These climate measures also reduce air polluting emissions (Figure S1). Emission reduction is most apparent for SO_2 and result mainly from the increasing decommissioning of coal-fired power plants, from the application of CCS (post-combustion capture in pulverised coal (PC)-fired power plants) and from the increased substitution of coal with biomass in coal-fired power plants. Many measures relating to fuel combustion also have effects on NO_x emissions. Ammonia emissions show a net increase, resulting from a possible NH_3 leak of the post-combustion CCS technology in coal-fired power plants. For particulate matter measuring 10μm or less (PM_{10}) and non-methane volatile organic compounds (NMVOC), emission effects are small.

The air pollution control costs of meeting the indicated national emission ceilings for air pollutants in 2020, in the Netherlands, will be reduced by between 5 and 50% (15 and 150 million euros) per year, because of climate policies. These cost reductions are relatively small, compared to the total of the indicated costs of the additional Dutch climate measures of 3-9 billion euros (Menkveld and Wijngaart, 2007).

Dutch climate programme reduces levels of GHG and, to a lesser extent, air pollutants
From the analysis (Figure S1) it is also clear that the Dutch climate programme will reduce greenhouse gas emissions and, to a lesser extent, air pollutants. Several reasons have been identified to explain why the reduction of air-pollutant levels is less than that of greenhouse gas levels:

- Synergy occurs mainly in energy-related emissions, but only part of the air pollutants and GHG emissions are linked to energy use (especially SO_2 and NO_x);
- Stimulating bioenergy (biofuels, biomass and biogas) leads to a reduction in CO_2 emissions, but not always to a corresponding reduction in air polluting emissions. For example, bioenergy combustion in small-sized installations (up to a few thermal megawatt [MW_{th}]) could increase air polluting emissions, in contrast to the heat/power production in large-scale installations with extensive flue-gas cleaning, or natural gas-fired combustion. To prevent this possible trade-off, policies are being developed in the Netherlands for more stringent emission limit values for these small-scale bioenergy installations;
- CCS technologies have specific effects on the levels of air polluting emissions, depending on the technology used. Post-combustion CCS, for instance, used in PC (pulverised coal)-fired power plants, can lead to a decrease in SO_2 emissions, but may lead to an increase in NH_3 and NO_x emissions, if no additional measures are taken.

Expected future increases in export of electricity reduce synergy nationally
The effects of national and European climate programmes on domestic emission levels in the Netherlands depend on assumed changes in the export of electricity. At present, the Netherlands is a net importer of electricity. However, an analysis of the north-western European electricity market for 2020, carried out by the Energy Research Centre of the Netherlands (ECN), has indicated that the Netherlands is likely to become an electricity *exporting* country, in the next

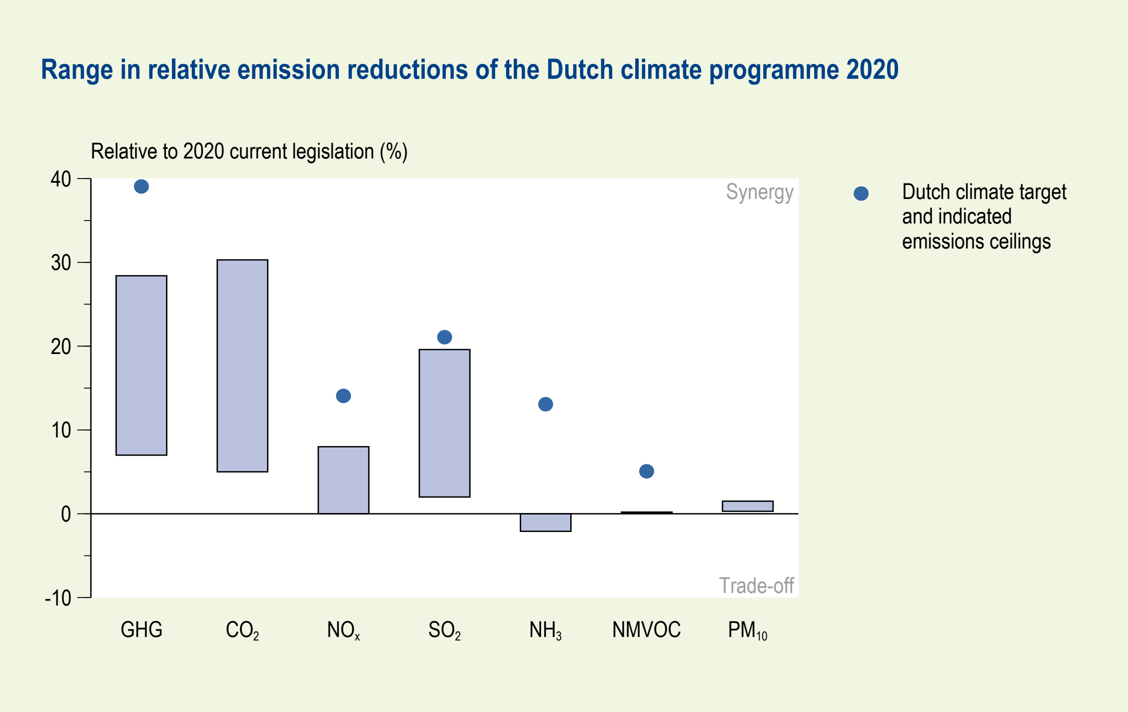

Figure S.1 Relative emission reduction in levels of GHG and air pollutants in the Netherlands in 2020, resulting from the Dutch climate programme 'Clean and Efficient' and EU climate policies. The range accounts for the uncertainty about, the future price of CO2 in the EU emission trading system (ETS), the effects of individual climate and energy measures and the import or export of electricity. Source: Daniëls et al. (2008), updated with results from the BOLK-research programme.

decade. This is due to the competitive advantage, which the Dutch electricity sector has over other countries, of being able to attract new power-plant investors, particularly in case of high CO_2 prices. The Netherlands has access to cheap cooling water from the sea, supply costs of coal are low due to its proximity to harbours, and the relatively easy access to geological CO_2 storage capacity in the available, empty gas fields.

The electricity sector is expected to buy CO_2 credits abroad within the Emissions Trading Scheme of the EU (EU ETS), to compensate for CO_2 emissions related to exported electricity. This implies that levels of CO_2 emissions and other air-pollutants will be reduced abroad. Consequently, because the climate–air synergy in this sector is relatively large, this development could roughly halve any effects of climate measures on air pollution levels (SO_2 and NO_x) within Dutch borders (Figure S2). Such a lessening of the climate–air synergy also implies a need for additional air pollution control measures, in the Netherlands - to meet the indicated national emission ceilings for air pollutants for 2020. In addition, the 'cost synergy' for air pollution control is also reduced, from between 35 to 50% (without export of electricity) to between 5 to 30% (with export of electricity). This implies that part of the 'cost synergy' benefits the countries that import Dutch electricity.

For reasons of comparison, the estimated effects of the European climate and energy package on the levels of GHG emissions and air pollutants in the Netherlands, have been included in Figure S2, according to estimations by the International Institute for Applied Systems Analysis (IIASA) (Amann *et al.*, 2008). These estimations, based on the PRIMES Energy System model (Capros

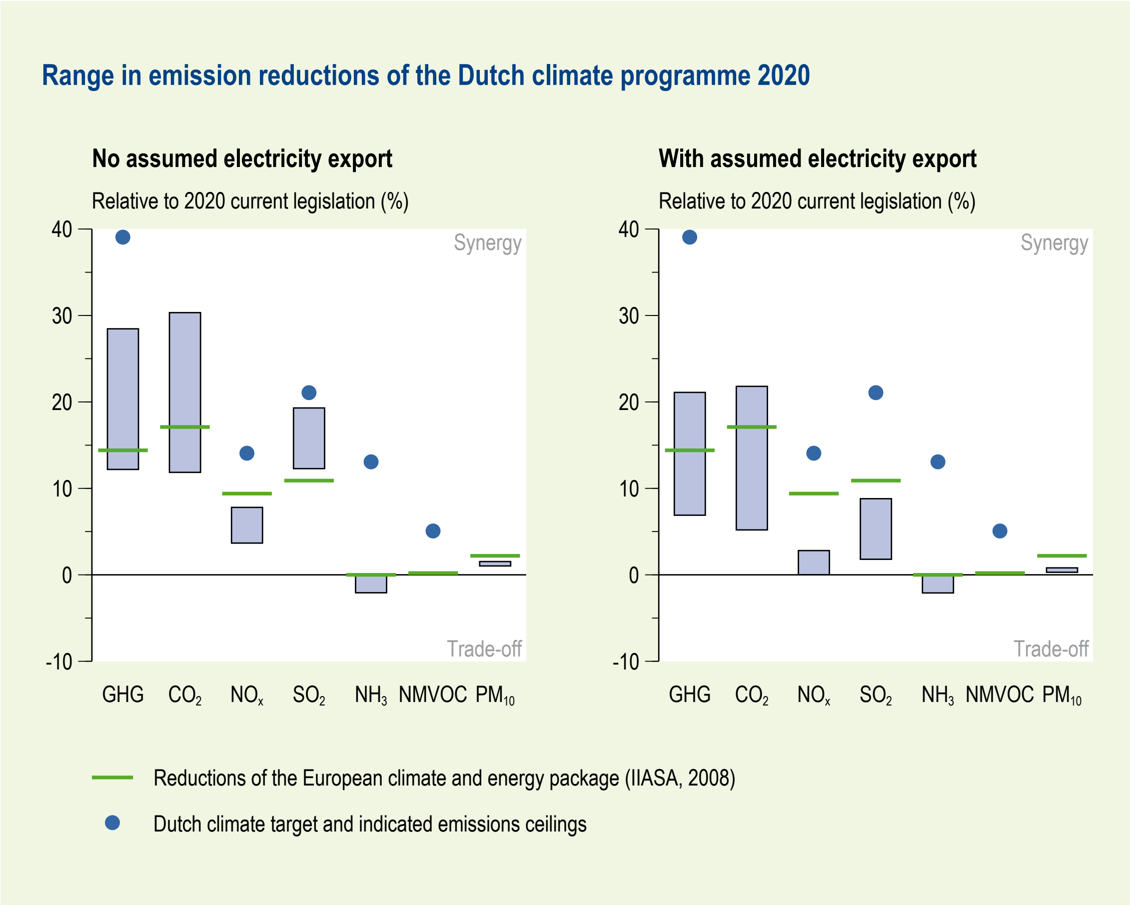

Figure S.2 Left: Relative emission reductions in levels of GHG and air pollutants within the Netherlands in 2020, as a result of implementation of the Dutch climate programme and EU climate policies. The range accounts for two target levels of EU climate policy and uncertainties in the effects of measures on the export of electricity. The left figure assumes that there is no net import or export of electricity. Right: situation with an assumed increase in net electricity export. Source: Daniëls et al. (2008), updated with the results of the BOLK research programme.

et al., 2008), use a CO_2 price of 30 euros/tonne and assume a low import of electricity, by the Netherlands. The IIASA estimates on GHG and CO_2 reductions for the Netherlands are within the ranges of the Dutch climate package (which includes a range in CO_2 price of between 20 and 50 euros/tonne), for situations with and without electricity export. In the situation that assumes electricity export, the beneficial effects of the Dutch climate programme on levels of SO_2 and NO_x which are estimated in this report, are clearly less than those estimated by IIASA. Apart from the differences between IIASA's report and this report which are caused by different assumptions on electricity export and CO2 price, other - different - assumptions on projected energy consumption, types of climate measures and related air emission factors, may further explain the differences in estimates in Figure S2.

Highlights from the dedicated BOLK studies on climate measures

Biofuels in road transport

It is not possible to reach a sound conclusion on the effects on air pollution of the most common low-blend biofuels (5-10% mixtures) used in mainstream vehicles, due to lacking comprehensive monitoring data. Monitoring data and theoretical studies on this subject often show effects that range from substantial increases or decreases in air polluting emissions, compared to pure (100%) fossil-fuel use. A sensitivity analysis based on such ranges, indicates that biofuel blends which achieve the 10% biofuels target by 2020 in the Netherlands, could lead to a change of the projected NO_x emissions from the Dutch road transport in 2020 (total about 40 kt) by between 5 and 10% (positive or negative effects of a few kilotonnes (kt)). The estimated change in the projected particulate-matter emissions (total 5 kt) is smaller (<5%).

Low biofuel blends for mainstream vehicles, high biofuel blends for dedicated vehicles
In general, the application of higher biofuel blends (20-100% biofuels) for current mainstream vehicles that are not adapted to such blends, could lead to higher air polluting exhaust emissions. This situation can be avoided by limiting biofuel use to low blends (5-10%) for mainstream vehicles, by 2020. The use of low blends for mainstream vehicles could make up between 4 and 7% of all the energy used in the road transport sector in the Netherlands, by 2020. To meet the 10% biofuels target, a significant number of vehicles would need to be adapted to running on high biofuel blends (e.g., 15-20% of Dutch trucks using 100% biodiesel).

Biodiesel and possible complications with future emission control equipment
Given that future diesel vehicles will be equipped with particulate filters and closed-loop NO_x control, the air polluting emissions from diesel and biodiesel-fuelled vehicles will be far less than from current diesel-fuelled vehicles. However, there are indications that the use of biodiesel may affect the proper functioning of advanced emission control systems, such as catalytic converters and diesel particulate filters, causing air polluting emissions to increase. This requires further research.

Emission legislation main instrument for avoiding excessive emissions
Emission legislation is seen as the main instrument for avoiding higher air polluting emissions from new vehicle types, in which the required blend ratios of biofuels are specified and mandatory to be used in de European type-approval tests, thereby showing the actual emission rate while biofuels are applied. This should not pose any problems, because the technologies for reducing the potential negative effects of biofuel use, are already available, today.

Other paths to reducing CO_2 from road transport may increase air quality benefits
A more efficient use of available bioenergy - as well as a potential gain in air quality - would be possible if renewable energy forms other than liquid biofuels would be stimulated to contribute to the proposed 10% renewable energy target for road transport. Examples of such alternatives for vehicles are ‘renewable’ hydrogen or green electricity. However, this pathway is not being stimulated in the current EC proposal on renewable energy in the transport sector, in its present form.

Indications of increased emissions in biofuels supply chain
Analyses of air polluting emissions from typical supply chains for biodiesel (rapeseed and palm oil) and bioethanol (sugar cane and sugar beet) indicate that chain emissions from biodiesel and bioethanol are higher than from their fossil-based equivalents. This holds true, especially, for NO_x, NH_3 and PM_{10}. In contrast, SO_2 emissions are less. A comparison between estimated supply-chain and end-use (exhaust) emissions from Dutch road transport, by 2020, shows that supply-chain emissions would substantially add to the share of certain pollutants in the overall road transport-related emissions. Because the production of biofuels is expected to take place mainly outside of the Netherlands, most of the negative effects on air polluting emissions from

the production of biofuels will also occur abroad. Some negative effects in the Netherlands may come from the expected increase in conversion, refining and transport activities involving crude feedstock and refined biofuels.

Biomass use in stationary applications
Co-firing biomass in coal-fired power plants can lead to lower emissions of SO_2, because the levels of sulphur in biomass is generally lower than that found in coal. The practice of co-firing biomass in these power plants has a limited impact on air-pollutant levels, because their sophisticated flue-gas cleaning equipment can filter flue gases of varying quality.
However, direct substitution of the relatively clean natural gas with biomass or biofuels in large natural gas-fired power plants, is likely to lead to higher amounts of air polluting emissions. The limited flue-gas cleaning equipment installed at these gas-fired plants cannot deal with the more polluted flue gases from burning biomass or biofuels.

Increasing small-scale bioenergy production is a potential problem for air pollution Small-sized
installations (up to several megawatt thermal [MW_{th}]), including those using biomass, biofuels or biogas, emit relatively high amount of air pollutants (per unit of heat or electricity), compared to large-sized installations. This is because small-sized installations use less advanced combustion technologies and flue-gas cleaning equipment. Moreover, the emission limit values for small-sized installations are less rigorous than those for the larger-sized installations. The number of small-sized bioenergy installations may grow, because of the influence of climate policies - for instance the installations that use biogas from co-fermentation of manure with combined heat and power and biomass-fuelled installations. While this does lead to CO_2 emission reductions, it may also result in more air polluting emissions. To compensate for this development, the Dutch Government is reviewing its decree on emission limit values for smaller combustion plants (BEES-B), thus, emission limit values are expected to be tightened (Kroon and Wetzels, to be published).

Carbon dioxide capture and storage (CSS)
Application of CCS in the Netherlands could lead to a decrease in SO_2 emissions, but also to an increase in NH_3 and NO_x emissions. Sulphur dioxide must be removed before the flue gas enters the CO_2 capture unit, to avoid a significant loss of the solvents which are used to capture CO_2. The NH_3 increase is assumed to be caused by degradation of the solvent (that is, an amine-based solvent) that is used in the post-combustion CO_2 capture process. However, research into the use of other solvents – which may result in lower emissions – is still ongoing. Without additional measures, higher NO_x emissions may result from CCS, because of the substantial amount of additional energy that is required to run a CO_2 capture unit (that is, the so-called fuel penalty of CCS). Calculations for a 4-10 Mt post-combustion CSS in the Netherlands (on PC-fired power plants), show increased emissions for NO_x and NH_3 of up to 2 and 3 kt and decreased emissions for SO_2 of up to 1 kt.

Air pollution performance of coal power plants with CCS relatively worse
The effects of capture technologies on air pollution levels show significant differences between coal-fired and gas-fired power plants. Coal-fired power plants with CO_2 capture emit more air pollutants than those that are gas-fired. Aside from the lower fuel quality of coal, efficiency losses (fuel penalties) are generally substantially larger at coal-fired plants than at gas-fired plants, leading to higher emissions per unit of electricity/heat produced. CCS requires an extra fuel input of thirty percent in coal or fifteen percent in gas, for equal electricity outputs.

Emerging technologies have more potential to reduce levels of air pollutants than available technologies in the short- and medium-term

Large-scale carbon dioxide capture with post-combustion technology will become available in the short term (from between 2020 and 2025), but has a relatively low environmental performance (without additional add-on measures), with the exception of SO_2. Post-combustion has the disadvantage of a substantial energy efficiency penalty. Pre-combustion technology promises a relatively better environmental performance with a lower energy efficiency penalty. However, its application in the power sector (e.g., in an integrated gasification combined cycle configuration) still has to be proven. Theoretically, capture technologies on oxy-fuel power plants (using pure oxygen) promises to be the cleanest (with the gas variant being referred to as an almost-zero emission plant), but it is also the least developed technology, at this moment (expected in the long term, from 2035 to 2050). However, CCS applied in an oxy-fuel configuration still results in a substantial fuel penalty.

Most of the information on the environmental effects of CSS is still largely based on literature. Practical demonstration projects are needed to generate more accurate estimates on the environmental performances of CCS technologies.

Remaining gaps in knowledge

The first phase of BOLK contributed to improved insights into the magnitude of the uncertainties in the synergy between climate measures and air pollution in the Netherlands. BOLK also identified some important knowledge gaps. The most important gaps are:

- Comprehensive and harmonised monitoring data on the effects on air polluting exhaust emissions from low and high biofuel blends used in current and future vehicles, is not available, yet. Research should also focus on possible incompatibilities between biodiesel use and future after-treatment technologies and on the effects of biofuel use on human health.
- Thorough forecasts of the composition of the biofuel spectrum, from 2020 to 2030, and of activities, such as bio-refineries and small-scale and large-scale bioenergy generation are needed.
- Information on supply-chain emissions from biofuels made from woody (lignocellulosic) materials, was not covered by the first phase of BOLK. Moreover, more information is needed on chain emissions of fossil fuels that are used as reference points.
- There is a lack of air emission monitoring data from small to medium-sized installations that use biomass, bio-oil or biogas. Moreover, limited data is available on emission reduction technologies on these types of installations and the associated costs.
- Real-time demonstration projects of large-scale CCS in which air pollutants are monitored, are needed to fill in the identified knowledge gaps. Preceding that, more work can be done in gathering detailed information (environmental and economic performances) on the implementation of CO_2 capture and storage, taking into account the specific situation of power generation and industrial installations in the Netherlands, in the period from 2020 to 2030.

1 Introduction

Climate change mitigation and air pollution are linked in many ways. Greenhouse gases (GHG) and air pollutants share a number of common sources, such as combustion of fossil fuels and agricultural activities. Moreover, many processes in the atmosphere and biosphere are linked. For example, air pollutants such as ozone (O_3) and particulate matter (PM) affect the climate system, while changes in temperature and precipitation affect air quality. It is well recognised that climate change policies generally have benefits for air quality (EEA, 2006a; IPCC, 2007).

Climate and air quality policies develop rapidly
In recent years, climate policies have rapidly intensified. In March 2007, EU leaders agreed upon a strategy to combat climate change, setting targets for the EU-27 (EC, 2007a):
- Greenhouse gas emissions should decrease by 20% by 2020 compared to 1990. This target becomes a 30% reduction target if other developed countries commit themselves to comparable emission reductions
- 20% of the energy should come from renewable sources by 2020, including a 10% share of biofuels in the road transport sector

In January 2008, the European Commission presented a set of proposals that intends to deliver on the European Union's ambitious commitment to fight climate change and promote renewable energy up to 2020 and beyond (EC, 2008a,b,c,d,e). In the Netherlands in February 2007, the Dutch Government agreed on the following climate and energy targets:
- GHG emisssions should decrease by 30% by 2020, compared to 1990
- 20% of the energy should come from renewable sources by 2020
- Energy saving rate should increase to 2% per year in 2020

In terms of European air pollution legislation, the National Emission Ceilings (NEC) Directive of the European Union and the Gothenburg Protocol from the UNECE are currently both under revision (EC, 2005; UNECE, 2008). The revised directives will set national emission ceilings for the following air pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x), Ammonia (NH_3), non-methane volatile organic compounds (NMVOC) and particulate matter (PM), to be met from 2020 onwards. The European Commission has delayed its review to account for the effects of climate change policies on the emission levels of air pollutants. An important issue for both air pollution and climate change mitigation policies are the synergies or trade-offs between climate and air quality policies.

Knowledge gaps on synergies and trade-offs between climate and air quality policies
Most of these synergies originate from energy savings, improving energy efficiency and a move towards lower, carbon-based energy production. Specific measures that can be taken are encouraging a switch from coal to gas and promoting the use of renewable energy such as wind and hydropower. The knowledge about synergies arising from such measures is generally quite good. For other climate measures, such as the use of biofuels in traffic, the use of biomass, biofuels and biogas in stationary installations and carbon dioxide capture and storage (CCS), effects on air polluting emissions are not well-known. These knowledge gaps prevent an accurate assessment of the future effects of climate measure packages on air polluting emissions and on local air quality. In order to identify in more detail and – where possible – to fill in the knowledge gaps on biofuels, biomass and CSS, a national policy research programme on air and climate, called '*Beleidsgericht Onderzoeksprogramma Lucht en Klimaat* (BOLK)', has been established in the Netherlands (see box here after).

The BOLK programme

The two-year programme (2008-2009) is split into two phases and is carried out by a consortium, led by the Netherlands Environmental Assessment Agency (PBL). The consortium consists of CE Delft, Ecofys, Energy Research Centre of the Netherlands (ECN), the Netherlands Organisation for Applied Scientific Research (TNO) and the University of Utrecht (UU).

The first phase, running from January to September 2008, is complete and is detailed in this report. The second phase, running until December 2009, aims to include an additional in-depth literature survey, expert interviews, modelling and monitoring activities. It is intended to solve the most important knowledge gaps that were identified in the first phase. With this knowledge, descriptions of the climate options, the associated costs and the effects on levels of CO_2 and air polluting emissions, will be possible. This can be useful in finding cost-effective policy packages to reach climate and air quality targets simultaneously.

Readers Guide

The new insights on the effects on levels of air pollutants from particular climate measures such as biofuels, biomass and CCS are summarised in Chapters 2 and 3. These summaries are based on four dedicated inventory reports that were made in the following first phase projects:

- Future biofuels mix and air pollutant emissions of the supply chains of biofuels and biomass (Ecofys; Koper et al., 2008)
- Effects of biofuels in traffic on air pollutants (TNO-CE; Verbeek et al., 2008)
- Effects of the use of biomass in stationary applications on air pollutants (ECN-TNO; Boersma et al., 2008)
- Effects of CCS on air pollutants (TNO-UU; Harmelen et al., 2008)

The methodology that has been used to assess the national effects of the Dutch climate programme on air on polluting emissions, and how new insights have been integrated into this assessment, is explained in Chapter 4. The integrated assessment of the effects of the Dutch climate programme ‘Clean and Efficient’ on levels of air pollutants, for 2020, is finally presented in Chapter 5. This report ends with Chapter 6 which outlines the knowledge gaps that have been identified and that remain unsolved after the first phase of BOLK. This may form the basis for further discussions on future research in the second phase of BOLK or elsewhere.

2 New insights into the effects of bioenergy options on air pollutants

2.1 Introduction

Increasing the use of biomass and biofuels are important options to reduce carbon dioxide (CO_2) emissions from electricity production and transport (see boxes on biofuels and biomass in Sections 2.2 and 2.4). In 2007, about 3% of the energy used in the Netherlands came from renewable sources (CBS, 2008). The most important source of renewable energy was combustion of biomass (1.8%), mostly due to co-firing of biomass in electricity plants and waste incinerators, and as biofuels in road transport. Wind energy was the second largest renewable energy source (0.8%). In 2007, 2.8% (in terms of energy) of the fuel sold in the Netherlands was biofuel. By far the largest part of this was introduced to the market through blending with fossil petrol and diesel. The current indicated EU target is to enhance this share to 5.75% in 2010. In the Netherlands, a binding target has been set, starting with a 2% share in 2007, and annual increments up to 5.75% by 2010.

Targets for renewable energy
To promote the use of renewable energy in electricity production, heating and cooling and transport, the European Commission made a proposal for a Renewable Energy Directive (EC, 2008c). This directive establishes at EU level an overall binding target of 20% of total final energy consumption as renewable energy sources by 2020. The Commission proposes a 14% target[1] for the renewable energy share for the Netherlands. Furthermore, a minimum target of 10% for biofuels in road transport must be achieved by each member state. These targets have been set to ensure improved environmental protection, as well as securing supply, while creating opportunities for the agricultural sector. The Commission also sets requirements for sustainability, which will influence both the choice of biofuels/biomass feedstock and the way in which individual supply chains are set up. However, these issues are still under discussion.

Uncertain effects of biomass on air pollutants
Many uncertainties exist about the effects of biomass and biofuel use on air polluting emissions. With this in mind, three projects in BOLK have been devoted to biomass and biofuel applications. The first project, described in Section 3.2, deals with the emissions of air pollutants in the production and processing chain before biomass and biofuels are used in stationary installations and road transport (the so-called ‘well-to-tank’ portion). Note that if large quantities of biomass are to be used, it will predominantly be imported from abroad, and hence these chain emissions will mainly occur outside the Netherlands. Accordingly, these emissions do not fall under the Dutch national emission ceiling, but may lead to deteriorating air quality elsewhere. The effects of the end-use of biofuels in road transport and biomass in industrial installations on levels of air polluting emissions, are summarised in Sections 3.3 and 3.4. Sustainability issues regarding biomass and biofuel production are briefly discussed in Section 3.5.

1 The target of 14% is calculated by the Commission using a definition based on final energy. In the Netherlands, a different definition is used based on primary energy. Using this Dutch definition, the Commission’s renewable target for the Netherlands would be between 15 and 19% (Olivier et al, 2008).

2.2 Future biofuel mixes and air polluting emissions from the supply chains of biofuels and biomass

Currently available biofuels will be important in the near future
The bioenergy spectrum in 2020 will consist mainly of biodiesel made from rapeseed and palm oil, ethanol produced from sugar cane and sugar beet as a replacement for petrol, as well as crude palm oil and wood pellets for heat and electricity generation. In the long-term, biofuel chains based on lignocellulose material are expected to make a larger contribution to the spectrum.

Biofuels increase supply-chain emissions of air pollutants
Life-cycle analysis indicates that the supply chain emissions (well-to-tank) of air pollutants from biodiesel and ethanol can be greater than from their fossil equivalents, especially regarding nitrogen oxides (NO_x), ammonia (NH_3) and particulate matter, measuring 10µm or less (PM_{10}). In contrast, sulphur dioxide (SO_2) emissions are probably less. A comparison between estimated supply chain and end-use (exhaust) emissions from Dutch road transport, by 2020, shows that supply chain emissions will have a substantial share in the overall road transport-related emissions of certain air pollutants.

Supply chain emissions mainly occur outside the Netherlands
The production of biofuels is expected to occur mainly outside of the Netherlands. As a result, most of the negative effects of its production on levels of air polluting emissions will also occur abroad. Some negative effects in the Netherlands may come from the expected increase in conversion, refining and transport activities involving crude feedstock and refined biofuels. Supply chain emissions in neighbouring countries will probably only marginally affect air quality in the Netherlands.

Biomass and biofuels in stationary installations increase/decrease supply chain emissions
When bio-oil is used in gas-fired power plants, supply chain emissions will increase. In contrast, when wood-pellets are used to replace coal, supply chain emissions will decrease.

This section focuses on the emissions of air pollutants in the production and processing chain before the end-use of biofuels in road transport or biomass in stationary installations (the so-called 'well-to-tank') (Koper et al., 2008). First, a selection is made of representative biofuels to be used in 2020, by an analysis of the factors which may influence the biofuels spectrum in 2020. Second, a modelling analysis is conducted using the 'SimaPro' model (version 7), to determine the amount of air polluting emissions and their geographical location.

Currently available biofuels remain important in the near future

To generate a picture of the types of biofuels that are likely to be used within the Netherlands in 2020, the following factors were included in the analysis:

- the current development of biofuels and biomass for the road transport market and stationary applications
- whether or not sufficient land is globally available to grow feedstock
- the production costs, energy demand, greenhouse gas (GHG) savings and overall crop yields

Based on this analysis, two chains were selected to substitute diesel (biodiesel from palm oil and from rapeseed), two chains to substitute petrol (bio-ethanol from sugar cane and sugar beet), and two chains were selected to substitute gas and coal for heat and electricity production (crude palm oil and wood pellets, respectively). For each type of end-use, a chain was considered which had feedstock of tropical origin, and one in which the feedstock was grown within Europe.

Road transport market and stationary applications

Given recent developments in the European road transport market, it is expected that biodiesel will be more popular than bio-ethanol. This is because biodiesel has lower investment costs and the petrol surplus within Europe favours biodiesel. On the other hand, bio-ethanol is more expensive in Europe due to import taxes, and is less compatible with current infrastructure due to the difficulties of managing its high vapour pressure. Hence, if no government incentive

What are biofuels?

Many different types of renewable fuels exist which can replace fossil petrol and diesel. For example, bio-ethanol, bio-methyl-tertio-butyl ether (bio-MTBE) and bio-ethyl-ter-butyl ether (bio-ETBE) are substitutes for petrol. Biodiesel, pure plant oil (PPO) and synthetic biodiesel are substitutes for diesel.

Biodiesel and bio-ethanol which currently hold the largest market shares, are expected to dominate the biofuels mix in 2020. Biofuels are currently produced from dedicated crops that can be grown in Europe (rapeseed, sugar beets, cereals) and some crops which are grown outside Europe (oil palm, sugar cane). Biofuels can also be produced from waste streams (e.g. agricultural waste or wood pellets). Biofuels can be used in its pure form, but is often blended with fossil petrol and diesel.

Biodiesel: Biodiesel is commonly produced from vegetable oils, extracted from oil palm, rapeseed, sunflowers, soybeans etc. The vegetable oils are converted through a process of transesterification to methyl esters which can be used as diesel. In principle, biodiesel can be blended with conventional diesel in any ratio. Its use in the mainstream market is presently limited to 5% by volume (labelled B5). In dedicated fleets, where engines are adapted to the use of higher blends of biodiesel, the fraction of biodiesel can be up to 100% (labelled B100). Biodiesel production already occurs within Europe (5.7 million tonne in 2007). The production of biodiesel in the Netherlands is at present limited, but is expected to increase more strongly in the coming years.

Bio-ethanol: Bio-ethanol is produced through fermentation of sugars. These sugars can be extracted from feedstock, such as sugar beet and sugar cane, or the sugars can be made from starch in crops, such as wheat, maize or potatoes. Sugars can also be extracted from residues such as potato waste. Bio-ethanol is commonly used in low blends in petrol, typically 5% by volume (E5) or 10% by volume (E10). Higher blends of bio-ethanol can be used in flexible fuel vehicles. Ethanol in its pure form (E100) containing an ignition improver, can also be used as a replacement for diesel (for example, in busses in Stockholm). Bio-ethanol is produced in Europe, albeit in lower quantities than biodiesel (1.7 million tonnes in 2007). In the Netherlands the production of bio-ethanol is practically non-existent but significant production is expected in the coming years. On a global scale, Brazil, China and Pakistan are major producers, while many countries in Africa are expected to become an important source in the near future.

ETBE / MTBE: Ethyl-tertiary-butyl ether (ETBE) and Methyl-tertiary-butyl ether (MTBE) are derivatives of ethanol and methanol, respectively. ETBE and MTBE are used as a fuel additive (limited to 15% by volume) and cannot be used as neat biofuels (in their pure form). ETBE and MTBE in lower blends are more compatible with current fuel specifications. For that reason, about 75% of ethanol used in the Netherlands is in the form of ETBE, and only 25% is in the form of ethanol. However, since ETBE partially originates from isobutylene, which is of fossil origin, only a proportion of it is considered to be a biofuel (47% for ETBE, 36% for MTBE).

Emerging biofuels: In addition, there are several new types of biofuels currently under development which could become available in the medium- or long-term. Most of these technologies make use of lignocellulose biomass ('second generation'), such as wood residues, paper waste, agricultural waste and dedicated energy crops. These are converted into biofuels, which could result in lower production costs (because they use cheaper bioenergy crops and residues), and could result in higher reductions in GHG emissions. Examples are Fischer-Tropsch diesel (also known as Biomass-to-Liquids or BTL), bio-methanol, ethanol produced by hydrolysis-fermentation and hydrogenated vegetable oil (e.g. NexBTL from NesteOil).

Volume base versus energy content: Blends of biofuels are expressed in percentage by volume (per litre). For example, E5 refers to a 5% blend of ethanol per litre of petrol. The current and proposed EU policy targets (5.75% in 2010 and 10% in 2020) refer to a percentage by energy content. Since the energy content of biofuels is typically lower than that of fossil petrol and diesel, a larger proportion of biofuels blends by volume is needed to reach the biofuels targets by energy content. This is not possible within the standards for mainstream diesel and petrol and therefore niche utilisation of higher blends of biofuels is necessary.

schemes are put in place, the European market is expected to choose biodiesel. Bio-ethanol is expected to play a more prominent role outside Europe since it is cheaper on a global scale.

Presently, commercially available biofuels already possess a considerable market share. The current biofuels chains are expected to have secured their market share by 2020, under current policies and technologies. Therefore the share of more advanced biofuels chains that are commercially available will not be very large in 2020. However, current biofuels policies and research and development (R&D) still leave a degree of uncertainty regarding the types of biofuels one may expect to see on the Dutch market in 2020. If, for example, stringent sustainability policies are put in place and subsidies are provided, one can expect that the more advanced biofuels, from waste streams and woody materials (lignocellulose biomass) will have a more significant share in the biofuels market in 2020. However, technological hurdles must still be overcome and costs must be brought down before biofuels made from woody materials can replace current biofuels made from vegetable oils and energy crops.

The development of biomass and biofuels use in stationary applications for heat and electricity production is mainly influenced by subsidy schemes and policies. At the moment, production of electricity using biofuels (instead of fossil fuels) is still relatively expensive. Therefore subsidy schemes continue to influence these developments. Lignocellulose biomass in 2020 is expected to come from a broad range of sources such as forestry residues and dedicated energy crops. Solid wastes from various biomaterial processes (sugar cane or palm kernel shell) may be used for stationary applications, either directly or after pre-treatment.

The production of biofuels may be limited by the amount of feedstock available at a European and global level. Several studies have shown that there is sufficient idle land available globally to grow the feedstock required to meet the 10% biofuels target in Europe in 2020. The total current EU consumption of petrol and diesel is about 12 exajoule (10^{18} J) (EJ); the global bioenergy supply, without compromising food or biodiversity, is estimated to range from 200 to 400 EJ (Hoogwijk, 2004). However in reality, extra biomass may not only be produced on idle land, but a proportion may be grown on land that is currently used for food or feed production, or on land that has high biodiversity. This may represent a risk to food production and biodiversity (see Paragraph 2.5). Currently and in the future, it is unlikely that arable land will become available for dedicated bioenergy crop cultivation in the Netherlands (EEA, 2006b).

Costs, energy demand, commercial availability, GHG savings and overall yields
In the following Tables 2.1-2.3, a number of different biomass chains are compared in terms of production costs, energy demand, commercial availability, GHG savings and crop yields per hectare.

Palm oil is commercially produced and is widely available because of its high yield per hectare and relatively low production costs. Palm oil can also be used in co-firing in gas power plants (Table 2.3). Palm plantations are located at warm latitudes. Within Europe, rapeseed oil is mainly used for biodiesel instead of palm oil because it meets mandatory European fuel specifications. Fischer-Tropsch biofuels look promising because of potentially higher GHG savings but in order to be successful, they must become less competitive with food crops and further research is still needed.

Table 2.1 Relative scores[a] of production costs, energy demand, commercial availability, GHG savings and crop yields for a selection substitutes for fossil diesel

	Production costs	Energy demand	Commercial availability in 2020	GHG savings	Crop yields per hectare
Biodiesel from palm oil	++	+	++	+	++
Biodiesel from rapeseed	+	-	++	-	-
Biodiesel from soybeans	++	-	++	+	-
Fischer Tropsch diesel	+/-	++	-	++	+/-
Dimethyl-ether	+/-	n.a.	-	++	+
Hydrogen fuel cells	+/-	n.a.	-	++	n.a.

[a] ++ Best, + Good, +/- Intermediate, - Unfavourable, -- Most unfavourable, n.a. Information not available. Source: Koper et al., (2008)

Table 2.2 Relative scores[a] of production costs, energy demand, commercial availability, GHG savings and crop yields for a selection of substitutes for fossil petrol.

Sources of ethanol	Production costs	Energy demand	Commercially available in 2020	GHG savings	Crop yields per hectare
Wheat	+/-	-	++	+/-	-
Sugar beet	+/-	-	++	+	+
Maize	+/-	-	++	-	+/-
Sugar cane	++	++	++	++	+
Cellulose (wood)	+/-	n.a.	-	+	+

[a] ++ Best, + Good, +/- Intermediate, - Unfavourable, -- Most unfavourable, n.a. Information not available. Source: Koper et al., (2008)

Table 2.3 Relative scores[a] of production costs, energy demand, commercial availability, GHG savings and overall yields for a selection of fossil fuels used in stationary applications for electricity or heat generation

	Production costs	Energy demand	Commercially available	GHG savings	Yield/land use
Palm oil	+/-	n.a.	++	+	n.a.
Wood	+	n.a.	++	+	n.a.

[a] ++ Best, + Good, +/- Intermediate, - Unfavourable, -- Most unfavourable, n.a. Information not available. Source: Koper et al., (2008)

The commercial cultivation of sugar cane for ethanol production (outside of Europe) is facilitated by the high yields per hectare, positive GHG savings and relatively low production costs. Within Europe, ethanol is produced from sugar beet which is widely available and has reasonable yields per hectare and GHG savings when compared to wheat and maize.

The cheapest biomass that can be used when co-firing with coal is lignocellulose biomass (e.g., waste wood, production wood and agricultural waste). Palm oil is also used in stationary installations, especially in its pure form, or when co-fired with gas or oil.

Based on this analysis, six biofuels chains were identified as those which could contribute most to the biofuels spectrum in 2020:

- biodiesel from rapeseed
- biodiesel from palm oil
- ethanol from sugar cane
- ethanol from sugar beet
- heat/electricity from crude palm oil
- heat/electricity from wood pellets

Most biofuels chains based on lignocellulose material are not yet commercially available so their contribution to the spectrum in 2020 is expected to be relatively low. However, their influence in the longer-term will be greater, due to positive effects on GHG emission reduction, production costs and increased availability of biomass.

Indications of increasing supply chain emissions of air pollutants from biofuels

Life-cycle analysis using 'SimaPro' (Version 7, www.pre.nl) indicates that supply chain emissions of air pollutants from biodiesel and ethanol (as a petrol replacement) may be larger than their fossil equivalents, especially in terms of NO_x, NH_3 and PM (Table 2.4). In contrast, SO_2 emissions from biofuels chains may be lower. Because the production of biofuels is expected to

Table 2.4 Estimated chain emissions (well-to-tank) for biodiesel, ethanol and their fossil equivalents resulting from the production of projected total fuel consumption for road transport in the Netherlands in 2020 (510 PJ)[a]. Locations of the emissions are indicated. Units: kt

	Biodiesel from rapeseed	Biodiesel from palm oil	Diesel fossil	Ethanol from sugar cane	Ethanol from sugar beet	Petrol fossil
	Location of emissions					
	EU	World/EU[b]	EU[c]	World	EU/NL	EU[c]
NO_x	41	20	14	18	24	5
SO_2	0	12	30	5	8	13
NH_3	21	8	0	1	1	0
PM_{10}	9	3	2	1	2	1
NMVOC	2	1	1	1	1	0

[a] original numbers from Ecofys standardised using lower heating values, general conversion factors and total fuel consumption projections of diesel and petrol in the Netherlands in 2020 (WLO, 2006). [b] only the final conversion step of crude palm oil into biodiesel may take place within the Europe. [c] SimaPro does not distinguish between parts of the fossil chain (production/refining etc), As a result, it is expected that the chain emissions within Europe as shown should be lower, since emissions from extraction and transport occur mainly outside of Europe.

occur mainly outside of the Netherlands, most of the negative effects of the production on air pollution levels will also occur abroad. Displacement of other agricultural activities in energy crop-producing countries has not been considered here. These displacement effects could change the picture. For example, displacing a less polluting crop (in terms of supply chain emissions) could lead to a net negative impact by energy crops. Some negative effects in the Netherlands may come from the expected increase in conversion, refining and transport activities involving crude feedstock and refined biofuels.

When comparing the supply chain emissions in Table 2.4 with end-use (exhaust) emissions in Table 2.5, it can be seen that biodiesel could substantially increase total road transport-related emissions of NO_x, NH_3 and PM_{10}. However, SO_2 emissions could decrease. The supply chain emissions related to the production of bio-ethanol could increase, especially, the total NO_x emissions and decrease the total SO_2 emissions. Supply chain emissions of volatile organic compounds (VOCs) are significantly lower than end-use emissions from petrol vehicles.

Most of the emissions from the majority of the biofuel chains come from feedstock production (in some cases, between 50 and 75% of the total emissions). Sugar beet and sugar cane ethanol chains are two exceptions as they are heavy products with high moisture content, and therefore produce high levels of emissions during transport. The use of tractors, nitrogen fertiliser and chemicals and heat in biofuel refineries are the main sources of NO_x, SO_2, PM and NH_3 emissions.

Most air polluting emissions from the least favourable biofuel chains - biodiesel from rapeseed and ethanol from sugar beet - will take place within Europe. The production of feedstock is not a significant agricultural activity in the Netherlands (EEA, 2006b). However, these emissions are influenced by current European legislation, which requires changes in practices on fertiliser use or sets limits on emissions from tractors. The latter is currently being enforced: levels of NO_x and particulates emissions from new tractors will be reduced by 95%, between 1999 (stage I) and 2014 (stage IV). Since this development is probably not included in the current chain emissions analysis, it is felt that a more thorough evaluation of input data of SimaPro 7 is needed to reach more robust conclusions.

Table 2.5 Projected exhaust or end-use emissions (tank-to-wheel) of the Dutch road transport in 2020[a]. Units: kt

	End use emissions of Dutch road transport system in 2020	
	Petrol	Diesel
NO_x	3.1	36.6
SO_2	0.1	0.2
NH_3	1.6	0.3
PM_{10}	1.5	3.7
NMVOC	10.3	1.2

[a] Based on projected fuel consumption of 510 (petajoule, 10^{15} J) (PJ) and expected vehicle fleet in the Netherlands in 2020 according to the global economy high oil price scenario (WLO, 2006). Projection includes the introduction of EUR-VI for heavy duty vehicles.

For the least polluting biofuel chains, air polluting emissions will largely occur in the country where feedstock production takes place, which in most cases is outside of Europe. Changing practices on a global scale are not expected within the next ten years.

Life-cycle analysis of biofuels and biomass used in heat and electricity generation, shows higher supply chain emissions from crude palm oil than from its fossil equivalent, natural gas. In contrast, supply chain emissions from wood are less unfavourable than from coal (Table 2.6). The data shown for wood may be underestimated, since the analysis here only includes pellets from wood residues, and excludes emissions from feedstock production. Natural gas, which is partly produced in the Netherlands, has the lowest supply chain emissions per unit of electricity generated. The replacement of gas with crude palm oil would result in a small reduction of the chain emissions in the Netherlands (< 1 kt NO_x and SO_2).

Table 2.6 Estimated chain emissions (well-to-tank) for crude palm oil and wood pellets and their fossil equivalents resulting from a 3% contribution to the total energy use in the Netherlands in 2020 (110 PJ)[a]. Locations of the emissions are indicated. Units: kt

	Crude Palm Oil	Natural gas	Wood pellets	Coal
Location of emissions	World/EU[b]	EU 75%/NL 25%	World/EU[c]	World 90%/EU 10%
NO_x	5.0	2.5	3.0	6.8
SO_2	3.4	2.8	3.5	4.4
NH_3	2.3	0.0	0.0	0.3
PM_{10}	0.8	0.2	0.5	0.5
NMVOC	0.2	0.0	0.4	0.3

[a] original numbers from Ecofys standardised using lower heating values and the amount of projected energy use by biomass in 2020. [b] the final conversion step of crude palm oil into biodiesel may occur within the EU. [c] Canada, North America, Scandinavia and the Baltic States

2.3 Effects of the use of biofuels in road transport on air pollutants

No firm conclusion regarding the effect of biofuels on air polluting emissions
Research on the effects of the use of low blend biofuels (5-10% mixtures) in mainstream vehicles on air polluting emissions is inconclusive, because of lack of harmonised monitoring data. Monitoring data and theoretical studies often show effects that range from substantial increases to decreases in air polluting emissions, compared to neat (100%) fossil fuel use. Effects of high blend biofuels in current diesel passenger cars (up to Euro5) may be more substantial than in petrol cars, since emission limits for diesel cars are less stringent (for NO_x and NMVOC) than for petrol cars. Synthetic biodiesel fuels (hydro-treated vegetable oil, biomass to liquid, biogas to liquid) and biogas are expected to result in lower air polluting exhaust emissions, especially when the fuels are used in the current fleet. However, available suppliesup to 2020 are expected to remain limite up to 2020 are expected to remain limited

Low biofuel blends in mainstream vehicles and high blends in adapted vehicles
In general, the use of higher biofuel blends (20-100% biofuel) in mainstream vehicles which are not adapted to use high biofuel blends, leads to higher air polluting exhaust emissions. This situation can be avoided by limiting biofuel use to low blends (5-10%) in mainstream vehicles, by 2020. The use of low blends in mainstream vehicles could make up between 4 and 7% of all the energy used in the transport sector in the Netherlands, by 2020. To reach the 10% biofuel target, a significant number of vehicles which are adapted to running on high biofuel blends, would be needed (e.g. 15-20% of Dutch trucks using 100% biodiesel).

Emission legislation is key to avoid excessive emissions
Emission legislation is seen as the main instrument for avoiding higher air polluting emissions from new vehicle types, in which the required blend ratios of biofuels are specified and mandatory to be used in de European type-approval tests, thereby showing the actual emission rate while biofuels are applied. This should not pose any problems, because the technologies for reducing the potential negative effects of biofuel use, are already available, today.

Biodiesel and possible complications with emission control equipment?
Given that future diesel vehicles will be equipped with particulate filters and closed-loop NO_x control, air polluting emissions from diesel and biodiesel vehicles will strongly decrease, compared to current vehicles. However, there are indications that using biodiesel may affect the proper functioning of advanced emission control systems, such as particulate filters, in which case the air polluting emissions from biodiesel-fuelled vehicles would increase. This requires further research.

Limited knowledge on health effects of exhaust emissions from biofuel combustion
At present, very little is known about the impact of biofuel use on the toxicological profile of exhaust emissions. The studies that have been published provide conflicting results, which may be explained by diverse study designs. A two-way approach may prove to be helpful: it is recommended that researchers compile data on a well-defined set of toxic chemicals, and develop a strategy to test the whole mixture of chemicals for its intrinsic hazard in screening assays, since ultimately it is the mixture (and not individual chemicals) which people are exposed to.

This section summarises the results from Verbeek *et al.* (2008) regarding the end-use effects (tank-to-wheel) on air polluting emissions from biofuel use in road transport. The current state of knowledge on the effects of biofuel use in current and future vehicles on air polluting exhaust emissions, is rather limited and uncertain. The possible benefits of biofuels, which can potentially create a win-win situation between air quality and climate policy, must be weighed against the trade-offs between its effects on air quality and on GHG emission levels. As road transport is a major source of emissions, due to the large amount of fuel consumed, knowledge on these effects is important for compliance with local air quality limit values and national emission ceilings.

The effects of bio-ethanol and biodiesel on exhaust air pollutants are inconclusive

Blends of bio-ethanol in fossil petrol are mainly used in light-duty vehicles (LDV) or passenger cars. The most common emission components from petrol (otto or spark ignition) engines are NO_x and unburned hydrocarbons (HC). The latter can contain toxic elements, such as aldehydes. For the influence of low and high blend ethanol in petrol on exhaust emissions, the majority of the information available is based on measurements carried out on Euro 2 and Euro 3 engines (up to 2005/2006). The data show considerable variation in emission levels when ethanol is added (Table 2.7). This is the case for both low blends in standard vehicles and high blends in 'flexi fuel vehicles' (FFVs). The variations are in the range from -50% to +50% for hydrocar-

Table 2.7 Air pollutant emissions from petrol engines that use ethanol blends. Data for Euro 3 and older vehicles are based on experimental data, while data for Euro 4 and later are based on an expert view (Verbeek et al., 2008).

		Euro 3 and older	Euro 4	Euro 5	Euro 6
		2000 - 2005	2005 - 2009	2009 - 2014	>2014
NO_x	E5	NO_x - 50% to + 50%	NO_x variations possible	NO_x variations within limits possible	
	E10-E20	NO_x - 50% to + 100%	NO_x large variations possible		
	E40-E85[b]	NO_x - 50% to + 300%	NO_x large variations possible		NO_x variations within limits possible
HC[a]	E5	HC - 40% to + 30%	HC variations possible	HC variations within limits possible	
	E10 - E20	HC - 40% to + 40%	HC variations possible		
	E40 - E85[b]	HC - 40% to + 30%	HC variations possible		HC variations within limits possible

[a] Hydrocarbons
[b] FFV- flexi fuel vehicle

bon emissions, to -50% to +300% for NO_x emissions. The range of variation is related to variations in engine technology, biofuels properties and test cycles or test circumstances. For future vehicles, sold after 2010/2012, it is expected that the possible negative effects from the use of ethanol blends on air polluting emission levels can be controlled by further improvements in engine design, in combination with the use of improved three-way catalytic converters or NO_x adsorption catalysts. Data show the impact of the use of ETBE-blends on air polluting emission levels is small (Koseki et al., 2007). It should be noted that NO_x levels for Euro 2 and Euro 3 petrol engines are low in comparison to the equivalent Euro-class diesel engines.

Biodiesel is used in passenger cars and trucks. The most common emission components from diesel engines are NO_x and particulates. Additional toxic components from these engines are poly-aromatic HC and their derivatives (see box on health effects of emissions from biofuel combustion at the end of this section).

Most of the available data on the influence of biodiesel on air polluting emission levels from passenger vehicles and trucks, are based on Euro 2/II and Euro 3/III engines (up to 2005/2006). The variation in emissions is larger for passenger vehicles than for trucks, with positive and negative effects on emission levels of NO_x and particulates (Table 2.8). For trucks of Euro III and older, particulates emissions decrease by between 0% and -70% with increasing biodiesel percentage, depending on the engine type (Table 2.9). However, NO_x emissions from trucks show an increase of between 0% and +30% when biodiesel is used. The variations in measurements observed are due to variations in biofuels properties, engine technology, and test cycle and test circumstances.

In addition, problems related to durability have been reported, particularly when high blends of biodiesel are used. These include dilution of motor oil, and decreased durability of emission control components, such as diesel particulate filters (Nylund, 2008). However, if low blends of biodiesel (up to 7%) are used for passenger cars; the potential negative impact of this would be limited.

Table 2.8 Effect of biofuels (blends) and synthetic diesel on passenger car diesel engines. Data of B5-B100 relate to FAME (fatty-acid-methyl ester made from vegetable oils). Data for Euro 3 and older vehicles are based on experimental data, while data for Euro 4 and later are based on an expert view (Verbeek et al., 2008)[a].

		Euro 3 and older	Euro 4	Euro 5	Euro 6
		2000 - 2005	2005 - 2009	2009 - 2014	>2014
PM	B5 - B10	PM - 20% to + 20%	PM - 20% to + 20%, no effect for vehicles with DPF	PM no significant effect	
	B20 - B100	PM - 80% to + 40%	PM reduction 0 - 40%, no significant effect for vehicles with DPF	PM no significant effect	
	pure XTL, HVO	PM reduction 0 - 40%	PM reduction 0 - 40%, significant effect for vehicles with DPF	PM no significant effect	
NO_x	B5 - B10	NO_x reduction 0 - 20%	NO_x some decrease or increase possible	NO_x decrease or increase possible with B10, probably no significant effect with B5	
	B20 - B100	NO_x - 10% to + 20%	NO_x - 10% to + 20%		Risks of larger NO_x variations with certain vehicle types
	pure XTL, HVO	NO_x reduction 0 - 20%	NO_x reduction 0 - 20%		

[a] XTL - biomass to liquid fuels, HVO - hydrogenated vegetable oil

Table 2.9 Effect of biofuels (blends) and synthetic diesel on truck diesel engines. Data for Euro III and older vehicles are based on experimental data, while data for Euro IV and later are based on an expert view (Verbeek et al., 2008)[a].

		Euro 3 and older	Euro 4	Euro 5	Euro 6
		2000 - 2005	2005 - 2009	2009 - 2014	>2014
PM	B5 - B10	no significant effect	no significant effect		
	B20 - B100	PM reduction 0 - 70%	PM constant to some reduction		no significant effect
	XTL,HVO	PM reduction 0 - 30%	PM constant to some reduction		no significant effect
NO_x	B5 - B10	no significant effect		no significant effect	
	B20 - B100	NO_x increase 0 - 20%	NO_x some increase	NO_x some increase or stable with special software or closed loop NO_x control	NO_x stable
	XTL, HVO	NO_x reduction 0 - 20%	NO_x reduction 0 - 30%		NO_x stable

[a] XTL - biomass to liquid fuels, HVO - hydrogenated vegetable oil

Measurement programme necessary to establish emission factors of biofuels

In the Netherlands, emission factors of road transport are determined using a well-defined methodology. Reliable estimates are produced of the average real-world emissions from various categories of vehicles (i.e. vehicle type, fuel, Euro class) for different road types and driving conditions, based on statistical analysis of the results from an extensive measurement programme. These emission factors are used in emission inventories, air quality modelling and monitoring, and in the evaluation of proposed policies and projects. In the emission measurement programme, data for the emission factor modelling is generated by testing dozens of vehicles on a chassis dynamometer, simulating a wide range of driving cycles derived from recorded real-world driving patterns for various road types and driving conditions.

It is of paramount importance that emission factors, used for the purposes mentioned above, correctly account for the effects that different uses of biofuels may have on vehicle emission levels. In order to derive statistically reliable data on emission factors for each biofuel type, extensive testing is necessary, as is carried out for vehicles which use conventional fuels. Such a large testing programme should be conducted at a European level in collaboration with research institutes and governments from other EU member states.

Biodiesel and possible complications with emission control equipment

The conversion efficiency of NO_x may be reduced with the use of high blends biodiesel (Kawano, 2007) in Euro IV and Euro V truck engines and future passenger vehicle engines equipped with de-NO_x catalysts. To prevent this, some truck manufacturers already provide special calibration software for adjustment of the NO_x catalyst if biodiesel is used. To further identify possible NO_x emission problems and to test available solutions, an extensive measurement and monitoring programme for vehicles using higher blends of biodiesel is recommended. The problem might be solved when closed loop NO_x control systems are implemented (which has an expected phase-in between 2008 and 2014).

As noted earlier, use of biodiesel can decrease the durability of emission control components, such as catalytic converters, diesel particulate filters, exhaust gas recirculation systems and fuel injection systems. These issues are likely to become more important in the future, with increasing use diesel particulate filters and catalytic converters in vehicles. Biofuels contain sodium (Na), potassium (K), or phosphorus (P) which can reduce the efficiency of catalytic converters. Biofuel components can also lead to durability problems of the engine itself. All future passenger cars with a closed diesel particulate filter regenerate this filter regularly via post-injection of fuel into the cylinder. More severe engine oil dilution is likely to occur in vehicles which use biofuels than those which use standard fuel. In addition, biofuel use can affect the regeneration characteristics of particulate filters, possibly leading to durability problems of the filter itself. Further, biodiesel may lead to severe wear of fuel injection system components or fouling of fuel injectors which is likely to cause an increase in particulates and HC emissions.

Is a win-win possible with synthetic biofuels?

Synthetic diesel fuels ((biomass to liquid [BTL] and hydrogenated vegetable oil [HVO]) have less negative effects on air polluting exhaust emissions from currently available diesel engines. Generally, reductions for both NO_x and particulates are in the range of 0% and 30% for passenger-vehicle and truck engines (Table 2.8). There is however a small reduction in fuel economy and power output due to the lower energy content of the fuel. Also, for future engines, synthetic biofuels have no negative effects on durability of emission control equipment and on air polluting emission levels.

Low blends for mainstream vehicles, high blends for captive fleets

There are indications that the use of high biofuel blends in mainstream vehicles will lead to an increase in air polluting emissions. However, if low blends are used (that is, bio-ethanol limited to 5-10% ethanol by volume, biodiesel limited to 7% biofuels by volume), the effects on air polluting emission levels are expected to be limited. The use of low blends does not require engine and fuel system adaptations in most of the vehicles currently on the road. Better compatibility is also expected with future improvements in engine technology. In addition, high blends

(85% ethanol 'E85' by volume, 20-100% biodiesel 'B20-B100' by volume) can be used in dedicated vehicles. These can be FFVs, which are designed to run on both fossil and varying levels of high biofuel blends, or adapted vehicles in captive fleets (i.e. public transportation, local freight transport, and refuse trucks) which are designed to run on a specific neat biofuel or blend. Synthetic (bio-) diesel fuels show some potential in reducing air polluting emissions, especially from current diesel engines.

Reaching the European target of 10% requires substantial application of high blends

The EU Biofuels Directive 2003/30/EC sets a European target of 5.75% of fossil fuels substituted with biofuels by 2010. Recent proposals for a climate and energy package by the European Commission state a target of 10% biofuels in 2020. The Dutch Government has investigated the possibilities of raising the national target to 20% in 2020. All of these biofuel targets are presented as percentages of the total energy use of road traffic while the above mentioned blends are given by volume in conventional diesel or petrol. These biofuel blends by volume correspond to lower percentages by energy content.

Table 2.10 shows possible blend percentages of bio-ethanol and biodiesel (by volume) for passenger cars and trucks in order to meet the biofuels target of 10% (by energy content) in 2020. It shows that the European biofuels target of 10% (by energy) can be reached with low blend biofuels such as 10% ethanol by volume (E10) and 7% biodiesel by volume (B7) in mainstream vehicles, in combination with all trucks running on a 20% biodiesel blend (B20). Another option would be to have 20% of trucks running on pure biodiesel (B100). The use of pure biodiesel is possible in trucks equipped with engine and fuel system adaptations which prevent negative effects on air pollutants and ensure durability of engine parts and after treatment devices. The biofuels target can also be reached with single ethanol or biodiesel strategies. Because of the projected relatively smaller contribution of petrol to the Dutch fuel consumption of road transport (about one third) and the substantially lower energy content of ethanol, compared to fossil petrol, a relatively high blend (E55) must be applied to meet the target. It should be noted that the blend options 3, 4 and 5 are not realistic options, since mainstream petrol vehicles will not run on E55, while B12 and B15 in passenger diesel vehicle engines with particulate filter (i.e. 70% of the new sales) would lead to engine durability problems (because of oil dilution).

Emission legislation main tool for avoiding excessive emissions

Potential negative effects on air polluting emission levels can be avoided if the necessary share of biofuels (that is, 10% ethanol and 7% biodiesel) is included in European reference fuels

Table 2.10 Several blend percentages of bio-ethanol and biodiesel (by volume) for passenger and cars and trucks that meet the biofuels target of 10% (by energy content) in 2020 in the Netherlands.

	Passenger cars		Trucks
Blend option	Bio-ethanol (by volume)	Biodiesel (by volume)	Biodiesel (by volume)
1	E10	B7	B20
2	E10	B7	20% of all trucks run on B100
3	E12	B12	B12
4	E55	B0	B0
5	E0	B15	B15

which, in turn, are used in vehicle emission legislation and type approval tests. Moreover, technologies to reduce potential negative effects of biofuels are already available.

At the moment vehicles are only tested on reference fuels that do not contain biofuels. According to an EU proposal (EC 2007b), low and high blends of ethanol and biodiesel will be phased in as reference fuels for the Euro 5 emission legislation for passenger vehicles and light-duty vehicles. The following is proposed and is likely to be accepted:

- Introduction of 5% bio-ethanol in reference petrol (E5), 5% biodiesel (FAME) in reference diesel (B5) as standard test fuels with Euro 5 (phase-in October 2009-2010).
- For FFVs, tests with E85, comply with Euro 5 petrol standards at a later stage (phase-in October 2011-2012). This includes a -7° C test, probably using E75, with separate limits for HC and carbon monoxide (CO).

This proposal is a first step to including requirements for biofuels in emission legislation and is important in securing exhaust emissions from biofuel use. However, requirements for high blends FAME (B20-B100) are not yet included in the proposal. Also, the proposal means that vehicles sold before 2010/2012 will not carry formal emission requirements for biofuels

Health effects of emissions from biofuel combustion from road vehicles

It is well known that there are certain health implications related to the combustion of fossil fuels, as fossil-fuel engine emissions contain mutagenic substances. However, there are concerns about the use of biofuels and their related emissions, since a change in fuel composition will eventually lead to a change in emissions and it is not known whether these changes will have a positive or negative impact on the environment and on public health. Furthermore, 'bio' in this context is not necessarily equivalent to healthy and good for humans and the environment. Another issue is that engines are currently not always designed for, and/or adjusted to, optimal biofuel combustion with the lowest harmful emissions. At present, there is limited knowledge on the impact of using biofuels on the toxicological profile of engine emissions (Gerlofs-Nijland et al., 2008). The effect of emissions from biofuel combustion on public health is a key concern
.

Biodiesel: The scientific literature suggests that exhaust emissions from biodiesel-powered engines are less likely to present a risk to humans, compared to those from engines powered by petroleum diesel. However, this assumption is based to a large extent on measurements of chemical components from a few engines rather than on hazard identification in biological systems. There is some evidence that combustion of biodiesel results in less mutagenic particle emissions, compared to petroleum diesel. This effect was more pronounced under idling conditions compared to rated power but cell toxicity increased under idling conditions.

Pure plant oil (PPO): The few studies that have been published provide conflicting results and diverse study designs may very well explain the differences. One study indicated that emissions from a rapeseed oil (RSO)-powered engine were ten times more mutagenic, compared to those from engines powered by petroleum diesel. Heating RSO prior to injection in the combustion chamber resulted in even higher mutagenic potency per litre of exhaust gas or per kilometre than unheated RSO. Another study, however, reported no increased mutagenicity of particle exhaust compared to petroleum diesel.

Bio-ethanol (E85): Several studies reported diminished emissions of the carcinogens benzene (C_6H_6) and butadiene (CH_2), but increased emissions of formaldehyde (H_2CO) and acetaldehyde (CH_3CHO), with unknown consequences for human health. In addition, a modelling study predicted that there will be a possible increase in ozone (O_3). Combustion of E85, compared to petrol, may result in an increased risk to mortality and morbidity, including exacerbation of asthma.

Ethyl tert-butyl ether (ETBE): ETBE has been shown to be relatively non-toxic with no persistent adverse neurotoxic effects. It does not affect the genetic material in cells (DNA), and evidence for mutagenicity or carcinogenicity is unconvincing. However, ETBE is a potential groundwater contaminant and this must be considered for large-scale introduction of ETBE into the environment.

In general, several aspects (unit, test condition, biological system) need to be considered when performing a risk assessment of emissions from biofuel combustion. For example, mutagenicity of biodiesel is shown to be increasingly expressed per unit mass but less per kilometre. The outcomes of recent studies are difficult to compare because of variation in test conditions and study design (i.e. engine type, test cycle, biological test system). This implies that there is a need for international harmonised and accepted protocols to test biofuels and compare the outcomes. A two-way approach may prove to be helpful: it is recommended that researchers compile data on a well-defined set of toxic chemicals, and develop a strategy to test the whole mixture of chemicals for its intrinsic hazard in screening assays, since ultimately it is the mixture (and not individual chemicals) which people are exposed to.

(blends), and only those requirements set for 100% fossil fuel remain valid. Moreover, for mainstream vehicles sold after 2010, formal emission requirements are limited to 5% biofuel blends, although higher blends may be needed to meet the proposed targets for 2020. Hence, to avoid negative effects on air polluting emission levels from biofuels, legislation regarding type approval tests should be consistent with targets for biofuel use.

In the longer term, it is also important to match the fuel composition for the type approval tests with the fuels that are expected to be available during the lifetime of the vehicles. In this respect, fuel composition projections for the period between 2015 and 2030 are required as input for the development of current emission legislation. The type approval procedure could also include requirements for an on-board diagnostic (OBD[2]) system for emission control, durability of emission control and real-world emissions (in-use compliance).

2.4 Effects of the use of biomass in stationary applications on air pollutants

Increasing small to medium-scale bioenergy generation can potentially increase air pollution
In general, small to medium-sized installations (up to several megawatt thermal [MWth]), including those using biomass, biofuels or biogas, emit relatively high amounts of air pollutants (per unit of heat or electricity), compared to large-sized installations. This is because small-sized installations use less advanced combustion technologies and flue gas cleaning systems. Moreover, the emission limit values for small-sized installations are less strict. The number of small-sized bioenergy installations are expected to grow as a result of climate policies, for instance, the installations that produce biogas from co-fermentation of manure and combined heat and power installations. While this may lead to CO2 emission reductions, it may result in higher emissions of air pollutants. To compensate for this development, the Dutch Government is reviewing its decree on emission limits for smaller combustion plants (BEES-B) and emission limits are expected to be tightened (Kroon and Wetzels, 2008).

Substituting coal in large power plants with biomass is neutral to positive for air pollution
Switching from coal to biomass use in large-sized installations may lead to unchanged levels of NO_x and NH_3, or decreasing SO_2 emissions. The existing extensive flue gas cleaning in these types of installations should be capable of cleaning flue gases from different energy carriers. Because biomass, in general, contains lower amounts of sulphur, these emissions may decrease.

Substituting natural gas with biomass or biofuels may increase air pollution
Direct substitution of the relatively clean natural gas with biomass or biofuels in large-sized natural gas-fired power plants, is likely to lead to higher air polluting emission levels. The limited flue gas cleaning at these gas-fired plants cannot deal with the more polluted flue gases.

In this section, the focus is on potentially important air pollution effects of bioenergy application in small-sized stationary installations (Boersma et al., 2008). However, available data on the effects of biomass utilisation in power stations, waste incinerators and industry have also been included.

Increasing the use of small-scale bioenergy can increase air polluting emissions
Small-scale biomass, bio-fuel or biogas combustion in stationary sources is carried out in a broad range of installations with different technologies, scales, fuels and emission reduction measures. In general, flue gas cleaning at these smaller installations is less regulated, relatively expensive and (consequently) more limited, compared to medium- and large-sized installations. Also, the monitoring of emissions (e.g. continuous emission measurements) is less intensive. As

2 An OBD notifies a driver if there is a malfunction in, or deterioration of, the emission control system that would cause emissions to exceed mandatory thresholds.

a result, emission factors can be relatively large. Emissions per produced unit of energy from these small-sized biomass and biofuel installations tend to be higher, compared to large-scale coal and gas-based energy production, see Table 2.11. Certain emission factors of small-scale biomass combustion (stoves with high PM emission levels), small-sized diesel engines using pure plant oil (PPO) (high NO_x) and digesters with boilers or gas engines (high NO_x), were found to be relatively high, compared to those of larger-scale biofuel applications.

Substituting natural gas with biomass or biofuels may have a negative impact on air polluting emissions

Measurements show that co-firing bio-oil in gas-fired power plant results in increased air polluting emissions (Table 2.11). The flue gas cleaning at the gas-fired power plant is limited and cannot adequately clean flue gases from less clean energy carriers. Although emissions from medium-sized biomass-fired installations (> 20 MWth) are regulated, the limited emission data (from one plant) suggest that the emissions per produced unit of energy are higher, compared to those from large-scale gas-based energy production. The number of medium-sized biomass installations is expected to grow rapidly. A study by Scotland (2006) also concluded that replacing gas with biomass leads to increased air polluting emissions, Table 2.12.

Substituting coal for biomass in large power plants has a neutral to positive effect on air polluting emissions

The co-firing of 10% mainly solid biomass in coal-fired power station results in reduced levels of SO_2 emissions due to the lower sulphur content of biomass. The impact on NO_x as well as on NH_3 is, however, less clear and contradictory data exist. No data are available on the effects of biomass use on NMVOC. Also, the effects of using a higher percentage of biomass in co-firing are not reported in the literature. In general, few negative effects of biomass use are expected at larger coal-fired power plants, compared to medium and smaller sized installations, since upper emissions limits are well-defined, regular monitoring of emissions takes place, and the existing extensive flue-gas cleaning systems can clean flue gases from different energy carriers.

Waste incinerators, cement kilns and sewage sludge incineration plants are partially fired with biomass. Their emissions are well-known under current operating conditions and no major changes are expected. However, future changes in the composition of waste flows (e.g. those with higher sulphur content) may alter the composition of air polluting emissions.

Biomass types and advantages of small-sized bioenergy installations

Biomass is already important for power generation, as it is currently used for co-firing in coal-(solid biomass) or gas (liquid biofuels)-fired power plants. Also, a single pure solid biomass power plant is in operation in the Netherlands (BEC Cuijk). The biogenic fraction in waste which is combusted in waste incineration plants is also considered to be biomass.

Types of biomass, biofuels and biogas that are used in stationary applications in the Netherlands are: wood pellets from waste wood, waste from domestic, agricultural and industrial origin, sewage and paper sludge, palm kernel shells, coffee husk pellets, palm oil, biogas from (co)fermentation of manure, sludge or organic wastes.

Although, in general, the air polluting emission performance from biomass combustion in larger-sized installations is better than those in small-sized installations, the small-scale use of biomass also has potential advantages:

- more possibilities for use of heat, compared to large-sized power plants (higher overall fuel efficiency)
- better electricity-grid management, as a result of decentralised production and use of power
- less transport of biomass and more local applications
- a potential use for residues that would otherwise be discarded

Emission regulations applicable to biomass installations

In the Netherlands, the emission regime applicable to installations depends on fuel type (clean or non-clean biomass), size, type of conversion equipment and date of permit of the installation. According to EU legislation, installations such as power plants and industrial installations larger than 50 $MW_{th,}$ operate under the Intergovernmental Panel on Climate Change (IPPC) Directive, and those larger than 300 MW_{th} operated under the Large Combustion Plant Directive. Waste incinerators operate under the Waste Incineration Directive. In the Netherlands, these directives are implemented through the so-called 'Dutch decree on emission limits for combustion plants A and B' (BEES-A and -B) and 'Dutch Decree on combustion of waste' (BVA). Smaller installations are not yet regulated at EU level, although the above-mentioned directives are being reviewed and extended to installations larger than 20 MW_{th}. In the Netherlands, installations larger than 1 MW_{th} fall under the BEES-B-regime, which allows emission factors that are substantially larger than those under the BEES-A-regime. In all other circumstances, the 'Netherlands Emission Guidelines for Air' (NeR) is used. At present, the BEES-B is under review and emission limits are expected to be tightened (Kroon and Wetzels, 2008).

Table 2.11 Summary of reported (ranges of) national and international emission factors for small- to large-scale bio-energy applications (Boersma et al., 2008). Based on lower heating value of the (wet) input fuel. Units: mg/MJ.

Installations	NO_x	SO_2	NH_3	Dust	NMVOS	Remarks
Coal-fired power stations	56-130	19	3-13	1-2	No data	100% coal
Direct co-firing (10% biomass)	99	11.2	100% Biomass: 1-5 (no de-NO_x) 5-10 (SCR) 21 (SNCR)	0.3-0.5	No data	10% biomass
Indirect co-firing (gasification)	No data	5	No data	2	No data	Assuming flue gases pass FGC in coal plant[a]
Gas-fired power stations,	46	1	No data	No data	No data	100% gas
Direct co-firing	54-66	3-4	No data	7-12	No data	100% Bio-oil
Waste incineration	60	2	0.1	0.5	0.9 (VOCs)	Fuel mix
Sewage sludge incineration	22.6	2	2.5	1.2	0.6 (VOCs)	Fuel mix, including 3% natural gas
Cement industry	416	118	25	5	No data	Fuel mix (47% renewable)
Brick industry	55	12	Nil	5	10.3 (VOCs)	Based on fossil fuels, no biomass used
Glass industry	310-700	190-220	Nil	0.4-20	Nil (VOCs)	Based on fossil fuels, no biomass used
Medium-scale biomass application						
Combustion	48-219	0.3-108	1-5 (no de-NO_x) 5-10 (SCR) 21 (SNCR)	1-10	1.5-1.8 (VOCs)	
Gasification (IGCC)	34-87	5-10	No data	0-2	0-1 (C_xH_y)	
Small-scale biomass combustion	29-420	10-50	5-9 (residential, commercial)	6-170	20-250	
PPO-fired diesel engines	630-1020	No data	No data	25-29	No data	
Digestion *Gas engine on biogas*	540 (168 (Danish data, see remarks) for 100% gas, or 13 with catalyst (Dutch data)	19	No data (0.11 for 100% gas and with catalyst (Dutch data)	2.6 (0.76 for 100% gas)	14 (117 for 100% gas)	Danish data, no gas cleaning factors based on energy content of the gas, probably no catalyst/SCR
Gas engine land-fill gas	211	27	No data	1.4	12	Factors based on energy content of the gas

[a] FGC - flue gas cleaning

Table 2.12 Qualitative assessment of replacing fossil fuel with biomass in modern combustion installations [Scotland, 2006][a]

Pollutant	Gas	Oil	Coal
SO_2	--	++	+++
NO_x	-	-	+
$PM/PM_{10}/PM_{2.5}$	---	--	+
NH_3	No data	No data	No data
NMVOC	-	-	+

[a] Advantage '+' or disadvantage '-' comparing modern biomass (clean wood) to fossil fuel use

Information on small and medium-sized bioenergy installations lacking
Dutch monitoring data on small and medium-sized bioenergy installations (< 50 MW_{th}) is scarce and it is difficult to asses how representative the mostly international data retrieved for the BOLK study is, for the Dutch situation. The scarcity of information is partly caused by the absence of a requirement for a centralised emission registration for smaller and medium-sized installations. Up-to-date cost data on reduction measures are also scarce. Available data are at least several years old.

2.5 Biofuels and biomass in a broader perspective

Other paths to reduce CO_2 in road transport may increase air quality benefits
A more efficient use of available bioenergy and also a potential gain for air pollution is possible if pathways other than liquid biofuels were stimulated to contribute to the proposed 10% renewable energy target for road transport. Examples of pathways of this kind are vehicles using 'renewable' hydrogen or green electricity. However, current EC proposal on renewables in the transport sector is not formulated in a manner which stimulates these pathways and the benefits to air quality are not yet evident.

On 23 January 2008, the European Commission released its climate and energy policy package, which included European targets for GHG reductions and shares of renewables for all EU Member States in 2020 (EC, 2008c). The intention of the Renewables Directive is to set a binding target for increasing the level of renewable energy in the EU final energy mix to 20% by 2020. The Renewable Directive is intended to replace earlier directives on renewables and biofuels and to introduce binding targets for all member states of the European Community. Specifically for the transport sector, the European Commission proposes a binding target of 10% of renewables in the final consumption of energy in the transport sector for each Member State in 2020. This 10%-target can only be met by biofuels that fulfil the sustainability criteria as proposed by the Commission (EC, 2008c).

The Commission focuses on sustainability criteria which must be met by individual economic operators. This means that criteria only apply to biomass which is produced at the level of each consignment. In the Commission's proposal, sustainability criteria are set for GHG reduction, land use change, biodiversity and agricultural practices, (the latter refers to biomass production within the European Union only) (EC, 2008c).

In the Netherlands, there has been a lot of interest in issues of sustainability of biofuels (and bioenergy). For example, the Cramer Committee composed a list of sustainability indicators relevant to bioenergy from all origins, including imports from Third World countries. The topics addressed are (Cramer et al., 2007):

- Greenhouse gas balance: measured over the complete production chain, a GHG reduction of 30%, compared to use of fossil fuels, must be met in the transport sector
- Competition with food and other local applications - production of biomass must not endanger food production and other applications (for medicines etc.)
- Biodiversity - biomass production must not affect protected or vulnerable biodiversity
- Environment - quality of soil, air and water must be sustained
- Welfare - production of biomass must contribute to local welfare
- Well-being - production of biomass must contribute to the well-being of employees and the local population

From this list it is obvious that not all topics of the Cramer Committee are translated into sustainability criteria in the proposal of the European Commission. For example, criteria on food security have not been established yet.

Since the European Commission only proposes to set criteria that can be met at a consignment level (e.g. one farmer), aspects that need to be covered at a higher (regional or national) level are not captured in the criteria yet. In particular, displacement effects of biomass production (indirect land use effects) and effects on food security cannot be met by criteria at a consignment level. The big question is how these indirect effects will play out in the future. Current scientific debate focuses on the extent of these two indirect effects of biofuels (and possibly bioenergy).

On indirect land use effects, Searchinger et al. (2008) present the most outspoken conclusions. Searchinger et al. (2008) assume that positive and negative effects on agricultural yields, caused by bioenergy production, will balance out - implying that land replacement will be the dominant strategy. They conclude that the carbon emissions due to replacement of farmland would exceed (cumulative) carbon savings from corn-based ethanol for a long period (Searchinger et al., 2008). However, in a review of the paper for the British Gallagher review, it was concluded that the basic issues raised by Searchinger are relevant, but that EU biofuel initiatives are fundamentally different from the US bio-ethanol initiative. Therefore, 'it must be concluded that the Searchinger approach involves a high level of uncertainty, to the extent that its specific conclusion should not be regarded as safe' (ADAS, 2008). Nevertheless, it clearly shows that it remains eminently feasible that effects of biofuels on indirect GHG emission levels could be significant, in relation to intended GHG savings. Therefore, the debate on indirect land use effects of biofuels is here to stay, for a while.

On the indirect effect of biofuels on food prices, the debate is continuing. Researchers at the International Food Policy and Research Institute (IFPRI) were the first to investigate the relation between food prices and the increase in growth of biofuels. They concluded that a price increase of between 16% and 43% at best and between 30% and 76% at worst, depending upon the commodity, could be expected (Von Braun, 2007). A study by the Agricultural Economics Research Institute, in the Netherlands (LEI) shows that the implementation of the EU directive on biofuels (10% in 2020) could lead to an increase in crop prices, compared to a baseline development ranging from 8% for oil seeds, to 3% for sugar (Banse et al., 2008). These results show that the obvious relationship between food prices and biofuel policies needs to be examined further.

These considerations show the uncertainties that exist around biofuels. However, often biofuels are mentioned as the only existing alternative to road transport fuel. This is true for the moment.

The advantage of biofuels is that they can easily be introduced into the present transport system, by blending a certain percentage of them with fossil fuels. In that sense, energy security is the most valid argument for using biofuels in the transport sector. Still, there are sustainable alternatives for road transport, both from an environmental and an energy security perspective. The most important new propulsion technologies for vehicles are: hydrogen fuel-cell cars, hybrid electric vehicles, plug-in hybrids and electric cars (Eickhout et al., 2008). Their costs are still relatively high; because they are in at development phase and their role in the future transport system is still highly uncertain. However, in a long-term transition process towards a new transport system, their potential is high, although their impact will ultimately depend on the future sustainability of hydrogen production and the generation of electricity. In theory, optimal use of biomass can be shown by doing a comparison of four pathways, which all start with same amount of wood as their initial source of energy. The reference point is the number of kilometres driven by an average vehicle (Figure 2.1). In the first three pathways, the wood is transformed into diesel, bio-ethanol or hydrogen which can be used in conventional cars, FFVs and fuel-cell cars, respectively. The excess heat released during the transformation processes can be used to generate extra electricity which can be used in an electric vehicle. Figure 2.1 clearly shows that the most efficient pathway is using wood to produce electricity for electric cars. Fischer-Tropsch diesel and bio-ethanol are less efficient. For efficient use of available biomass and to support potentially attractive options from a long-term perspective, it is therefore recommended that all pathways are allowed to contribute to the proposed 10% renewable energy target for road transport - which is currently not the case in the current European proposal.

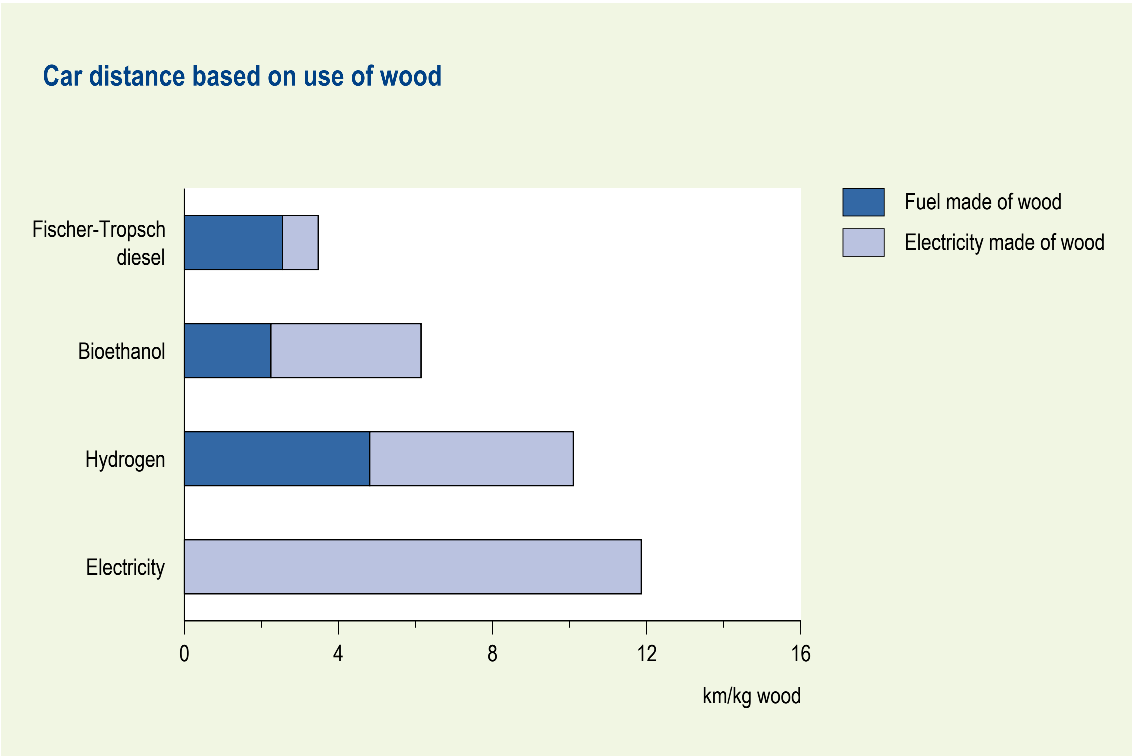

Figure 2.1 The efficiency of using wood for transport in four different pathways (Eickhout et al., 2008)

3 New insights into the effects of carbon dioxide capture and storage (CSS) on air pollutants

3.1 Introduction

One of the mid- and long-term mitigation options to combat climate change is CCS. It involves capturing of carbon dioxide (CO_2) from flue gases and storing it, instead of releasing it into the atmosphere. Storage of the CO_2 is envisaged either in deep geological formations, in the deep ocean, or in the form of mineral carbonates.

Technology for large-scale capture of CO_2 is fairly well-developed and already commercially available to some extent (e.g. for some industrial processes). However, up to now, there are no large-sized power plants in operation which run a full CO_2 capture and storage (CCS) system. Moreover, although CO_2 has been injected into geological formations for various purposes (e.g. enhanced oil recovery), the long-term storage of CO_2 remains a relatively untried concept. Therefore, the environmental effects of CCS, including its effects on air polluting emission levels, are not well-known yet and could be significant.

Three types of CO_2 capture technologies can be discerned, namely post-combustion, pre-combustion and oxy-fuel combustion.

- Post-combustion technologies capture CO_2 from the flue gas using membranes or solvents such as amines and chilled ammonia (NH_3). The post-combustion process requires additional energy (in the order of 15% for gas and 30% for coal-fired plants), and reduces the overall efficiency of the plant, but does not interfere with the combustion process itself, making it a robust technology suited for retrofitting existing power plants. Post-combustion using amines is a well-developed technology and is likely to be ready for full-scale implementation by 2020. Direct chilling, suited for flue gases with high CO_2 concentrations and potentially applicable in industry in Rotterdam, is in principle not an option for post-combustion CO_2 capture, unless 'waste cold' is available.
- Pre-combustion technologies use a gasification step in which fuel is converted into so-called synthesis gas (or syngas) from which the CO_2 can be captured with solvents, solid sorbents and membranes. The hydrogen-rich syngas can be used in an adapted combustion plant to produce power. Today, only a few integrated gasification combined cycle (IGCC) power plants are in operation. This technology has a lower efficiency penalty and promises better environmental performance than post-combustion technologies using amines.
- Oxy-fuel combustion processes use nearly pure oxygen for combustion instead of air. The resulting flue gas contains mainly CO_2 and water. This technology is not operational yet, hence data are surrounded with large uncertainties. The oxy-fuel technology promises to have the highest CO_2 removal efficiencies and best environmental performance.

The following estimation has been made about the possible application of CO_2 capture technologies in the Netherlands:

Main characteristic[a]	Capture technology and application
Short-term & relatively cheap	Post-combustion amine pulverised coal (PC)
Short-term & relatively clean	Post-combustion amine natural gas combined cycle (NGCC)
Mid-term & relatively clean	Pre-combustion coal-integrated gasification combined cycle (IGCC)
Long-term & clean	Oxy-fuel gas cycle
Long-term & cheapest	Chilled NH_3, PC

[a] Short term ~ 2020-2025, mid term ~ 2025-2035 and long term ~ 2030-2050

In the next section, we present a comparison of the different CO_2 capture technologies in terms of their stage of development, area of application and environmental performance (Harmelen et al., 2008). This provides an overview of major weaknesses and strengths that are relevant for the future development and application of different types of capture technologies. Also, air pollution effects of several CCS implementation scenarios for 2020 are summarised. In the final section of this chapter, we present a broader perspective on technological, social, legal and economical barriers of CCS.

3.2 Effects of the application of CCS on air pollutants

CCS may have a substantial impact on levels of air polluting emissions

Application of CCS in the Netherlands could lead to a decrease in sulphur dioxide (SO_2) emissions and to an increase in NH_3 and nitrogen oxide (NO_x) emissions. Sulphur dioxide is removed before the flue gas enters the CO_2 capture unit in order to avoid significant loss of the solvents that are used to capture CO_2. The NH_3 increase is assumed to be caused by solvent degradation (i.e. an amine-based solvent) that is used in the post-combustion CO_2 capture process. However, research with other solvents that may result in lower emission levels, is still ongoing. Without additional measures, higher NO_x emission levels may result from CCS as a result of the substantial amount of additional energy that is required to run a CO_2 capture unit (i.e. the so-called 'fuel penalty of CCS').

Air pollution performance of coal power plants with CCS relatively worse

Environmental performance of capture technologies shows significant differences between coal- and gas-fired power plants. The emissions of most air pollutants from coal-fired power plants with CO_2 capture are higher than those from gas-fired power plants. Leaving aside the inferior fuel quality of coal, efficiency losses are generally substantially larger in coal-fired plants than in gas-fired plants, leading to higher emissions per unit of electricity/heat produced. For a similar electricity output, 30% more coal or 15% more gas as fuel input is required to run CCS.

Emerging technologies promise better environmental performance than technologies available in the short- and medium-term

Carbon capture with post-combustion technology is ready for use in the short and medium-term but with the exception of SO_2, has a relatively poor environmental performance (when no additional add-on measures are used). Post-combustion has a substantial energy efficiency penalty. Pre-combustion technology promises better environmental performance with a lower energy efficiency penalty. However, its application in the power sector (in for instance an IGCC configuration) must still be proven. In theory, oxy-fuel capture technology promises to be the cleanest (with the gas variant being referred to as an 'almost-zero' emission plant) but also the least developed technology available at the moment.

Most of the information on environmental effects of CCS is still based on literature. Real demonstration projects are needed for better estimates on environmental performances of CCS technologies.

Table 3.12 shows a summary of a comparative assessment of the different CO_2 capture technologies in terms of their stage of development area of application and environmental performance. It provides an overview of major weaknesses and strengths that are relevant for the future development and application of different types of capture technologies. In the table, coal with

CO_2 capture is compared to coal without CO_2 capture and the comparison is made again for gas. This is done by using three colours. Red (an aspect is considered a weakness, i.e. worse than average), green (an aspect is considered strength, i.e. better than average) and yellow (an aspect is considered neutral, i.e. average). The colour scheme emphasises the large uncertainties surrounding the data. Note that the colour green does not mean 'good' as in 'good for the environment'. The main message from the table is that there is not a clear winning technology which is better in most aspects than others.

Air pollution performance worse with coal power plants that have CCS

In terms of the environmental performance of capture technologies, major differences exist between capture technology in coal-fired plants and in gas-fired plants. Coal-fired plants show ranges that can be characterised as worse to average, while gas-fired plants show ranges from average to better. The efficiency losses are generally larger for coal-fired plants than for gas-fired plants, leading to higher emissions per unit of fuel input. The impact of coal-fired power plants (including IGCC) with CO_2 capture on air polluting emission levels, is less than that of gas-fired power plants.

Emerging technologies promise better environmental performance than technologies available in the short- and medium-term

Capture technologies display major differences. Post-combustion technologies are relatively well-developed in industry although they need to be scaled up considerably in order to be applied on a full-scale in power plants. Their use is expected to be low risk since these technologies leave the present power plant intact (add-on or retrofit technology). These technologies are ready for application in the short to mid-term, but with the exception of SO_2, they display a relatively low environmental performance (without additional add-on measures). SO_2 needs to be removed before the flue gas enters the CO_2 capture unit to avoid significant losses of the chemicals that are used to capture the CO_2.

Pre-combustion technology has a better environmental performance and is applied on a large-scale in present day industry. However, its application in the power sector (in for instance an IGCC configuration) has yet to be proven. The real challenge lies in the integration and optimisation of the CO_2 capture process in the already complex IGCC power plant to produce a reliable power plant.

In theory, oxy-fuel capture technology is the cleanest (with the gas variant being referred to as an almost-zero emission plant) but also the least developed and robust at the moment. Demonstration of both the coal- and gas-fired process before 2015 is however very likely.

Chilled NH_3 and membranes are both promising techniques which use less energy compared to the amine system. However the latter is by far the most developed technology. A large amount of research is needed for chilled NH_3 and membranes before they can be used commercially. Recently pilot tests with chilled NH_3 and membrane contactors have begun (see Harmelen et al., 2008).

Lack of quantitative estimates on air pollution from CO_2 capture technologies

Emission factors presented in the literature for energy conversion technologies with CO_2 capture are most often based on assumptions, and not on measurements. For the technologies that are currently in the laboratory or at pilot phase, far less information is available and environmental performance is often discussed qualitatively in the literature, if at all. Moreover, data collected

Table 3.1 Overview of aspects and criteria to characterise several CO2 capture technologies and their equivalent technologies (green is better than average, yellow is average and red is worse than average). This table only shows average values. Detailed data is given in Harmelen et al. (2008).

Technology			Development phase	Application	Electric performance		CO₂ and air pollutant effects				
Capture technology		Application[a]		Retrofit/ Robust/ Process industry	Electrical efficiency (%)	Efficiency penalty (% pts)	CO_2	NO_x	SO_2	PM_{10}	NH_3
							g/kWh				
no capture		PC	commercial		40[b]	0	830	0.39	0.44	0.05	0.01
		NGCC	commercial		56	0	370	0.17	-	-	-
		IGCC	commercial		42	0	766	0.23	0.05	0.014	-
Post-combustion	amine	PC	pre-commercial	yyy	30	11	145	0.57	0.001	0.06	0.23
	amine	NGCC	pre-commercial	yyy	49	8	55	0.19	-	-	0.002
	chilled ammonia	PC	pilot	yyy	39	n.a.[c]	na (estimated in order of amine PC)				-
	mem-branes		lab scale	n.a.	n.a.	n.a.	n.a.				
Pre-combustion		GC	demonstration	nyy	49	9	21	na (estimated in order of amine NGCC)			
		IGCC	demonstration	yyy	36	7	98	0.21	0.016	0.003	0.0007
Oxyfuel		PC	pilot	y?ny	32	11	47	0.17	0.025	0.0003	-
		GC	pilot	y?ny	53	4	10	-	-	-	-
		NGCC	pilot	y?ny	46	11	8	0	0	-	-

[a] PC = Pulverized Coal, NGCC = Natural Gas Combined Cycle, IGCC = Integrated Gasification Combined Cycle, GC = Gas Cycle
[b] New coal-fired power plants have a higher efficiency,
[c] n.a. = not available

for the inventory are not consistent with respect to year of costs, time horizon, interest rates, lifetime, reference technology, and fuel quality and prices. In the current framework, only the first aspect could be corrected. From the available information, the following conclusions can be drawn about the air polluting emissions from power generation technologies with different types of CO_2 capture technology:

Coal power plants with CO_2 capture technologies are expected to emit lower SO_2 emissions
In general, SO_2 emissions are expected to be very low from power plants with CO_2 capture. For all coal-firing conversion technologies, the application of CO_2 capture results in a decrease in the emission of SO_2 per megajoule (10^6, MJ) of fuel input. Sulphur must be removed to avoid degradation of the solvent in post-combustion processes. In pre-combustion and oxy-fuel capture, the efficient treatment of the syngas and flue gas, respectively, is expected to result in low SO_2 emission levels. Remaining SO_2 emissions can be co-stored with CO_2 (acid gas) or removed with additional scrubbers. The sulphur content of natural gas is very low and, thus, SO_2 emission levels are expected to be negligible in natural gas-fired power plants, with or without CO_2 capture.

Carbon capture technologies may lead to increased NO_x emissions
In the post-combustion process, NO_x emissions increase almost proportionally with the increase in primary energy demand required to run the plant with post-combustion capture (that is, the energy penalty). The NO_x emission factor per unit of energy (MJ) is believed to be largely unaffected by the (amine-based) capture process itself, although there is no consensus on this issue. The small nitrogen dioxide (NO_2) part of NO_x, at 5-10%, is assumed to be partially removed through reaction with the amines; and this would slightly reduce the emission factor. In the literature, lower, equivalent and higher NO_x emissions are reported per MJ when applying pre-combustion CO_2 capture. NO_x emissions from oxy-fuel processes are in general expected to be very low, particularly for natural gas, since only fuel-bound nitrogen can be transformed into NO_x. The literature is less clear on this subject for coal-fired plants; coal contains more nitrogen than natural gas, although some NO_x will still be formed as combustion occurs in a denitrified medium. For both pre-combustion capture and oxy-fuel combustion, any remaining NO_x emissions can be removed in a separate facility.

Potential increase in NH_3 emissions with post-combustion CO_2 capture technologies
With the exception of one post-combustion capture process, NH_3 emissions are estimated to significantly increase (possibly more than by a factor of 20). This is assumed to be caused by solvent degradation (i.e. an amine-based solvent) that is used in the post-combustion capture process. However, there is considerable uncertainty about this estimate and improvements to amines are currently being researched, developed and tested.

Emerging CO_2 capture technologies may result in low PM emissions
It is necessary to remove a large part of the PM before the post-combustion capture process, in order to stabilise the process. This occurs in the electrostatic precipitator and additionally in the SO_2 removal step. On the other hand, PM emissions could increase as a result of the efficiency penalty. In the literature, assumptions on this matter vary considerably. It was found that the application of pre-combustion CO_2 capture may lower particulate matter emissions measuring 2.5µm or less ($PM_{2.5}$) from a coal power plant (IGCC), due to enhanced capture of sulphur compounds which can hinder the formation of ammonium sulphate. Also, from coal-fired oxy-fuel processes, PM emissions are estimated to be lower in terms of unit of energy (MJ), compared to conventional PC-fired power plants. A high degree of PM removal is required for the reliable operation of compressors and fans. Particulate matter may also be partly co-sequestered with the CO_2. In general, the emission of PM from natural gas-fired cycles can be considered to be negligible.

Lack of information on effects of CO_2 capture technologies on NMVOC
Pre-combustion CO_2 capture can increase or decrease the emission of non-methane volatile organic compounds (NMVOC). Quantitative estimates of this reduction are not available in the literature. It is largely unknown whether, and to what extent, NMVOC emission levels are affected by the CO_2 capture process in the oxy-fuel and post-combustion processes. Quantitative estimates for NMVOC emissions were not found in the relevant literature.

Biomass and CO_2 capture
The effect of biomass (co-)firing in coal power plants, with pre- or post-combustion CO_2 capture, is not well researched, although it seems likely that both SO_2 and NO_x emission levels will be lower, since biomass contains less sulphur and nitrogen than coal. For other emissions, is it not possible to make an educated guess. The effects of biomass (co)-firing in oxy-fuel processes on the performance and emission profile are currently also unknown.

Other effects of CO_2 capture technologies
Other effects of CO_2 capture are the safety of CO_2 transport, and storage of toxic wastes (of chemical solvents) that are produced in large quantities. Also the impact of amines and degradation products in air can be significant. These are not studied in detail in this project.

CCS may have substantial effects on air pollution
The fourth BOLK project also included a scenario analysis for 2020, to illustrate the potential effects of CCS use on air polluting emission levels. This scenario involved a large contribution from new IGCC and NGCC, and in from oxy-fuel power plants. The conclusion from the scenario analysis is that the application of CCS may lead to a substantial decrease in levels of CO_2, SO_2 and NO_x emissions but may also cause an increase in NH_3 emission levels. This increase is assumed to be caused by solvent degradation (i.e. an amine-based solvent) that is used in the post-combustion capture process. However, the uncertainty regarding this estimate is considered to be high. Large-scale implementation of post-combustion technology on existing coal-fired plants in 2020, may result in higher NO_x emission levels, compared to other CO_2 capture technologies in the analysis, or to no capture, if no additional measures are taken.

3.3 CCS in a broader perspective

Technological barriers: A wide number of studies conclude that the cost of GHG emission reduction pathways will become more expensive without the use of CCS. The Intergovernmental Panel on Climate Change (IPCC, 2005) estimates that the costs of stabilising CO_2 concentrations would be reduced by 30% or more if CCS was included in a mitigation portfolio. Other studies indicate that if stored CO_2 leaked into the atmosphere, the potential contribution of CCS decreases significantly at leakage rates of 0.1% or more (Van der Zwaan, 2008).

It is generally considered that CO_2 storage suffers from both technological and social barriers. Geologists and scientists argue that injection of CO_2 into geological reservoirs basically works, that technologies such as natural gas storage and acid gas injection provide useful analogues and add to the expertise available in this respect, and that the use of existing technologies to contain and monitor CO_2 is all that is required. Good data on CO_2 permanence in geological reservoirs are scarce, and are only collected in a few large-scale projects, such as the Sleipner project in Norway and the enhanced oil recovery (EOR) operation in Weyburn, Canada. Although geological sites can be identified and managed safely so as to practically eliminate leakages, this does not imply that they will be identified and managed in this way. While appropriate site selection and monitoring approaches for operations are being developed, unfamiliarity with this option has proven to be a barrier to its implementation. This was illustrated by recent public consultations for CO_2 injection near Lacq, southern France, by Total Oil and in Barendrecht, by the '*Nederlandse Aardolie Maatschappij* (NAM)'.

Economical barriers: Up scaling of CO_2 capture in the power sector might still pose technological and economical challenges. Full-scale demonstrations have not been implemented so far, although a number of proposals have been made by power companies worldwide. With no demonstration projects in place and soaring steel prices, the incremental costs might rise considerably. On the other hand, lessons learned could bring down costs. Overall, cost uncertainties are large, although the technology is not entirely new.

Legal and supportive barriers: A legal framework for CCS implementation is also important for several reasons: it limits risks of CO_2 storage, eases public concern, and provides legal certainty to the project developer, especially for long-term, post-closure liability, which is something that insurance companies have indicated they cannot insure against.

Perhaps the least tangible and most complex barrier relates to public support for CCS. Public perception studies have shown a 'reluctant rather than enthusiastic' attitude towards CCS. CCS would be perceived more negatively if it was held responsible for price rises in consumers' electricity bills. Where storage is offshore, it is likely that CO_2 pipelines may elicit the greatest public concern. For onshore storage, it may be the storage site itself that emerges as the focal point. So far, existing efforts at communicating CCS to the public have in general not been well coordinated or effective.

What are the information gaps and challenges? Behind the wealth of information on CCS, however, many gaps and uncertainties still exist. The EU ACCSEPT (Anderson et al., 2007) project assessed the main information gaps and problems. Despite the large number of engineering cost studies, most of those studies use data from just a few baseline studies, and referencing the same work often occurs. The considerable body of literature creates the impression that there are many independent sources on cost estimates, but, in reality, those many sources share a few common origins.

Most studies assume pre-2005 oil and gas prices and lag behind in incorporating recent changes in fuel and material costs, particularly steel. This mostly affects steel-intensive options which already have high investment costs, in particular IGCC with CO_2 capture, often hailed as a low-cost CCS option.

4 Methodology used for assessing effects of the Dutch climate programme on air pollutants

The new results and insights from the first phase of the BOLK programme have been evaluated, in terms of their potential contribution to the national assessment of the effects of the Dutch climate programme on air polluting emissions. Some results, such as the discovered effects of biofuels on levels of exhaust emissions, were not statistically sound enough to be integrated into the national assessment. Other results, such as newly found emission factors for air pollution from biogas applications and carbon dioxide capture and storage (CCS), were evaluated as being useful and have been included in the national assessment.

The national assessment is carried out using the methodology of the Dutch options document and the analysis tool, which are introduced in Section 4.1. The integration of the new insights of the BOLK projects (Chapter 2 and 3) into this methodology, is described in more detail in Section 4.2.

4.1 The Dutch options document and analysis tool

The Options Document for Energy and Emissions 2010/2020 consists of a large number of option descriptions (measures) and an analysis tool (Daniels and Farla, 2006). The option descriptions provide the reduction potential(s) in 2010 and 2020, for 170 climate, energy and air pollution options, for a Dutch baseline projection of activities and emissions (i.e. the Dutch global economy baseline scenario; WLO, 2006). Each option description includes a comprehensive fact and data sheet, including specifications of the effects on levels of GHG and air polluting emissions, energy consumption, investment and operational costs, cost-effectiveness, the possible policy instruments and additional information regarding support and barriers. The option document also contains options on biofuels in road transport, small-sized bioenergy installations and CCS.

The analysis tool uses the 170 options to put together cost-optimal option packages, that starting from a baseline projection contain a set of targets for carbon dioxide (CO_2), other greenhouse gas (GHG)[3)] and the air pollutants; sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), particular matter (PM) and non-methane volatile organic compounds (NMVOC). The tool provides several possibilities for managing cost-optimal solutions. For instance, it is possible to instruct the tool to select certain options, sometimes for a certain percentage, or to exclude certain measures. The model takes into account possible interactions between options. It is also possible to conduct a hybrid analysis using this tool. The tool starts with a fixed set of measures, which for instance are prescribed by a climate programme, and it searches for a cost-optimal set of options that are required to reach certain climate and air pollution targets. The output of the tool is a list of options, costs and GHG and air polluting emissions effects.

3 The other greenhouse gases are methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6)

Table 4.1 The number of options in the Dutch Options Document that match with to the research projects of BOLK

BOLK research project	Number of options in Dutch options document
Carbon capture and storage	14
Biomass in stationary applications	14
Biofuels in transport	1
Chain emissions biomass and biofuels	0

4.2 Integrating new BOLK insights into the options document

As stated earlier, certain newly found emission factors of air pollutants from biogas applications and CCS, were included in an update of the national assessment of the Dutch climate programme. The update was compiled from previous national assessments of the climate programme on GHG (Menkveld et al., 2007) and on air pollution (Daniels et al., 2008). In these assessments, the existing and proposed policies of the Dutch climate programme had already been translated into option packages and subsequently into estimated effects. Here, the newly found emission factors from the BOLK study had to be integrated into the relevant options of these packages. Subsequently, the analysis tool was used to calculate the total effects of the programme on levels of air pollutants, once again. The new results are presented in Chapter 5.

A more thorough description of the integration of BOLK results into the relevant options of the climate programme is given below and in Appendix 1. Table 4.1 shows the number of options in the Dutch options document that match with the research projects of BOLK.

Updated options descriptions for CCS

Of the 14 CCS options currently in the options document, six relate to centralised power production, four options are concerned with decentralised combined heat and power production (CHP) and another four are related to industrial sources. The information from BOLK could be used to update the six centralised CCS options and to create one new CCS option with new information from the Harmelen et al. (2008) study on:

- generation efficiencies
- CO_2 capture efficiencies
- NO_x emissions (due to the energy penalty)
- SO_2 emissions
- NMVOC emissions [4)]
- first time estimate of NH_3 emissions

The new option involves new coal power plants with post-combustion CCS. The higher NH_3 emissions stems from the degradation of amine-based solvents, occurring inside the CO_2 capture unit (Chapter 3). The uncertainty regarding this amine degradation estimate is considered to be high and improvements of amine in this respect are currently being researched, developed and tested. For SO_2 the reported emission factors stem from international data and may not be applicable to the Netherlands, therefore, the emission factors of CCS plants have been proportionally converted using current Dutch SO_2 emission factors. Table 4.2 shows the effects on the levels of air pollutants from the updated CCS options on the Dutch climate programme.

4 For CCS options, no NMVOC emissions are reported; however for pulverised coal (PC) without CCS an emission factor of 1.1 g/GJ (g/gigajoule – 10^9 J)is given and has been added to the options document database. The difference is calculated as emission reduction in Table 4.2.

Table 4.2 Differences between current and updated effects of the CCS options on air pollutant emissions[a]. Positive numbers refer to an emission reduction (synergy), negative numbers refer to an emission increase (trade-off).

Current and updated options	GHG	NO_x	SO_2	NH_3	NMVOC	PM_{10}	$PM_{2.5}$
	(Mt)			(kt)			
Current CCS options	4 to 10	-0.2 to -0.4	0.8 to 1.9	0	0	0 to 0.1	0
Updated CCS options	4 to 10	-0.2 to -1.9	0.5 to 1.2	-1.2 to -2.9	0.1 to 0.2	0	0

[a] The range covers the effects under the more stringent European climate policy variant (see Section 5.1).

The BOLK results have been used to estimate the indirect effects on emission levels of CCS, related to the manufacturing of capture solvents and to solvent waste treatment. These indirect emissions could increase levels of air polluting emissions from the CCS application by 0.1 kt NO_x and 0.1 to 0.4 kt SO_2. These indirect emissions – like others in fuel chains or infrastructure (construction) – are not included in any reported table, throughout this report. This is because it is not clear where all the indirect emission effects occur –whether it is within or outside the Dutch national borders.

Some qualitative information is given here but this was not sufficient to update industrial CCS options. Application of CCS to decentralised smaller scale combined heat and power production was not covered by BOLK.

Updated options descriptions for biomass

The stationary biomass options can be further subdivided into direct and indirect co-firing in power plants (six options), upgrading biogas to natural gas quality (green gas) (three options), (co-)fermentation (four options) and waste incineration (one option). The options concerning mainly (co-) combustion, fermentation and waste incineration could be updated with the information from the BOLK biomass report (Boersma et al., 2008) A higher NO_x emission factor is now used for gas engines fired with biogas. Moreover, emission factors for NMVOC and $PM_{2.5}$ (particles measuring 2.5μm or less) have been incorporated into these fermentation options and some minor revisions on SO_2 and PM_{10} (particles measuring 10μm or less) emission factors have been carried out. These adjustments may not be robust since the information from the biomass report is based on international data. The Dutch situation may be different that previously thought because the Netherlands has a particular gas engine market with deviating engine emissions specifications (as stated in the Dutch decree on emission limits for combustion plants Bees-B), compared to other European countries. Further study on emission data for the Dutch situation could well revise the used-emission factor once more. Table 4.3 shows the effects of the new insights on synergies and trade-offs of the fermentation options on air polluting emissions.

Options descriptions for biofuels and BOLK

The report on the effects of biofuels in road transport (Verbeek *et al.*, 2008) on air polluting emissions, did not culminate in a robust conclusion on synergies or trade-offs, especially given the uncertainty about future alternative fuel characteristics and engine developments. The information collected in this study on biofuels presents an indicative range of effects on air pollutants levels from biofuels use in petrol or diesel cars, or diesel trucks in varying mixtures. Different ranges are also given per euro standard. The best cases in these ranges often imply reduced air polluting emissions (i.e. a net synergy), compared to fossil fuel use and the worst cases often imply increased emissions (i.e. a trade-off). So far, not enough measurements have been

Table 4.3 Differences between current and updated synergies and trade-offs of the fermentation options on air pollutant emissions[a]. Positive numbers refer to an emission reduction (synergy), negative numbers refer to an emission increase (trade-off).

Current and updated options	GHG	NO_x	SO_2	NH_3	NMVOC	PM_{10}	$PM_{2.5}$
	Mt			kt			
Current co-fermentation	1.9 to 2.1	-0.1	0.1 to 0.2	0	0	0.01	0
Updated co-fermentation	1.9 to 2.1	-1.2	0.1 to 0.2	0	-0.2	0.01	-0.01

[a] The range covers the effects under the modest and more stringent European climate policy.

conducted to derive statistically sound average emission values for the use of biofuels in road transport. Therefore, the biofuels option in the options document has not been changed. Instead, a sensitivity analysis is presented in Chapter 5, which estimates the indicative effects of biofuels based on the variation in test results collected and analysed in (Verbeek *et al*., 2008).

Chain emissions in the options document

Life cycle effects - or resulting indirect emissions – have not been part of the Dutch emission projections or the option document so far. Although the BOLK reports do contain information on estimation of the indirect effects of bioenergy chains and CCS, it was not included here. If indirect or chain emissions from bioenergy were included, this would distort the comparison or the substitution with fossil fuels (currently only refinery effects from liquid fossil fuels are taken into account). Secondly the data presented is for complete chains without a detailed specification of the effects attributable to the Netherlands.

5 Updated integral assessment of the effects of the Dutch climate programme on future air pollutants

BOLK research confirms the beneficial effects of the Dutch climate programme on air pollutants, as well as the uncertainties surrounding these estimates
The integrated results of the first phase of the BOLK Research programme confirm that the Dutch climate programme, together with the measures from the EU climate programme, reduce emissions of greenhouse gases (GHG) and most of the priority air pollutants in the Netherlands. Clearly, there is a large range of projected emission effects. These ranges stem from a large degree of uncertainty about: future carbon dioxide (CO_2) price in the EU Emissions Trading System (EU ETS), the effects of individual climate and energy measures and also on the import or export of electricity.

Dutch climate programme reduces GHG and air pollutants to a lesser extent
The assessment here shows that the Dutch climate programme substantially reduces GHG emissions (7-28% reduction relative to the 2020 baseline) and reduces emissions of most air pollutants by just a few percent. The effects of the reductions on the levels of air pollutants are most substantial for sulphur dioxide (SO_2) (2-20%) and nitrogen oxides (NO_x) (0-8%). Ammonia (NH_3) emissions may show a net increase.

Various reasons for limited climate-air synergy
The reduction in levels of air pollutants is less than the reduction in levels of GHG (i.e. smaller synergy) because of the following:
- Synergy occurs mainly in energy-related emissions, but air pollutants and GHG emissions are only partly linked to energy use.
- Stimulating use of bioenergy (biofuels, biomass and biogas) leads to reductions in CO_2 emissions, but not necessarily to reductions in air polluting emissions.
- Some types of CCS technologies (e.g. post-combustion CCS in a coal-fired power plant), could lead to decreasing SO_2 emissions but also to increasing NH_3 and NO_x emissions.

Expected increase in export of electricity in the future reduces synergy nationally
Dutch electricity production and export (60-140 petajoule 10^{15} J [PJ]) is expected to increase because of current climate policies (e.g. ETS) and because of the benefits of a number of Dutch assets (e.g. harbours that provide a cheap supply of coal, the vicinity of the North Sea for cooling water and abandoned gas fields for geological storage of CO_2). The effects of the climate programme on national levels of air polluting emissions could be halved as a result of the expected export of electricity. The rest of the beneficial effects will flow to the countries that import the Dutch electricity.

Indicative effects of biofuels on NO_x and $PM_{2.5}$ emission levels from road transport
A sensitivity analysis based on monitored effects, indicates that biofuel blends that achieve the 10% biofuels target in 2020 in the Netherlands, could lead to a change of between 5 and 10% in the projected NO_x emission levels from road transport, in 2020 (about 40 kt). The indicative change in PM emissions is smaller (<5%).

This chapter presents an updated assessment of the effects of the Dutch climate programme on Dutch air pollution levels, in 2020. New information from the first phase of the BOLK research programme, on synergies and trade-offs of some specific climate measures, is incorporated in this assessment. Special attention is given here to the role of electricity import or export in the national effects of climate measures on air polluting emissions. The outcome of the Dutch assessment is compared to a similar assessment of the effects of the European climate and energy proposals by Amann *et al*., (2008) for the Netherlands. A sensitivity analysis of the air pollution effects from biofuels in Dutch road transport is presented at the end of this chapter.

5.1 Effects of the Dutch climate programme on future air pollutants

In 2007 the Dutch Government published the programme ‘Clean and Efficient’ (*Schoon en Zuinig*) which contains policies and options to reach the Dutch energy and climate targets for 2020, see Chapter 1. The effects of this programme on GHG energy savings and renewable energy have been assessed by ECN and MNP (Menkveld *et al*., 2007). In this assessment the proposed policies of the programme were translated into two policy packages and subsequently into estimated effects. The two policy packages are based on two scenarios that take into account the possible stringency of EU climate and energy policies. The first scenario uses a CO_2 price of 20 euros/tonne and low CO_2 and energy performance standards for passenger vehicles, office and residential buildings and electrical equipment. The second scenario uses a CO_2 price of €50/tonne CO_2[5)] and higher CO_2 and energy performance standards. To account for the uncertainty in the effects of policy measures, a lower and upper estimate is presented for each of the two scenarios.

Important measures of the Dutch programme that lead to GHG reductions within the Netherlands include: energy saving, mainly through European directives on more efficient electrical appliances, more efficient passenger cars and better insulation of houses and buildings; the use of biofuels in road transport; road pricing; subsidising renewable energy such as wind and solar energy; stimulating the use of combined heat and power (CHP) including CHP using biogas from co-fermentation of manure and CO_2 capture and storage (CCS). These developments will lead to additional decommissioning of existing coal- and gas-fired power plants. In the package that assumes €20/ton CO_2, more use is made of CDM/JI and energy saving, while in the package that assumes €50/ton CO_2, more use is made of CCS (4-10 Mt in 2020) and fuel switch.

In 2008, ECN assessed the effects of the Dutch climate programme on air polluting emission levels (Daniels *et al*., 2008). Here, new insights from the BOLK study, on the air polluting effects of biomass/biogas and CCS (Chapter 4), have been integrated by ECN into their previous assessment. The most significant new insights comprise adjustments to the co-fermentation options (1 kt higher NO_x emissions) and the CCS options (up to 1.5 kt higher NO_x emissions, 1-3 kt higher NH_3 emissions and lower SO_2 emission effects compared to the previous assessment).

BOLK research confirms the beneficial effects of the Dutch climate programme on air pollutants, as well as the uncertainties surrounding these estimates

The integrated results of the first phase of the BOLK Research programme confirm that the Dutch climate programme, together with the measures from the EU climate programme, reduce GHG and most of the priority air pollutants in the Netherlands (Table 5.1, Figure 5.1). Clearly, there is a large range in projected emission reductions. These ranges stem from a large degree of uncertainty about: the future CO_2 price in the EU ETS; the effects of individual climate and energy measures and; the import or export of electricity. The lower end of the range takes an assumed modest European CO_2 price of €20/tonne CO_2 into account and the higher end includes a high CO_2 price of €50/tonne CO_2. The analysis shows that the Dutch climate targets and the indicated national emissions ceilings for priority air pollutants are outside these of ranges, and that additional measures are needed to comply with the targets.

The Dutch climate package also reduces SO_2 and NO_x. For SO_2, emission reductions are largest, and result mainly from the additional decommissioning of coal-fired power plants, from the use of CCS (post-combustion capture on pulverised coal (PC) power plants) and from increased substitution of coal by biomass in coal-fired power plants. Many climate measures that affect energy production (e.g. energy savings, wind and solar power) result in net reductions in NO_x emissions. Within the climate package, the application of CCS (post-combustion capture in PC-power plants) could lead to an increase in NO_x emissions due to increased energy consumption needed to run the capture process itself (the so-called ‘energy penalty’). Ammonia

5 Note that the carbon price estimated by the European Commission resulting from the climate package proposed thus far is €30/t CO_2, which is between the values used in the assessment of Daniels et al., (2008) and Menkveld et al., (2007).

Table 5.1 Emission projections for 2020 with current legislationa (PBL, 2008) and the updated effects of the Dutch 'Clean and Efficient' climate programme on the CO_2 and air pollutant projections (Daniels et al., 2008; this study). Positive numbers refer to an emission reduction (synergy), negative numbers refer to an emission increase (trade-off).

	GHG	CO_2	NO_x	SO_2	NH_3	PM_{10}	NMVOC
	Mt		kt				
National projecttion CLE[a] 2020	246	211	206	56	143	39	170
Potential reduction by Dutch climate programme[b]							
- Without assumed electricity export	30-70	25-64	8-17	7-11	0 to -3	0.4-0.6	0.2-0.4
- With assumed electricity export	17-52	11-46	0-6	1-5	0 to -3	0.1-0.3	0.2-0.4
National projection CLE including Dutch climate programme[b]	194-229	166-200	212-217	52-56	145-148	39	170
Dutch climate targets and indicated air emission ceilings for 2020[c]	150	n.a.	177	44	125	n.a.[d]	161

[a] This includes current legislation and the estimated effects of EURO VI proposal for heavy-duty vehicles (Velders et al., 2008) and the SO_2 covenant 2008 between the Dutch government and the energy sector (VROM, 2008). [b] The range covers the effects under the modest and more stringent European climate policy (Daniels et al., 2008; Menkveld et al., 2007). [c] National GHG targets of the Dutch cabinet (VROM, 2007), and indicated national emission ceilings of air pollutants (Amann et al., 2008). [d] An indicated target for a Dutch $PM_{2.5}$ emission ceiling is presented in Amann et al., (2008) of 16 kt in 2020.

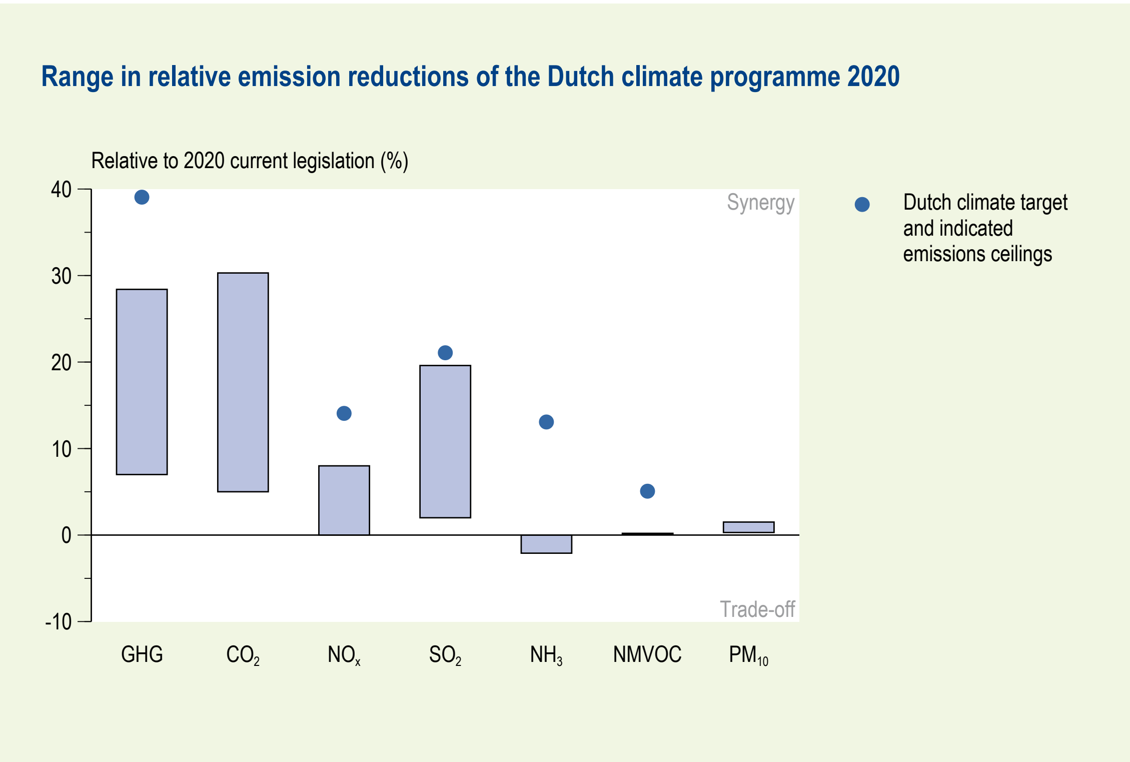

Figure 5.1 Relative emission reductions of GHG and air pollutants within the Netherlands in 2020, resulting from the Dutch climate programme and EU climate policies. The range accounts for two target levels of EU climate policy (see text), uncertainties in the effects of measures and on the export of electricity. The figure is based on Daniëls et al. (2008), updated with results of the BOLK research programme

emissions could show a net increase, resulting from a possible NH_3 leakage during the post-combustion CCS technology in coal-fired power plants. Additional measures could compensate for this effect. For PM_{10} (particles measuring 10µm or less) and non-methane volatile organic compounds (NMVOC), emission effects are negligible.

Climate measures reduce cost for additional air pollution control
Because of these climate policies, additional air pollution control costs for reaching the indicated national emission ceilings (NEC) for air pollutants in 2020 in the Netherlands (Table 5.1) will be reduced by between 5 and 50% (15-150 million euros) per year. Additional air pollution control costs in the Netherlands are calculated using information on effects and costs of specific measures based on the options document (Daniels and Farla, 2006), Peeters-Weem, (2006) and Emission care (2008). These cost reductions are relatively small, compared to the total of the indicated costs of the additional Dutch climate measures of 3-9 billion euros (Menkveld and Wijngaart, 2007).

Climate programme reduces GHG more strongly than air pollutants
The assessment here shows that the Dutch climate programme reduces GHG and air pollutants to a lesser extent. Several reasons have been identified that explain why the reduction in levels of air pollutants is less than the reduction in levels of GHG (i.e. smaller synergy):
- Synergy occurs mainly in energy-related emissions, but the air pollutants (especially SO_2 and NO_x) and GHG emissions are only partly linked to energy usage. The other air pollutants NH_3, volatile organic compounds (VOCs) and PM are related to activities in agriculture, industry and households.
- Stimulating use of bioenergy (biofuels, biomass and biogas) leads to reductions in CO_2 emissions, but not necessarily to reductions in air polluting emissions. In contrast, bioenergy combustion in small-sized installations (up to a few megawatt thermal [MW_{th}]), could increase levels of air polluting emissions compared to heat/power production in large-sized installations with extensive flue gas cleaning, or compared to natural gas-fired combustion. To prevent this possible trade-off, the Netherlands is working on more stringent emission limits for small-sized bioenergy installations.
- Application of CCS could have very specific effects on air polluting emission levels, depending on the technology. The most developed CCS technology, such as post-combustion CCS in a PC-fired power plant, could lead to decreasing SO_2 emissions but also to an increase in NH_3 and NO_x emissions.

Expected increase in export of electricity in the future reduces synergy nationally
In the Netherlands, the effect of national and European climate programmes on domestic emission levels depends on assumed changes in the export of electricity. At present, the Netherlands is a net importer of electricity. It is likely that the Netherlands will become an electricity exporting country during the next decade following an analysis of the north-west European electricity market in 2020 and considering the planned construction of new power plants (Daniels et al., 2008). The export is expected to amount to 60-140PJ, which is 10-25% of total projected Dutch production in 2020. The Dutch electricity sector experiences some competitive advantages, particularly in the case of high CO_2 prices. There are a number of attractions for potential investors who are interested in establishing new power plants the Netherlands: ease of access to cheap cooling water from the sea, low supply costs of coal due to the proximity to harbours, and availability and relatively easy access to geological CO_2 storage capacity in empty gas fields.

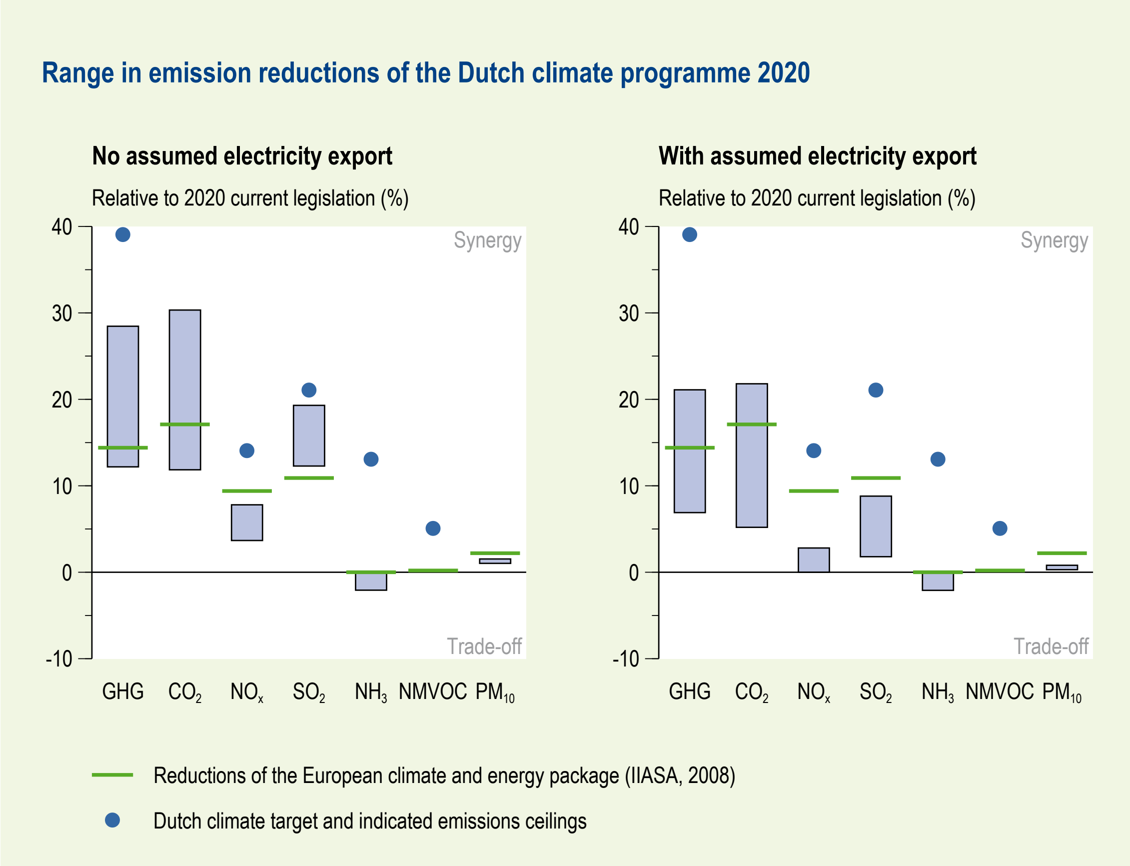

Figure 5.2 Left: Relative emission reductions of GHG and air pollutants within the Netherlands in 2020, resulting from the Dutch climate programme and EU climate policies. The range accounts for two target levels of EU climate policy (see text), uncertainties in the effects of measures on the export of electricity. The figure is based on Daniëls et al. (2008), updated with results of the BOLK-research programme. The left figure assumes that there is no net import or export of electricity. Right: The situation with the assumed increase in net electricity export

To compensate for CO_2 emissions arising from this electricity export, the energy sector is expected to buy CO_2 credits abroad within the ETS system. This means that both CO_2 emissions and air pollutants will be reduced abroad. As the climate–air synergy is relatively large in the energy sector, this export development could halve the synergy between climate measures and air pollution (especially SO_2 and NO_x) within the borders of the Netherlands (Table 5.1, Figure 5.2).

The smaller climate–air synergy also means that more additional air pollution control measures are needed (to meet the indicated national emission ceilings, see Table 5.1), and that 'costs synergy' for air pollution control is reduced from between 35 and 50% (no export of electricity) to between 5 and 30% (with export of electricity). This implies that part of the

For reasons of comparison, the estimated effects of the European climate and energy package on the levels of GHG emissions and air pollutants in the Netherlands, have been included in Figure S2, according to estimations by the International Institute for Applied Systems Analysis (IIASA) (Amann et al., 2008). These estimations, based on the PRIMES Energy System model (Capros et al., 2008), use a CO_2 price of 30 euros/tonne and assume a low import of electricity, by the Netherlands. The IIASA estimates on GHG and CO_2 reductions for the Netherlands are within the ranges of the Dutch climate package (which includes a range in CO_2 price of between 20 and 50 euros/tonne), for situations with and without electricity export. In the situation that assumes electricity export, the beneficial effects of the Dutch climate programme on levels of SO2 and NO_x which are estimated in this report, are clearly less than those estimated by IIASA. Apart from the differences between IIASA's report and this report which are caused by different assumptions on electricity export and CO_2 price, other - different - assumptions on projected energy consumption, types of climate measures and related air emission factors, may further explain the differences in estimates in Figure S2.

Sector emission ceilings in the Netherlands may disguise synergy
The SO_2 reductions in the Dutch climate programme are influenced by assumed decommissioning of coal-fired power plants. Synergy would be in fact lower if gas-fired plants were decommissioned. However, the calculated SO_2 reductions may not occur in reality, due to the effect that a fixed SO_2 emission ceiling (13.5 kt in 2020) could have on other installations. Essentially, the electricity sector in the Netherlands has a fixed sector SO_2 emission ceiling, and reduced emissions from decommissioned power plants could be used by the remaining power plants to decrease their flue gas desulphurisation efficiencies and associated costs.

5.2 Indicative effects of biofuel use in road transport on air pollutants

The current state of knowledge does not allow for a reliable quantification of emission effects from biofuels and hence the bio-fuel option in the options document could not be updated (Chapter 4). However, the provided information (that is, ranges of possible effects indicated by available measurement results and other studies) is used to perform a sensitivity analysis which gives us an insight into the effects of biofuel use in road transport on levels of air polluting exhaust emissions, in 2020.

In this analysis, average emission effects have been estimated within the range of indicative effects of biofuel use in light-duty petrol or diesel, or heavy-duty diesel vehicles (see Chapter 2, Tables 2.7 to 2.9). This range does not take into account possible exhaust durability problems after treatment systems associated with high biodiesel blends (Paragraph 2.3). The effects are further examined by blending percentages per euro standard. The effect of the use of biofuels on CO_2 emission factors is assumed to be a constant effect over the different euro standard vehicle classes. The best cases in these identified ranges often imply reduced air polluting emissions (i.e. a net synergy), compared to fossil fuel use and the worst cases often imply increased emissions (i.e. a trade-off).

Additional information and assumptions were gathered on the vehicle fleet composition in 2020, by construction year, by category (passenger cars, light-duty vehicles, trucks and other heavy-duty vehicles) and the mileage driven (Uyterlinden et al., 2008). Other information concerned the emission factors and fuel efficiency corresponding to each vehicle category. In this information it was accounted for that by 2020 older vehicles (Euro-2 or Euro-3) will have a lower annual distance driven than newer vehicles (Euro 5 and 6).

With the best and worst case estimates for emission factors, the vehicle fleet composition and the five different sets of biofuel blends that achieve the 10% biofuels target in 2020 (Table 5.2, more details in Paragraph 2.3), detailed emission effects were estimated for CO_2, NO_x and PM (from combustion only). Appendix 2 contains the detailed data with which the calculations have been performed.

Table 5.2 Several possible blend percentages of bio-ethanol (e.g. E10=10% ethanol) and biodiesel (e.g. B7 = 7% biodiesel) for passenger and cars and trucks to meet the biofuels target of 10% (by energy content) in 2020 in the Netherlands.

		Passenger cars	Trucks
Blend option	Bio-ethanol (by volume)	Biodiesel (by volume)	Biodiesel (by volume)
1	E10	B7	B20
2	E10	B7	20% of all trucks run on B100
3	E12	B12[b]	B12
4	E55[a]	B0	B0
5	E0	B15[b]	B15

[a] This would require that all petrol cars are FFVs
[b] Higher blend fuels can cause engine durability problems for cars with diesel particulate filters

For the smaller share of liquefied petroleum gas (LPG)-based passenger cars and light-duty vehicles (vans), no assumptions on emission effects have been included. With about 2% of passenger cars travel and less than 1% of kilometres travelled, possible effects would only make a marginal difference compared to the current estimates.

Indicative effects of biofuels on NO_x and $PM_{2.5}$ emission levels from road transport
The indicative effects of the various blends on NO_x emission levels (Figure 5.3), show increases (trade-offs) of up to 9% (3.5 kt) or reductions (synergy) of up to 5% (2 kt), compared to the projected baseline road transport emissions for 2020 (about 40 kt). The effects of the various blends on particulate matter emission levels, show increases of up to 4% (0.2 kt) or reductions by as much as 2% (0.1 kt).

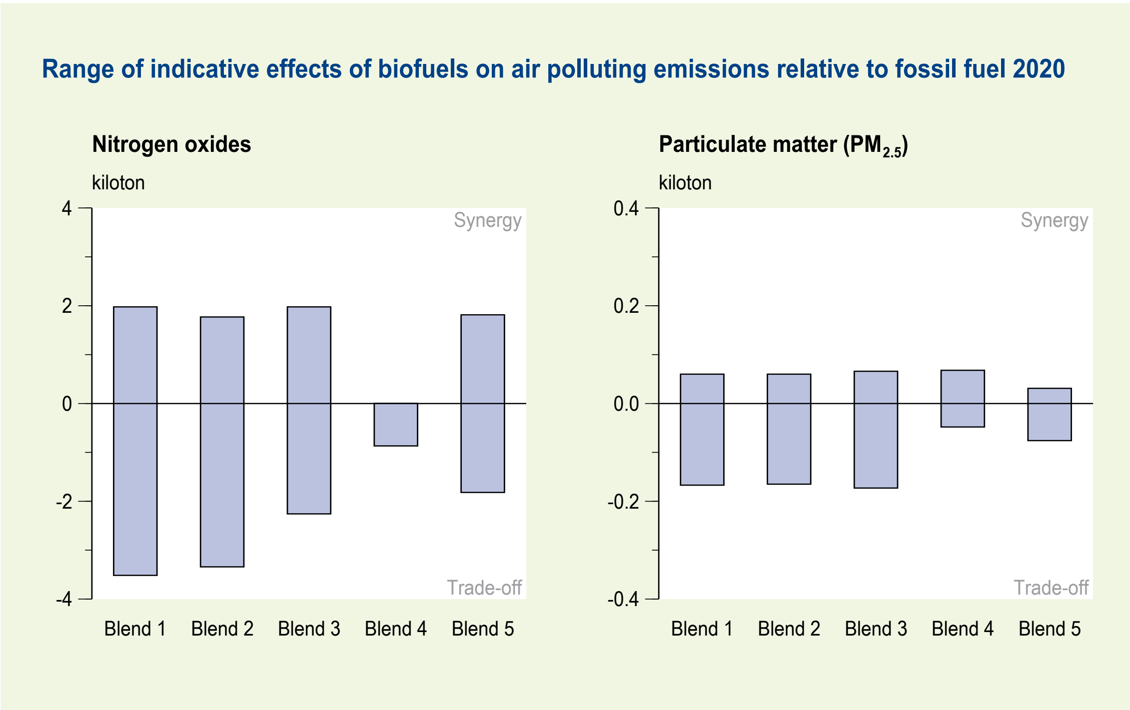

Figure 5.3 Effects of five biofuels blends in the Dutch vehicles fleet of 2020 on NO_x and $PM_{2.5}$ emissions.

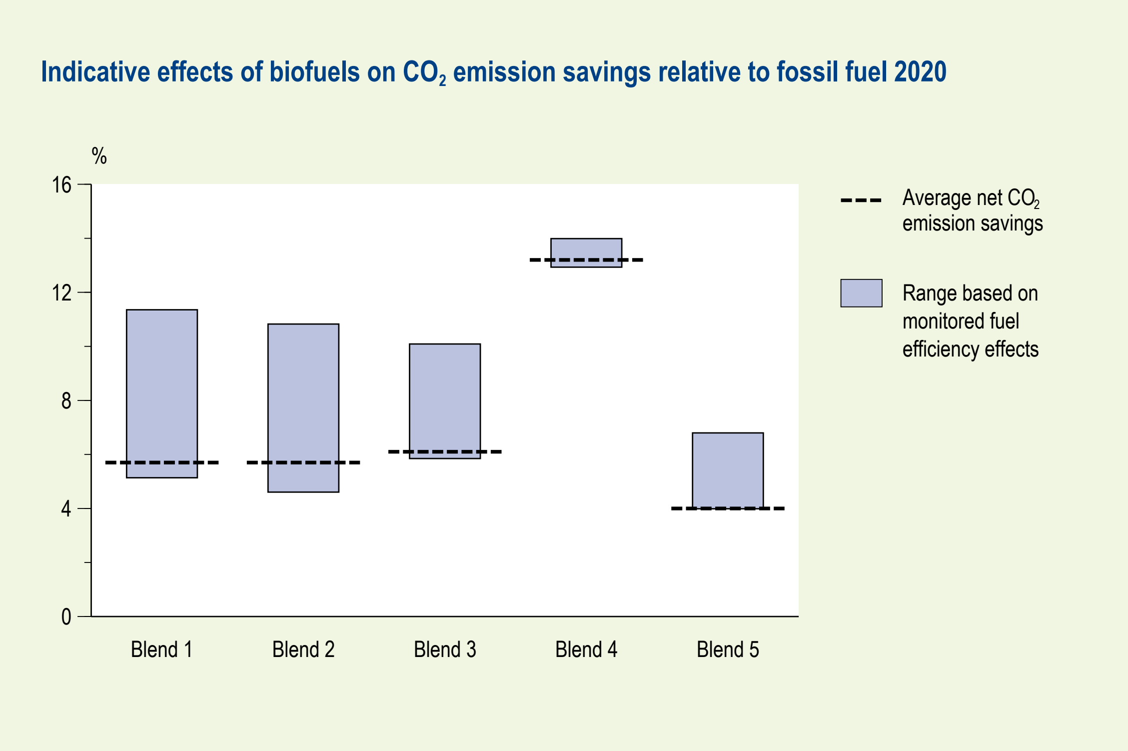

Figure 5.4 Potential CO_2 emissions reductions of five bio-fuel blends applied in the Netherlands in 2020.

It should be noted that the five sets of blends studied here do not cover the complete range of available biofuels and road transport modes. For instance, synthetic biodiesel fuels (hydrogenated vegetable oil, biomass to liquid, biogas to liquid) and biogas are expected to result in lower air polluting exhaust emissions, especially when used in the current fleet (Chapter 2). However, available quantities for up to 2020, are expected to remain limited. Inclusion in the analysis of other modes of road transport with potential high emission levels (e.g. inland shipping) could enlarge the insights into the effects from biofuels use in mobile sources.

Do low blends biofuels use indicate better fuel efficiency?
The sensitivity analysis shows that the various biofuel blends reduce net CO_2 emissions by at least 4%, compared to neat fossil fuel (Figure 5.3). This is related to the average net CO_2 savings of the biofuel blends [6]. There are indications that larger emission reductions may take place. Whether this is the result of a slightly better fuel efficiency of light-duty diesel engines using lower blends biofuels, or not, is not clear yet. More research is needed on this subject.

The fourth blend, 55% bio-ethanol, shows the highest CO_2 reduction compared to the other fuels due to the high CO_2 savings realised in the ethanol production chain. The 10% bioenergy target can only be met in this case, with a high level of blending because of the relatively low energy content of ethanol and the expected relatively small contribution of petrol cars to the total fuel consumption in the Netherlands in 2020.

6 The assumed bio-diesel mix consists of 90% rapeseed (CO_2 saving 35%) and 10% palm oil (saving 60%). The assumed bio-ethanol mix originates for 15% from sugar beet (saving 57%) and 85% from sugar cane (saving 90%). The savings are compared to an average complete fossil fuel chain.

6 Remaining gaps in knowledge

The current estimations on synergies between climate and air pollution policies in the Netherlands indicate that, overall, net beneficial effects do occur, but that uncertainties in the estimates are large. The first phase of BOLK contributed to more insight into the potential effects of these uncertainties and identified some important knowledge gaps. These knowledge gaps, described in more detail below, could form a starting point for further research in the second phase of the BOLK programme, or elsewhere.

6.1 Future biofuel mixes and supply-chain emissions from biofuels and biomass

The inventory study (Koper et al., 2008) of chain emissions from biofuels and biomass in 2020, resulted in the modelling of five likely biofuel chains and one wood chain. In the light of emerging feedstocks and technologies and developing sustainability criteria, it is expected that biofuel chains will increasingly play an important role in the biofuels spectrum of 2020. Further analysis of the biofuels mix could also isolate those chains or the aspects of those chains which might have more beneficial impacts on air quality and which should be given more attention. Other chains which can possibly be included are other commercially available biofuel chains and the so-called 'second generation chains', such as ethanol from straw, ethanol from lignocellulose biomass (wood), or Fisher-Tropsch diesel from biomass. Also a more detailed analysis of fossil diesel and petrol chains is needed as a reference point.

The inventory study was performed using the life-cycle analysis tool SimaPro (version 7). It was not possible to report on all aspects of the content of the SimaPro tool and to check its validity. Therefore, further scrutiny of certain essential processes (i.e. activity levels and emission factors) in SimaPro may be necessary in order to validate the results of the chain emissions. Subsequently it may be necessary to update outdated data. It may also be useful to study those aspects which could be improved or changed due to policies (i.e. technological change, agricultural improvements etc.). Other gaps in knowledge that deserve more attention are:

- lack of knowledge on the expected activity increase in conversion, refining and transport of crude feedstock and refined biofuels in the Netherlands
- lack of detail on the possible locations of chain emissions (within the Netherlands, the EU or outside the EU)
- lack of estimated effects of displacement of food and feed crops by biofuel crops in biofuel-producing countries
- the effect of the use of bioenergy instead of fossil energy, on supply-chain emission levels within the supply chain itself

6.2 Biofuel use in road transport

There are a number of factors which influence the relationship between biofuels and exhaust emissions in current and future vehicles; these are biofuel quality, vehicle technology and driving behaviour. In addition, the use of biofuels (blended or neat fuel) in different vehicles may influence evaporative emissions, driveability, maintenance schedule or sustainability of a fuel system. Essentially, the current state of knowledge does not allow a reliable quantification of emission effects from biofuel use in current and future vehicles (Verbeek *et al.*, 2008). The state of knowledge for current vehicles and biofuels is based on measurement data obtained in various laboratory tests which were performed in a non-systematic and non-comparable manner. A comprehensive systematic investigation (i.e. a broad and practical approach) of biofuel emission effects in combustion engines, has not been reported yet.

A limited amount of literature has been found which considers the effects, for future vehicles, of biofuels on air polluting emission levels. In (Verbeek *et al.*, 2008), an attempt has been made to draw more general conclusions about the impact of biofuel use, based on considerations about fuel composition and future engine characteristics. Important uncertainties that remain concern the most likely engine-fuel combinations for the 2015-2025 period, and the compatibility of biofuels with future after-treatment technology. In fact, one study found the use of biodiesel caused an increased sensitivity (i.e. increase in levels of NO_x emissions) from future after-treatment equipment (Kawano, 2007). This illustrates the need for more research on the compatibility of future after-treatment technology with biofuels.

Apart from the expected effects of mainstream biofuels on air pollution levels, very little measurement data is available for promising niche fuel engine combinations, such as compressed natural gas, biogas, and liquefied petroleum gas (LPG) in future (Euro 5/6) gaseous fuel engines and butanol (all blends) in petrol engines. Other gaps in the knowledge concern the toxicity of exhaust gases from vehicles which use biofuels. While little data is currently available, some studies reported increased emissions of certain toxic components, or increased mutagenicity of exhaust gas.

It is clear that a comprehensive systematic international emissions measurement programme is needed to fill the large knowledge gaps that have been identified. Such a programme should focus on low-blend biodiesel, high-blend biodiesel in trucks, and low- and high-blend ethanol. The focus should be on the most modern vehicles or engines with advanced emission control devices. It should also include non-regulated toxic components and preferably biological toxicity tests. Such a measurement programme should probably be split into two programmes. The first programme should scan many vehicles for the standard components (nitrogen oxides [NO_x], hydrocarbons [HC], carbon monoxide [CO] and particulates). This should be combined with a second programme which carries out an in-depth analysis of non-regulated toxic emission components and toxicity for selected vehicles. Measurements of future niche-engine combinations are important for determination of, for instance, local air pollution effects of captive fleet use.

6.3 Bioenergy use in stationary applications

Recent data on small and medium-sized installations are scarce, and if available, originates from a wide range of installations (i.e. scale, type, fuel used, and operating conditions), some located in the Netherlands and some outside its borders (Boersma et al., 2008). A centralised emission registration requirement for installations smaller than 50 megawatt thermal [MW_{th}] is currently not required in the Netherlands and this is one underlying cause for the current lack of information. The emission factors reported in the literature are very diverse and show a large spread. It is often not possible to cite one typical emission factor with confidence, not even within one category of bioenergy usage. Moreover, it is difficult to assess how representative the (inter) national data is for Dutch installations.

Also, up-to-date cost data of air polluting emissions reduction measures are scarce. According to the information obtained from operators and suppliers of small and medium-sized bioenergy applications, the installations comply with the required emission limit values. However, actual emission data are often not made accessible, making it difficult to reach firm conclusions on the effects of biomass use.

In general, the effect of bioenergy use on non-methane volatile organic compounds (NMVOC) and ammonia (NH_3) emission levels, is not known for small and medium-sized installations. This is because emissions of these compounds are expected to be low, and emission limits for these pollutants doesn't exist, so there is no reason for installation operators to measure these emissions. For small-sized installations using clean biomass, sulphur dioxide (SO_2) data are often missing for the same reason. Moreover, the sub-division of PM into PM_{10} (particles measuring 10μm or less) and $PM_{2.5}$ (particles measuring 2.5 μm or less) is frequently not observed.

In order to assess the relative importance of the above uncertainties, projected emissions from small to large-sized bioenergy installations in 2020, have been estimated using worst-case emission factors, provided by the BOLK study of Boersma et al. (2008) (for more details see Appendix 3). This shows that nearly 90% (187 petajoule 10^{15}J [PJ]) of the projected Dutch bioenergy in 2020 will be generated in large-sized coal, gas- and waste-fired power plants. The worst-case estimates in 2020 contribute about 5% to the total projected emissions of NO_x and SO_2 from all sectors, except traffic. Medium-sized bioenergy installations (using waste and demolition wood or palm oil) and small-sized wood stoves are expected to generate about 8% (17 PJ) of the projected Dutch bioenergy in 2020. The worst-case estimate contributes around 10% to the total projected emissions of NO_x (except traffic). The limited application of small-sized bioenergy installations (e.g. using landfill or biogas) is expected to contribute less than 1% to air polluting emissions, in 2020. Although the above estimates need further refinement, they indicate that further research into the effects of stationary bioenergy applications on air pollution levels in the Netherlands, should focus on medium-sized bioenergy installations and wood stoves.

6.4 Carbon dioxide capture and storage (CCS)

The BOLK study (Harmelen *et al.*, 2008) covered the review of available, international data on CCS and the effects on priority air polluting emission levels, mainly in the power sector. Overall it is found that accurately estimating the emission profile - and with it, the emissions of NEC substances - for power plants equipped with post- and pre-combustion carbon dioxide (CO_2) capture is rather difficult. Reported emissions are mostly based on numerous assumptions about the technological configuration and performance, which may vary considerably in the literature. For more accurate estimates, measurements of demonstration projects using capture technologies are required.

There is also a considerable lack of data on emissions (estimations) from gas-fired oxy-fuel processes with CO_2 capture. The emission factors of oxy-fuel applications in coal-power plants are based on pilot tests and desktop studies. Practical demonstration of this technology using emission monitoring is required for more accurate estimation of emission factors.

Other gaps that have been identified include:
- effects of co-combustion of biomass or biofuels in power plants equipped with a CO_2 capture unit

- effects and cost of options to reduce NH_3 emissions by the capture unit
- effects of others solvents
- effects of CO_2 capture in industry
- effects of retrofitting existing systems versus installing new integrated systems, with CO_2 capture
- effects of small-scale CO_2 capture, (e.g. on combined heat and power production plants)

Also, specific data for the Dutch situation regarding technology or fuel quality is not covered. Moreover, the available information about costs is very limited and is not applicable for the Netherlands.

Appendix 1. Overview of updated option descriptions

Table A1.1 Overview of current options covered by the technical BOLK reports - description of updates and reasoning for performing updates.

	Option	Update	Reasoning	Update
B1	CO_2-ENE-01 (AVI)	Yes	New information	Updated emissions based on BOLK; updated heat share and GHG emissions, based on recent AVI statistics
B2	CO_2-ENE-02 (indirect co-firing gas power plants)	No	No data available for co-firing of gasified biomass in gas power plants	None
B3	CO_2-ENE-03 (indirect co-firing new coal power plants)	Yes	Data on emission factors are not different to current data. Possibly lower SO_2 emission factor, but reference projection needs to change as well first.	None
B4	CO_2-ENE-04 (indirect co-firing new coal power plants)	Yes	Data for emission factors are not different to current data.	None
B5	CO_2-ENE-05 (biomass power plants)	Yes	Range for emission factors covers current data.	None
B6	CO_2-ENE-06 (direct co-firing gas power plants)	Yes	Same data as is currently in use	None
B7	CO_2-ENE-07 (direct co-firing coal power plants)	Yes	Not enough data available to alter emission factors	None
B8	CO_2-ENE-16 (green gas from (co-fermentation)	Yes	Not enough data available to alter emission factors	None
B9	CO_2-ENE-17 (green gas from waste disposal and RZWI)	No	Not a reduction option, no information available	None
B10	CO_2-ENE-18 (green gas from biomass gasification)	Yes	New information available	Higher efficiency and updated emissions and cost data.
M1	OBG-LTB-03 (co-fermentation manure dairy cattle)	Yes	New information available. Emission effects of land use for co-substrate production are not (yet) included.	Emissions updated
M2	OBG-LTB-04 (co-fermentation pig manure)	Yes	New information available. Emission effects of land use for co-substrate production are not (yet) included.	Emissions updated
M3	OBG-LTB-05 (fermentation manure dairy cattle)	Yes	New information available	Emissions updated
M4	OBG-LTB-06 (fermentation pig manure)	Yes	New information available	Emissions updated
C1	CO_2-ENE-09 (CCS existing gas power plants)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated
C2	CO_2-ENE-10 (CCS existing coal power plants)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated
C3	CO_2-ENE-11 (CCS existing coal, Buggenum)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated
C4	CO_2-ENE-12 (CCS new gas power plants)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated

	Option	Update	Reasoning	Update
C5	CO_2-ENE-13 (CCS new coal power plants)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated
C6	CO_2-ENE-14 (CCS eldest 5 coal power plants)	Yes	New information, but no cost data available	Emissions, power plant and capture efficiency updated
C7	CO_2-ENE-15 (CCS post-combustion new coal)	Yes	New option	Emissions, power plant and capture data and description added
C8	CO_2-IND-03 (CCS NH_3 production)	Yes	No information available	None
C9	CO_2-IND-04 (CCS ethene production)	Yes	No information available	None
C10	CO_2-IND-05 (CCS existing large CHP)	Yes	No information available	None
C11	CO_2-IND-06 (CCS new large CHP)	Yes	No information available	None
C12	CO_2-IND-07 (CCS primary iron and steel	Yes	No information available	None
C13	CO_2-IND-15 (CCS new processes CHP)	Yes	No information available	None
C14	CO_2-IND-17 (CCS potential existing CHP)	Yes	No information available	None
C15	CO_2-OVG-02 (CCS refineries)	Yes	No information available	None
T1	CO_2-TRA-12 (biofuels transport)	Yes	Data not available to alter emission factors. Large uncertainty about fuel and engine characteristics.	None
C16	Indirect CCS post- combustion	Yes	New option	Emissions from solvent handling post-combustion CCS added
C17	Indirect CCS pre- combustion	Yes	New option	Emissions from solvent handling pre-combustion CCS added
C18	CCS new coal power plants, post- combustion	Yes	New option	Emissions and costs estimates added

Appendix 2. Details of sensitivity analysis of biofuels in transport

Table A2.1 Road emission factors for the Dutch situation [7] (g/km)

Cars	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Petrol					
NO_x	0.17	0.05	0.04	0.03	0.03
PM	0.007	0.005	0.004	0.004	0.004
Diesel					
NO_x	0.65	0.61	0.31	0.19	0.09
PM	0.062	0.045	0.037	0.007	0.007
LPG					
NO_x	0.32	0.19	0.07	0.04	0.04
PM	0.006	0.005	0.005	0.005	0.006
Light-duty vehicles	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
Petrol					
NO_x	0.17	0.05	0.04	0.03	0.03
PM	0.006	0.004	0.004	0.004	0.004
Diesel light					
NO_x	1.15	0.92	0.50	0.34	0.15
PM	0.114	0.066	0.072	0.009	0.009
Diesel heavy					
NO_x	1.40	1.10	0.49	0.35	0.16
PM	0.158	0.093	0.045	0.004	0.004
LPG					
NO_x	0.44	0.25	0.13	0.10	0.10
PM	0.006	0.004	0.004	0.005	0.005
Heavy-duty vehicles - trucks	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
Small					
NO_x	4.66	0.34	2.16	1.26	0.25
PM	0.079	0.077	0.013	0.013	0.007
Medium					
NO_x	7.51	5.68	3.48	2.04	0.41
PM	0.132	0.135	0.023	0.023	0.011
Large					
NO_x	10.62	7.99	4.98	2.90	0.58
PM	0.181	0.179	0.029	0.030	0.015
Heavy-duty vehicles - other	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
Trailer					
NO_x	10.03	7.69	4.71	2.76	0.55
PM	0.174	0.176	0.029	0.030	0.015
Bus					
NO_x	9.09	7.30	4.39	2.64	0.53
PM	0.167	0.163	0.031	0.032	0.016
Other					
NO_x	7.93	6.41	3.71	2.23	0.47
PM	0.174	0.178	0.038	0.030	0.015

7 The data used are average values per km driven and are based on a complex distribution of road share per vehicle type and per fuel characterizing the Dutch situation and on estimated emission per road type. Data for Euro 5 and 6 (V and VI for heavy duty vehicles) are extrapolated. Therefore it is possible that these data differ (slightly) from the European standard emission values, which are test cycle emissions, not road emissions.

Table A2.2 Transportation demand in 2020 (in million km)

Cars	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Petrol	60	1706	7189	18061	33178
Diesel	31	1002	5765	16161	41248
LPG	4	71	284	735	885
Total	94	2779	13238	34957	75311
Light-duty vehicles					
Petrol	2	6	6	46	127
Diesel	176	682	693	4542	16438
LPG	2	3	1	17	54
Total	180	690	700	4605	16619
Heavy-duty vehicles- trucks					
Light	13	17	17	105	454
Medium	46	60	59	363	1575
Heavy	51	66	66	401	1742
Total	111	143	142	869	3772
Heavy-duty vehicles- others					
Trailer	12	45	61	636	4367
Bus	7	36	33	153	430
Other	94	52	23	86	231
Total	113	133	116	875	5028

Table A2.3 Estimated emission effects relative to fossil fuel emission values (in %)

Cars and light-duty vehicles					
NO_x	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
Worst case					
E10	100	100	50	20	20
B7	0	0	20	20	20
E12	100	100	50	20	20
E55	250	250	100	35	20
B15	7	7	10	10	10
B12	2	2	10	10	10
Best case					
E10	-50	-50	-25	-10	-10
B7	-15	-15	-10	-10	-10
E12	-50	-50	-25	-10	-10
E55	-10	-10	0	0	0
B15	-12.50	-12.50	-10	-10	-10
B12	-15	-15	-10	-10	-10

PM	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Worst case					
75	50	50	50	50	75
15	15	10	0	0	15
75	50	50	50	50	75
50	20	20	20	20	50
30	30	15	0	0	30
20	20	10	0	0	20

Cars and light-duty vehicles					
NO_x	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Best case					
E10	-40	-40	-30	-20	-20
B7	0	0	0	0	0
E12	-40	-40	-30	-20	-20
E55	-50	-50	-40	-25	-25
B16	-10	-10	-5	0	0
B12	-5	-5	-2	0	0

Heavy-duty vehicles					
NO_x	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Worst case					
B12	10	10	5	0	0
B15	10	10	5	0	0
B20	10	10	5	0	0
B100	25	25	10	5	0
Best case					
B12	-5	-5	-2	0	0
B15	-5	-5	-2	0	0
B20	-5	-5	-2	0	0
B100	0	0	0	0	0
PM	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
Worst case					
B12	0	0	0	0	0
B15	0	0	0	0	0
B20	0	0	0	0	0
B100	-20	0	0		
Best case					
B12	-2	0	0	0	0
B15	-10	-5	-2	0	0
B20	-10	-5	-2	0	0
B100	-80	-10	-5	0	0

Table A2.4 Estimated CO_2 emission effects relative to fossil fuel emission values for light and heavy-duty vehicles (in %)

LDV			HDV
Worst case			
E10	2%	B12	0%
E12	2.50%	B15	0%
E55	2%	B20	0%
B7	0%	B100	15%
B12	-1%		
B15	0%		
Best case			
E10	-4%	B12	0%
E12	-3%	B15	-1.5%
E55	-5%	B20	-2%
B7	-10%	B100	0%
B12	-8%		
B15	-6%		

Appendix 3. Projected bioenergy installations and worst case estimates of air pollutants

Projected emissions from small- to large-scale bio-energy installations in 2020 have been estimated using the activities projections of the global economy scenario (WLO, 2006) and emission factors based on the BOLK study of Boersma et al. (2008). High-end emission factors have been used to represent a worst case scenario.

Table A3.1 Projected generation of bio-energy in 2020 in Dutch installations and the related air pollutant emissions (based on background data for WLO, 2006 and Boersma et al., 2008).

	Bio-energy use 2020 (PJ)	Source of emission factors Boersma et al., 2008	Air pollutant emissions (kt)				
			NO_x	SO_2	NH_3	PM_{10}	VOCs
Co-firing in coal and gas power plants	107	Table 4-1	4.3	1.2	0.5	0.1	n.a.
Waste incineration installations	80	Table 4-4	2.8	0.1	0.1	0.0	0.1
Other bio-energy combustion[1]	8.6	Table 4-24	8.8	n.a.	n.a.	0.3	0.0
Wood stoves	8.1	Table 4-21	1.2	0.2	0.1	0.9	0.4
Sewage sludge gas combustion	2.9	Table 4-5	0.1	0.0	0.01	0.0	0.0
Landfill gas combustion	1.2	Table 4-27	0.3	0.0	n.a.	0.0	0.0
Other sources (e.g. co-fermentation manure)	0.8	Table 1-1	0.2	0.1	0.00	0.0	0.0
Total	215		17.6	1.7	0.7	1.2	0.5

[1] This comprises mainly clean wood and waste wood biomass combustion installations and small- to medium-scale diesel generators using palm oil. n.a. =F information not available

Table A3.2 Projected energy use in 2020 in Dutch sectors (excluding transport) and the related air pollutant emissions (Based on WLO, 2006 and Velders et al., 2008).

	Energy use 2020 (PJ)	Air pollutant emissions (kt)				
		NO_x	SO_2	NH_3	PM_{10}	VOCs
Total Dutch sectors without transport in 2020	3192	111	51.4	140.7	28.5	170

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List of abbreviations

B7	Mixture of 7 % biodiesel and 93% fossil diesel
BEES-B	Dutch decree on emission limits for smaller combustion plants – '*Besluit Emissie-Eisen Stookinstallaties'*
bio-ETBE	bio-ethyl-ter-butyl ether
bio-MTBE	bio-methyl-tertio-butyl ether
BOLK	Dutch Policy Research Programme on Air and Climate -*Beleidsgericht Onderzoeksprogramma Lucht en Klimaat*
BTL	biomass to liquids
BVA	Dutch degree on combustions of waste – *Besluit Verbranding Afvalstoffen*
CCS	CO_2 capture and storage
CH_4	methane
CLE	current legislation
CO	carbon monoxide
CO_2	carbon dioxide
E5	Mixture of 5 % bioethanol and 95% fossil petrol
EC	European Commission
ECN	Energy Research Centre of the Netherlands
EJ	exajoule (10^{18} J)
ETBE	ethyl-ter-butyl ether
ETS	emission trading scheme (of the EU)
EU	European Union
FAME	fatty-acid-methyl ester made from vegetable oils
FFVs	flexi-fuel vehicles
GC	gas cycle
GE	global economy scenario from the WLO (2006) study
GHG	greenhouse gas
GJ	gigajoule (10^9 J)
HC	hydrocarbons
HFCs	hydrofluorocarbons
HVO	hydrogenated vegetable oil
IGCC	integrated gasification combined cycle
K	potassium
kt	kilotonnes
LPG	liquefied petroleum gas
MJ	megajoules (10^6 J)
Mt	megatonnes (10^6 tonnes)
$MtCO_2$	megatonnes of carbon dioxide
MTBE	methyl-tertio-butyl ether
MW_{th}	thermal megawatt
N_2O	nitrous oxide
Na	sodium
NAM	Netherlands oil company – *Nederlandse Aardolie Maatschappij*
NEC	national emission ceiling
NeR	Netherlands Emission Guidelines for Air – *Nederlandse Emissierichtlijn*
NGCC	natural gas combined cycle
NH_3	ammonia
NMVOC	non-methane volatile organic compounds
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
P	potassium
PC	pulverised coal
PFCs	perfluorocarbons
PJ	petajoule (10^{15} J)
PM	particulate matter
$PM_{2.5}$	particles measuring 2.5μm or less
PM_{10}	particles measuring 10μm or less
PPO	pure plant oil
RIVM	National Institute for Public Health and the Environment – *Rijksinstituut voor de Volkgezondheid en het Milieu*
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
TNO	Netherlands Organisation for Applied Scientific Research
UNECE	United Nations Economic Commission for Europe
UU	University of Utrecht
VOCs	volatile organic compounds
WLO	Dutch study on Prosperity and Environment - *Welvaart en leefomgeving*

Colophon

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Effects of climate policy on air quality favourable, although yet uncertain

The measures of the Dutch climate policy plan ‘Clean and Efficient’ *(Schoon en Zuinig)* aim to reduce greenhouse gas emissions. Some of these measures, such as energy saving and an increased application of wind energy, can lead to a reduction in the emission of air polluting compounds, as well. However, the effects of a number of other significant climate measures on the emission levels of air pollutants, is unknown and/or uncertain. To quantify these uncertainties, research has been done, in 2008, as part of the Policy Research Programme on Air and Climate *(Beleidsgerichte Onderzoeksprogramma Lucht en Klimaat(BOLK))*.

This research has shown, that measures, such as those implementing the use of biofuels and biomass, and carbon capture and storage, will not necessarily lead to a reduction in the emission of air pollutants. On top of that, the emission of certain air pollutants could even increase, in some cases. Nevertheless, the net effect of all measures of the Dutch climate policy plan on air quality is positive. Uncertainties around these effects, however, still remain.

The knowledge acquired within the BOLK programme on the specific climate measures, can add to an efficient design of future Dutch policies on climate and air quality. Moreover, this knowledge could also benefit other countries which are considering or implementing similar measures.

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