Co-impacts of climate policies on air polluting emissions in the Netherlands

Final report of the Dutch Research Programme on Air and Climate

Policy Studies

PBL Netherlands Environmental Assessment Agency

ECN
Energy research Centre of the Netherlands

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Final report of the Dutch Research Programme on Air and Climate (BOLK)

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Inhoud

Findings

Co-impacts of climate policies on air polluting emissions in the Netherlands

Final report of the Dutch Research Programme on Air and Climate (BOLK)

Summary

- Measures that reduce greenhouse gas (GHG) emissions can also contribute to improving air quality in the Netherlands. The BOLK Programme shows substantial net co-benefits from the three climate packages for 2020 under consideration especially for sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions, the co-benefits are smaller for particulate matter emissions (PM_{10}). However, there are limited disbenefits for non-methane volatile organic compounds (NMVOC) and ammonia emissions ($NH_{3;}$ see Table S1).

  Measures that stimulate energy saving, energy efficiency, and the use of wind, solar and geothermal energy always benefit air quality.

  The net co-benefits for SO_2 emissions in this study have been found to result from climate measures that stimulate fuel switches from coal to gas and biomass, more nuclear and wind power, energy savings and application of carbon capture and storage (CCS). The net co-benefits for NO_x emissions result from energy savings in the residential, industrial, and transport sectors.
  Limited disbenefits for NO_x and NH_3 emissions have been found to result from CCS and bio-energy use in small to medium-scale stationary installations. To reduce the potential risks of certain climate measures for air quality, the Dutch Government could decide to tighten the emission limit values for the relevant installations or to introduce technology standards.

  Limited disbenefits for NMVOC emissions have been found to result from an increase in small to medium-scale combined heat and power installations (CHP), and biomass and biogas combustion installations. To reduce NMVOC emissions from these installations, technical measures such as oxidation catalysts are available. But more research is needed on the effects on catalyst materials of impurities in the flue gas from biogas and biomass combustion.

- The co-impacts of the envisaged Dutch climate package – Clean and Efficient – are smaller than the policy package needed to meet EU and Dutch targets (see Table S1), because the envisaged climate package as defined in 2009 has a smaller set of climate measures. With those measures, the envisaged policy package does not meet either European or Dutch climate and energy targets for 2020. The indicative EU and Dutch target packages include additional measures to reduce GHG emissions that are based on national insights on cost and co-impacts, and that meet exactly the EU and the Dutch targets, respectively.

- Use of biofuels in road transport up to the EU target for 2020 is expected to have negligible effects on exhaust air polluting emissions. Some potential risks of failure of emission control devices have been identified with the use of high biodiesel blends. To abate those risks, both biofuel quality and emissions from vehicles using biofuels should be monitored effectively, which allows for timely measures where necessary.

Impacts of climate policy on GHG and co-impacts on air polluting emissions in the Netherlands, 2020[1] **Table S1**

	GHGs	NO_x	SO_2	NH_3	PM_{10}	NMVOC
	Megaton	Kiloton				
Dutch baseline emissions 2020	254	199	48	129	35	165
Emissions including Dutch envisaged package	218-241	192-195	42-47	129-131.5	34.4-34.6	165
Emissions including EU target package	172	185	38	129-131.5	34	168
Emissions including Dutch target package	150	184	32-37	129-131.5	34	169

[1] The Dutch baseline emissions for 2020 include only current climate (Kyoto) and air pollution legislation (Daniels and van der Maas, 2009). Green colours refer to an emission reduction (co-benefits), red colours to an emission increase (disbenefits).

- Climate policies in 2020, may lead to net cost savings for new air quality policy of up to 100 million euros per year. These cost savings are a few percent of the indicated costs in 2020 of current Dutch air quality policies (around 3 billion euros in 2020) or the additional Dutch climate packages (3-9 billion euros in 2020).

- Because not all climate measures have co-benefits for air polluting emissions, climate policy packages by definition do not necessarily lead to improvement in air quality. To guarantee that a certain emission level or air quality standard will be met everywhere in a certain year, specific air quality policies (air quality limit values, emission limit values, emission ceilings) will still be needed.

- The greatest uncertainty in the estimates of the co-impacts is caused by the fact that climate policy measures needed to meet climate and energy targets have not yet been approved by the Dutch cabinet and parliament.

  Other uncertainties in the co-impact estimates are related to the future prices for carbon dioxide (CO_2) in the EU Emission Trading System, the amount of foreign CO_2 credits that will be bought, the amount of electricity that will be exported, and the real life efficiency of individual climate and energy measures and instruments.

  How to incorporate these uncertainties into the revision of the national emission ceilings for air pollutants is an important element to be considered by policymakers involved in this process. The risk is that if the anticipated co-benefits for air polluting emissions in 2020 do not occur, additional national air pollution abatement measures will have to be implemented in order to meet the national emission ceilings based on too optimistic assumptions on the co-benefits of climate policy. The risk for countries assuming large co-benefits is that eventually more stringent air pollution measures may be needed than those needed elsewhere.

- The estimated co-benefits for Dutch NO_x and SO_2 emissions in this study are lower than European estimates previously provided by the European Commission within the framework of the revision of the national emission ceilings. The differences are explained by different assumptions for 2020 on electricity export, the distribution of climate measures over the sectors, economic growth rate, and the application of CCS. The sensitivity of the co-impacts for these types of assumptions needs to be checked because larger co-benefit estimates used by the European Commission may lead to stricter national emission ceilings.

  The comparability with the estimates of the European Commission for the co-impacts is especially hampered by the use of different assumptions for economic growth. The European Commission uses a post-crisis scenario with moderate economic growth, while the Dutch analysis in this report is based on a pre-crisis scenario with relatively high growth. To improve the comparability, a new Dutch study on co-impacts has started that will use a moderate (post-crisis) view on economic growth.

Introduction

Synergy between climate and air quality policies becomes increasingly important

Climate and air pollution policies are linked because Greenhouse gases (GHG) and air pollutants have a number of common sources, such as combustion of fossil fuels and agricultural activities. Despite these links, policies on climate change and air pollution have often been developed separately. Currently, a more integrated approach towards climate and air quality policy is becoming increasingly important. In particular, climate policy plays an important role in the revision of the UNECE Gothenburg Protocol (GP) and the EU NEC Directive (NECD). These revisions aim at setting stricter national emission ceilings for 2020 for nitrogen oxides (NO_x), sulphur dioxide (SO_2), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC). Also, a national emission ceiling for particulate matter ($PM_{2.5}$) will be established. Both revisions had been delayed because of increasing awareness of the implications on air pollution of the ongoing EU policy process on climate and energy. For instance, European analysis by the International Institute of Applied System Analysis (IIASA, Austria) had shown that integrating climate and air pollution policies substantially reduces air pollutants and results in overall cost savings.

These benefits in turn are additional incentives in developing climate policies. The ongoing EU policy process on climate and energy led to the adoption of the European climate and energy package in April 2009. That package sets an EU-wide target to cut GHG emissions to at least 20% below 1990 levels by 2020. Other EU-wide and national targets were set, to improve energy efficiency and increase the proportion of renewable energy in total energy consumption and in transport by 2020.

Several member states have formulated additional targets to mitigate climate change. For example, in 2008, the Dutch Government set a national target of 30% reduction in GHG emissions in 2020 compared to 1990, and stricter targets to improve energy efficiency and the share of renewable energy, compared to those of the EU. All of these targets will contribute to decreasing GHG emissions, as well as decreasing dependence on imported energy, decreasing air polluting emissions, and to stimulating technological developments.

Co-impacts of climate policies on air polluting emissions

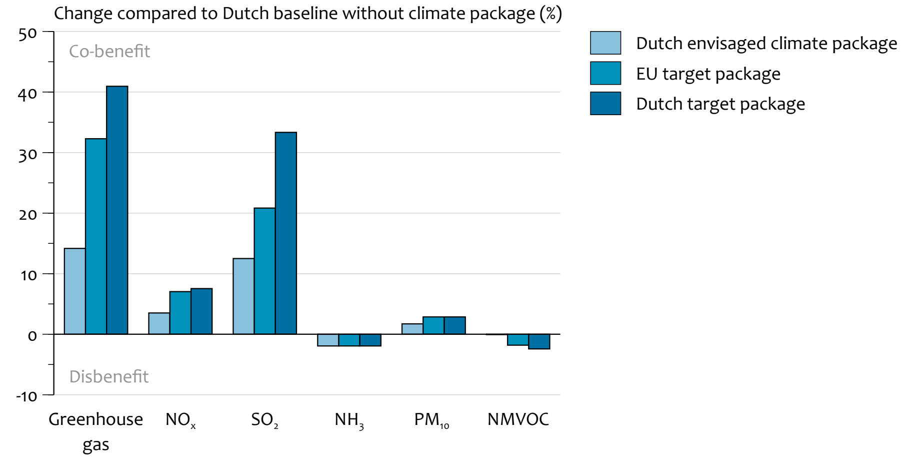
Climate policies also often lead to less air pollution as well. These co-benefits for air polluting emissions originate mostly from energy savings, improved energy efficiency, a switch from coal to gas, and use of renewable energy such as wind, solar and hydropower. There is considerable awareness about the co-benefits from such measures. However, there are also a number of climate measures of which little is known about the co-benefits or disbenefits, together referred to as co-impacts. These measures include use of biofuels in transport, use of biomass, biofuels and biogas in (small scale) stationary installations, combined heat and power generation, and CO_2 capture and storage (CCS). National co-impacts of climate policies on air polluting emissions are also influenced by the amount of climate measures that countries might take in another country, through the flexible mechanisms. Any co-impacts associated with these climate measures also occur elsewhere.

Reliable estimates of co-impacts essential for revision of national emission ceilings

Previous European analysis have shown that inclusion of the co-impacts of climate and energy policies lead to more stringent national emission ceilings for the Netherlands than those calculated without these policies (Amann et al., 2008). Although analysis of the first phase of the Dutch Research Programme on Air and Climate (BOLK) has confirmed the net beneficial effects of envisaged climate policies on mainly SO_2 and NO_x emissions, these estimates are surrounded by large uncertainties (Hammingh et al., 2008). These uncertainties imply that if climate policies do not deliver the estimated net co-benefits, attaining the national emission ceilings might be at risk, or the costs for air pollution mitigation may increase. To further optimise synergies and to prevent trade-offs between climate and air pollution policies, the first phase report of the Dutch research Programme (Hammingh et al., 2008) recommended refining and updating the analysis of the co-impacts of climate policies on air pollutants in the Netherlands.

Photo 1 Climate policies that stimulate wind energy decrease emissions of GHG and air pollutants (copyright M. Wijnbergh)

Maximum net (co-)impacts on greenhouse gas and air polluting emissions from climate policies by 2020 **Figure 1**



Impacts of climate policy on GHG and co-impacts on air polluting emissions in the Netherlands, 2020[1] **Table 1**

	GHGs	NO_x	SO_2	NH_3	PM_{10}	NMVOC[2]
	Megaton	Kiloton				
Dutch baseline emissions 2020	254	199	48	129	35	165
Emissions including Dutch envisaged package	218-241	192-195	42-47	129-131.5	34.4-34.6	165
Emissions including EU target package	172	185	38	129-131.5	34	168
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[1] The Dutch baseline emissions for 2020 include only current climate (Kyoto) and air pollution legislation (Daniels and van der Maas, 2009). Green colours refer to an emission reduction (co-benefits), red colours to an emission increase (disbenefits).
[2] NMVOC = non-methane volatile organic compounds

Aim of this report

This report presents the updated analysis of the co-impacts on air polluting emissions of the envisaged Dutch climate package 'Clean and Efficient' (in Dutch: 'Schoon en Zuinig') by the Dutch cabinet (VROM, 2007). This package however, does not lead to meeting EU climate and energy targets for the Netherlands or the more challenging Dutch targets (Van Dril, 2009). Therefore, the co-impacts have been analysed of two indicative packages that do meet the EU and Dutch targets. These packages are referred to as 'EU target package' and 'Dutch target package', respectively.

In this study, the national analysis methodology has been used, which comprises national projections of energy use and emissions, and national insights in costs and effects of additional emission reduction measures. Results obtained using this national analysis methodology, have been compared with those obtained with the European analysis methodology that is used in the framework of the revisions of the GP and the NECD.
Moreover, this study presents summaries of separate in-depth studies into the co-impacts of specific climate measures in the Netherlands, see list of BOLK reports at the end of this section. These cover the application of bioenergy in small to medium-scale combustion installations and in combined heat and power installations, biofuels in road transport, and CCS in power generation and industry. Finally, recommendations for policymakers are made to optimise synergies and to prevent trade-offs between climate and air pollution policies.

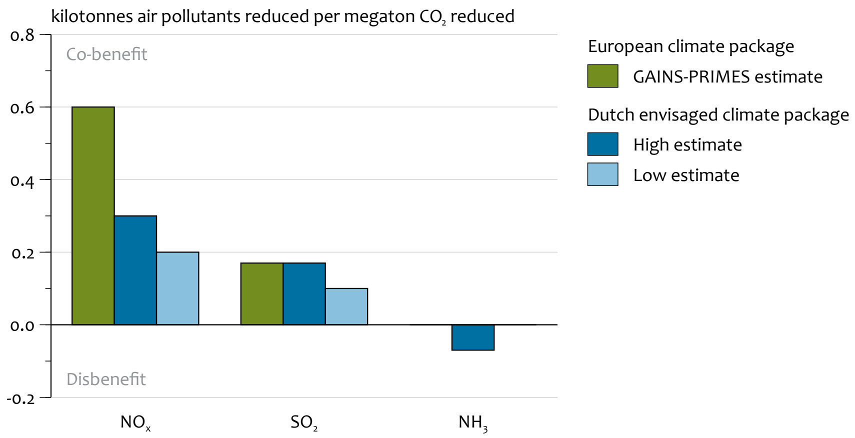
Co-impacts of climate packages on air polluting emissions

Envisaged Dutch climate packages have net co-benefits for SO_2 and NO_x emissions

The results of this second phase of the Dutch Research Programme on Air and Climate (BOLK) confirm that the envisaged Dutch climate (policy) package 'Clean and Efficient' reduces emissions of GHG and the air pollutants SO_2, NO_x and PM_{10} in the Netherlands (Table 1 and Figure 1). The range in the estimated emission reductions accounts for uncertainty in the price of CO_2 in 2020 in the EU Emissions Trading Scheme or EU ETS (between 20 and 50 euros/tonne CO_2), the amount of biofuels (between 10 and 20% in 2020) and a range in the effectiveness of individual climate and energy measures and instruments (lower and higher assumptions for the effectiveness in 2020).

The net co-benefits for NO_x emissions are dominated by emission reductions from energy savings, mainly in stationary energy use. This is achieved by measures such as improved efficiency of appliances in households and service sectors, heat demand reduction in the built environment and in ETS sectors, and recycling of plastics. It also includes emission reduction in transport by measures such as road pricing for cars, increased road fuel taxes, speed limits on motorways and stimulating more fuel-efficient car tyres. There are some small increases in NO_x emissions (disbenefits) that result from CCS measures in power, biogas production and the use of co-digestion of manure. The co-benefits for SO_2 emission

Co-impacts ratios for air pollutants by European and Dutch climate packages in 2020 **Figure 2**



result from energy savings, CCS in power generation and an increase in renewable energy. The limited co-benefits for PM_{10} emissions result mainly from reduced traffic volume in road transport.

The disbenefits of the envisaged Dutch package are less substantial than the co-benefits. NH_3 emissions could increase to a limited extent with the application of CCS in power plants and biomass use in stationary installations. However, these increases can be abated with existing abatement technology at limited costs.

European and Dutch target packages lead to more substantial co-benefits

Even with strict implementation of the envisaged Dutch climate package (leading to an estimated GHG emission of 218 Mt in 2020), the European and Dutch targets are not met for GHG emission reductions (~172 megaton and 150 megaton, respectively in 2020), neither are the energy targets for energy efficiency (annually 1.4% and 2%, respectively) and share of renewable (annually 14% and 20% respectively). To meet the targets, the Dutch Government will need to develop additional climate and energy policies.

In order to estimate the co-impacts on air pollution of an additional Dutch climate and energy package that meets the European or Dutch climate and energy targets, two cost-optimal climate and energy packages have been constructed using the national insights in costs and effects of additional emission reduction measures (Section 1.4). Both packages lead to more substantial net co-benefits for SO_2 and NO_x emissions than those of the envisaged Dutch climate package (Table 1). Even though more energy saving and renewable energy measures are incorporated, the renewable energy target of the Dutch cabinet cannot be met with the options currently available and the maximum feasible share is about 18%.

The net co-benefits for NO_x emissions mainly result from the stricter energy savings measures compared to those taken in the envisaged package. Some disbenefits on NO_x emissions result from CCS application, renewable energy (biomass in small to medium scale installations), and non CO_2 GHG measures (co-digestion of manure).

The SO_2 co-benefits result from switches from coal to gas and to bio-energy in both centralised power plants and in CHP, increased use of nuclear and renewable energy and more energy savings. The co-benefits from the target packages for PM_{10} emissions are limited and result from volume reductions in transport, energy savings and fuel switches. The increase in ammonia emissions originates mainly from increase in post-combustion CO_2 capture. Non-methane volatile organic compounds emissions (NMVOC) may increase more substantially because of an increased number of combined heat and power installations (CHP) with gas engines (without additional NMVOC mitigation measures) and increased use of biomass in stationary installations.

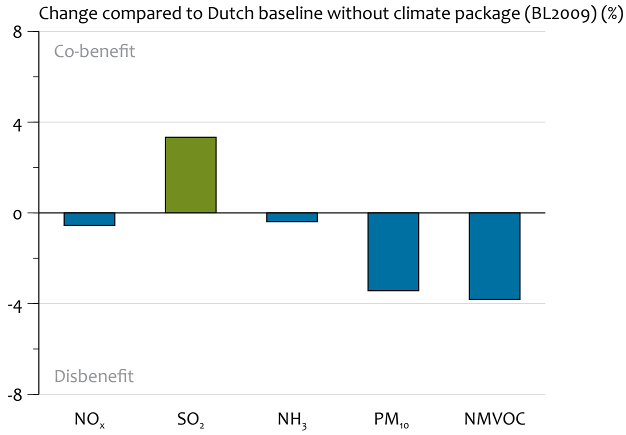
NO_x co-benefits from envisaged climate policies higher according to European assessment

The estimates for co-impacts of envisaged climate policies on air polluting emissions from this study have been compared to the available estimates from a European analysis (CIAM, 2008). The European analysis, in the framework of the revisions of the GP and the NECD, is carried out by amongst others IIASA and the National Technical University of Athens (NTUA). Important models in the European analysis methodology are the GAINS and PRIMES models (Amann et al., 2007a, 2008; IIASA, 2010; Capros et al., 2008a, b, c).

The comparison shows that the European analysis estimates higher co-benefits for NO_x and SO_2 emissions than this study (see Figure 2) and estimates no net disbenefits for NH_3 emissions. Incorporating the European estimates for co-impacts in the revision of the NEC, may lead to more strict national emission ceilings for the Netherlands, than if national estimates for co-impacts would be used.
The differences between the Dutch and European analysis result from differences in the assumptions on the effects of climate policies on projected coal and gas use in power generation, CCS application, and oil use in transport.

The European assessment assumes larger decreases in coal and gas use than the Dutch assessment due to decommissioning of Dutch coal and gas fired power plants and hence relatively large co-benefit ratios for NO_x and SO_2 per megaton CO_2 reduction. In the Dutch assessment, coal and gas use do not decrease as much as the European

Indicative co-impacts on air polluting emissions of a high bioenergy scenario by 2020 **Figure 3**



assessment because the Dutch expect the export of electricity to grow towards 2020 (Daniels & Van der Maas, 2009). The expected growth in export of electricity is a consequence of the projected decrease in national electricity demand due to climate policies, and the scheduled construction of a number of new power plants. The Dutch electricity sector experiences some competitive advantages such as: ease of access to cheap cooling water from the sea, low supply coast of coal due to proximity to harbours, and availability and relatively easy access to geological CO_2 storage capacity in empty gas fields.
The smaller co-benefit ratio for NO_x in the Dutch assessment is also caused by the assumed application of CCS at a few coal fired power plants, which is not assumed in the European assessment. This study shows that CCS application leads to extra NO_x and NH_3 emissions but to less SO_2 emissions.

A further explanation for the lower co-benefit for NO_x emissions in the Dutch assessment compared to those of the European assessment, is that the Dutch estimates include larger reductions in oil use in road transport due to stricter CO_2 standards (95 g CO_2 per km) in 2020 and a higher share of biofuels (20%[1]). However, both efficiency improvement and biofuel use have little effect on NO_x emissions from road transport. Tail-pipe air polluting emissions from cars and trucks are regulated by the Euro standards.

Co-impacts of specific climate measures on air pollution

Bioenergy use in stationary installations increases most air polluting emissions except for SO_2

A dedicated what-if scenario study was used in a detailed analysis of the co-impacts on air pollution of increasing small to medium-scale bioenergy use in the Netherlands from 2 to about 6% of the total primary energy use in 2020 (Boersma et al., 2009). The scenarios include co-firing biomass in large-scale power plants (2.2% of primary energy use) because this is one of the more substantial and cheaper biomass options. Further, assumptions have been made for a low and high expansion of medium-scale biomass combustion, biomass use in household stoves and biogas production. These are called the low and high bioenergy scenarios, respectively.

The study results for the high bioenergy scenario indicate increases in most air pollutants in 2020, compared to the baseline. As shown in Figure 3, NO_x increases by less than 1% (~1 kiloton), PM_{10} by about 3% (~1 kiloton), NMVOC by up to 4% (~6 kiloton). SO_2 emissions decrease by about 3% (~1.5 kiloton). These effects are explained by the fact that small to medium-sized installations emit relatively higher amounts of air pollutants (per unit of heat or electricity) than do large installations. Small installations use less advanced combustion technologies and flue gas cleaning systems as a result of technological restraints and cost considerations. If small installations are also located nearer to residential areas and with lower chimneys, the contribution to local air pollution can become even more substantial. In a recent decree on emission limit values for small to medium installations, the Dutch Government has anticipated the envisaged effects by setting stricter emission limit values for installations using fossil and bio energy fuels (VROM, 2009). SO_2 emissions decrease because biomass generally contains less sulphur than do fossil fuels.

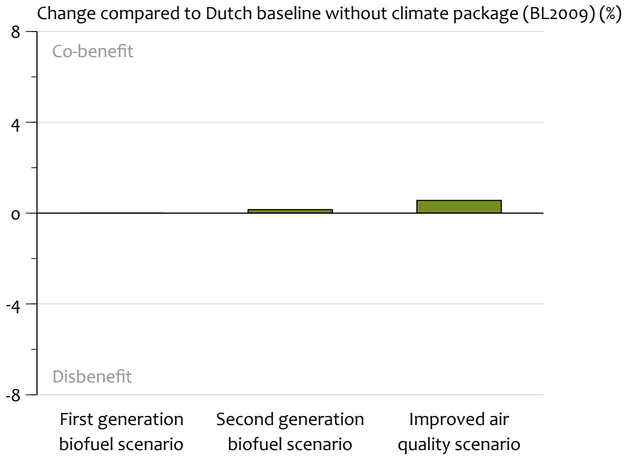
Substituting biomass for coal in power plants has limited effects on air pollution

Replacing part of the coal with biomass in power plants may not reduce NO_x and NH_3 levels (Boersma et al., 2008). The present extensive flue gas cleaning in these installations should be sufficient to clean flue gases originating from different type of fuels. Because generally biomass contains less sulphur, emissions of SO_2 are expected to decrease.

Wood burning is major contributor to particulate matter and NMVOC emissions

In spite of a trend towards the use of certified household wood burners with improved emission performance, wood burners could be responsible for up to 5% of particulate emissions (PM_{10}) in the Netherlands in 2020 with a twofold increase in this type of energy use. Also, emission factors for NO_x and NMVOCs are relatively high for domestic wood burners. Stimulating the use of certified burners is one of the more cost-effective measures for reducing air pollution from these sources.

Indicative co-impacts on NO_x emissions in scenarios to achieve the EU biofuel target for 2020 **Figure 4**



Increases in small-scale CHP generation could increase NMVOC emissions

Stimulating small to medium-size combined heat and power generation fuelled by biogas or natural gas contributes to meeting energy efficiency targets. An analysis showed that switching from separate power and heat generation to small to medium scale CHP generation (up to 40 PJ fuel input) could increase NMVOC emissions by about 3% (6 kiloton). This assumes no additional control measures. Small reductions are estimated in NO_x and SO_2 emissions but no noticeable changes in PM_{10} and NH_3 emissions.

Biofuels in road transport expected to have small co-impacts for air pollutants

The effect on NO_x and PM_{10} emissions of the mandatory 10% share of biofuels in road transport in 2020 have been analysed in three biofuel scenarios (Verbeek et al., 2009). One scenario assumes that more mature first generation biofuels from energy crops will be in use in 2020. The second scenario assumes that sustainability issues favour production of second generation biofuels from lignocellulosic origin. The third scenario includes a larger share of specific biofuels (such as synthetic biofuels and biogas) and electric vehicles that potentially lead to less air polluting emissions.

Analysis of the three scenarios showed that the effects on national NO_x and PM_{10} emissions in 2020 are probably less than 1% (for effects on NO_x emissions, see Figure 4). The reason is that a greater part of the biofuels requirement can be achieved with low blend biofuels (up to 10% ethanol and 7% biodiesel blended into fossil fuels). These are not expected to lead to significant changes in exhaust emissions from new cars in the future because these vehicles already need to pass type approval tests that include use of low blend biofuels. Another part of the explanation is that some contribution of second generation biofuels is assumed in 2020. These biofuels count double for the EU target. Hence, they reduce the need for high biofuel blends that have higher risks of increasing air pollution. This also means that if renewable energy targets for road transport are increased substantially in the future and more high biofuel blend are used, air polluting emissions may change more substantially unless additional measures are taken.

Natural gas, biogas, electric vehicles and synthetic biofuels are better for air quality

Of the three biofuels scenarios, the scenario with the largest share of natural or biogas, (plug-in) electric vehicles and synthetic biofuels is expected to lead to the least air polluting emissions from road transport. The lower air polluting emissions are partly due to the cars running on natural/biogas and synthetic biodiesel replacing fossil diesel powered cars with relatively higher NOx and PM_{10} emissions. The extra electric cars result in lower air pollutant emissions locally but emissions from the power sector increase somewhat.

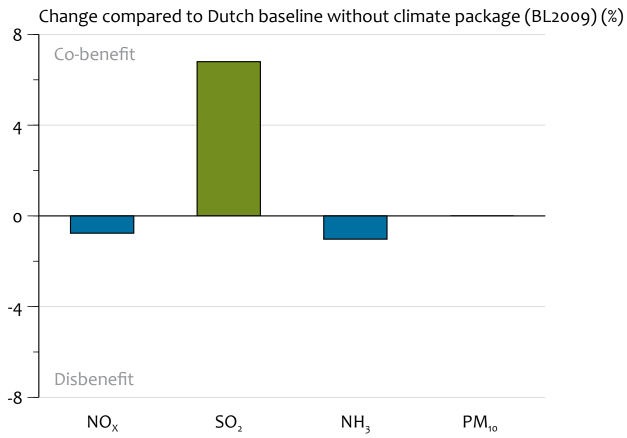
Potential failure risks of emission control devices with high biodiesel blends

There are technical risks with the functioning of emission control devices using high biofuel blends (FAME) in diesel engines. Failures of "after-treatment" devices are related to possible inadequate responses of catalyst and dust particulate filters. This may be due to changing flue gas composition and/or to problems such as injector fouling and catalyst poisoning that may be caused by impurities in biofuels. No substantial technical risks are currently foreseen with high blends of ethanol, hydro-treated vegetable oil (HVO), synthetic biodiesels such as biomass-to-liquid (BTL) or Fischer-Tropsch (FT) diesel. Similarly, there are no such risks with engines with factory-installed natural gas/biogas fuel systems.

CCS in power generation and in industry may lead to short-term increases in air pollutants

If CCS would be applied in four new coal power plants in 2020 in the Netherlands, NO_x, PM_{10} and NH_3 emissions may increase (Figure 5) compared to plants without CCS (Horssen et al., 2009). At the same time, SO_2 emissions will most likely decrease. NO_x and PM_{10} emissions increase due to additional energy consumption of the CO_2 capture units. NH_3 is emitted as a result of the degradation of CO_2 solvents (amines). SO_2 concentrations in flue gases have to be reduced for the CO_2 capture unit to function properly. There are standard NO_x and NH_3 emission reduction measures available to abate possible increases at limited costs. These costs are not a bottleneck in CCS implementation.

Indicative co-impacts on air polluting emissions of a high CCS scenario by 2020 **Figure 5**



Large-scale CCS in the power sector in 2050 leads to substantial reductions in air pollutants

A number of CCS scenarios for the power sector for 2030 and 2050 indicate dramatic reductions in emissions of SO_2 (>90%), NO_x (>65%), NMVOC (>40%) and particulate matter (>30%) compared to a business-as-usual (BAU) scenario without CCS. This is mainly due to a switch from pulverised coal power plants without CCS (in the BAU scenario) to the cleaner coal gasification power plants (IGCC) with CCS combined with natural gas power plants (NGCC) without CCS. SO_2 emissions are estimated to decrease the most. NO_x emissions also decrease because of the favourable NO_x performance of IGCC and NGCC. However, NO_x emissions do not decrease as substantially as SO_2 because of the extra energy consumption of the capture units.

CCS in industry has limited effect on reducing in air polluting emissions

There is a potential for CO_2 capture of about 5 Mt per year in the Dutch industrial sector in 2020 for costs of around 40 euros per tonne of CO_2 avoided. This covers hydrogen production and iron and steel production. CO_2 capture at other industrial sources such as refineries and ethylene production is expected to be more expensive. CO_2 capture at iron and steel production is expected to decrease SO_2 emissions (a few hundred ton maximum) and particulate matter emissions. The effect on NO_x emissions largely depends on the future choices on the combination of the combustion concept and CO_2 capture technology used in an iron and steel plant.

Optimising co-benefits and reducing disbenefits

To optimise the co-benefits of climate policies for air quality and to prevent disbenefits, climate and air quality policymakers need to work closely together. This study provides information for that process. It provides estimates for the potentially substantial co-impacts of climate policies in the Netherlands on air polluting emissions. In addition, it appoints the substantial uncertainties that surround the estimates for those co-impacts. Recommendations are given how to reduce or prevent disbenefits of specific climate measures. These points are discussed in detail below.

Develop long-term vision and harmonise strategies on air quality and climate

In many countries and institutions, climate and air pollution policies initially tended to be developed more or less independently. Climate policy in the Netherlands focuses heavily on reducing GHG emissions, sometimes without taking into account the effects it may cause on other fields of environmental policy, such as air pollution. Air quality policy has not always taken into account climate policy processes. For instance, the European revision of national air pollutant emission ceilings initially started without any real consideration of the implications for the ongoing EU policy process on climate and energy. Another emerging issue requiring attention is the potential effects of air pollution measures on short-term global warming.

The lack of coordinated climate and air pollution policies has drawbacks from both an economic and an environmental standpoint. Industry, for instance, may be faced with situations in which carbon reductions need to be made in one year and reductions in conventional air pollutants in another year (Climate Institute, 2010). This reduces the opportunities industries may have (under coordinated policies) to take more cost-effective measures to reduce CO_2 and air polluting emissions simultaneously. Eurelectric (2008) stated, for instance, that uncoordinated climate and air policies are a hindrance to long-term planning and investment in industry.

Lack of coordinated policy can lead to climate policy packages with measures that are not optimal for reducing air pollutants. This study confirms trade-offs with a number of climate measures such as bioenergy in small to medium installations, stimulating small to medium-scale combined heat and power generation, and some types of CCS. These trade-offs imply that climate policies and targets for the short or longer term alone do not guarantee decrease in air pollutant emissions. Clear intermediate air pollution targets, such as national emission ceilings, are a better guarantee. With better coordination, climate packages can be chosen that contribute (partly) to decreasing air pollutant emissions as well and so also to reducing the cost of air pollution policies. These benefits in turn are additional incentives in developing climate policies.

Lack of policy coordination yields less overall environmental protection for the societal resources expended and does not contribute to societal support for climate and air policies. The lack of coordination may result from lack of a shared long-term vision and a harmonised strategy towards short to long-term targets (Maas et al., 2009). In aiming for more integrated policy, an initial step would be to develop a shared long-term vision and harmonised strategy towards short to long-term climate and air quality targets.

Co-impacts, uncertainties and revision of national emission ceilings

In the ongoing revision of NECs from the GP and the NECD for 2020, co-impacts of European climate and energy policies are to be incorporated in air pollutant emission projections for 2020, also called baselines. The UNECE and EC use the GAINS and PRIMES models to construct air polluting emission baselines. These baselines, and their estimated effects on air quality, are the starting point in the revision. Subsequently, a number of ambition levels for an improved air quality, will be translated (with the GAINS model) into indicative national emission ceilings for all the countries under the GP and the NECD. That information will be used within the negotiation processes towards a new GP and NECD.

The comparison of GAINS-PRIMES baselines (CIAM, 2008) and Dutch baselines with and without an envisaged climate package reveals the differences in co-impact estimates. That shows that the GAINS-PRIMES estimates larger co-benefits for Dutch NO_x and SO_2 emissions compared to the Dutch estimates. The differences are explained by different assumptions for 2020 on electricity export, the distribution of climate measures over the sectors, economic growth rate, and the application of CCS. Because larger co-benefit estimates may contribute to stricter national emission ceilings, it is important to check the validity of the assumptions that are used in the supportive European analysis for the policy processes towards new NECs.

In February 2010, UNECE proposed using the newest PRIMES 2009 baseline (Maas, 2010). This baseline includes not only most of the agreed European climate and energy package but also takes into account the post-crisis effects on economic growth (assumes relatively low economic growth in the Netherlands of 1.4% up to 2020). This leads to relatively low baseline emissions especially for SO_2 (33 kiloton) and NO_x (166 kiloton) in the Netherlands in 2020. It remains to be seen whether additional ambition levels for an improved air quality lead to a proposal for a new GP with even lower national emissions ceilings for the Netherlands.

The Dutch estimates for a baseline that includes most of the agreed European climate and energy policies (i.e. the EU target package) indicates that SO_2 and NO_x baseline emissions in the Netherlands could decrease to about 40 and 190 kiloton, respectively, in 2020. If the stricter climate and energy targets of the Dutch Government (i.e. the Dutch target package) are taken into account, the baseline SO_2 and NO_x emissions could decrease by a further few kilotons.

Taking into account these co-impacts of climate policies in 2020, may lead to cost savings for additional air quality policy of up to 100 million euros per year. These cost savings are a few percent of the indicated costs in 2020 of current Dutch air quality policies (about 3 billion euros in 2020) or the additional Dutch climate packages (about 3-9 billion euros in 2020).

The estimated co-impacts from the European and the Dutch analysis should be considered as indicative and should be interpreted with caution. A first reason for caution is that the co-impacts of the target packages are not based on a complete and agreed Dutch climate and energy policy plan that meet the targets. Instead, the analysis has been carried out using assumptions on possible (mostly technical) options and a cost-optimal order in which options (measures) are taken. The list of possible options can never be complete since other technical measures may emerge or new policy measures with different costs and effects may be developed. Also, the cost-optimal order in which options are assumed to be taken may be quite different in reality because reasons other than cost-effectiveness can play a determining role. Such reasons could be related to energy security, or to the distribution of reduction efforts over sectors or GHGs.

A second reason for caution is that the analysis includes only (additional) national climate and energy measures in the ETS and non-ETS sectors. In reality, the Netherlands could decide to combine additional national policies with the purchase of CO_2 credits abroad to meets non-ETS targets. These credits can be purchased through the Clean Development Mechanism (CDM) or Joint Implementation (JI). To meet the EU greenhouse gas target, the Netherlands can purchase credits for about 4 Mt CO_2 equivalents per year in 2020. For the more stringent national target, the Netherlands is allowed to buy a maximum of about 25 Mt CO_2 equivalents per year. A disadvantage of buying a large amount of credits (abroad) is that it is more difficult for the Netherlands to achieve its national targets for renewable energy and energy efficiency. With regard to the ETS sector, Dutch participants in the EU-ETS are not forced to take measures (national) but are free to buy credits in the EU-ETS. Moreover, some credits may be bought through CDM and JI. Any co-impacts associated with foreign credits will also occur abroad.

A third reason for caution is that the Dutch analysis was carried out with a baseline that uses relatively high economic growth of 2.9% up to 2020. That growth is currently seen as less realistic in the light of the effects of the economic crises. Velders et al. (2010) show that lower economic growth could have substantial impact on future emissions because of fewer activities and less energy used. If the assumption on economic growth (in emission baselines) is reduced from 2.5 to 1.5% per year between 2010 and 2020, national NO_x and SO_2 baseline emissions could reduce by about 10 and 2 kiloton, respectively. The volume effects of lower economic growth also affect climate and energy measures needed to meet the targets. Probably fewer measures will be needed to achieve GHG and energy targets in 2020, and subsequently less co-benefits.

Photo 2 Dutch Minister Van der Hoeven (Economic Affairs) purchases CO2-credits in Latvia. (Photo: Goos van der Veen/Hollandse Hoogte).

To understand the net effects on air pollutant baseline emissions, a national baseline needs to be prepared for air polluting emissions. This should integrate post-crisis (lower) economic growth and preferably all necessary climate and energy measures or several policy packages.

Reducing disbenefits from specific climate measures

Air pollutant reduction technologies to reduce disbenefits of bio-energy

The number of small to medium-scale combustion installations (up to 20 megawatt thermal using fossil and bio energy fuels) is expected to grow as a result of climate policies. Despite a recent Dutch degree with tighter emission limits for medium combustion installations (1-20 MWth), an increase in these type of installations still carries the risk of increasing most air polluting emissions. Emissions of NMVOC in small to medium scale biomass and biogas combustion (10-14 g NMVOC per gigajoule) are relatively high compared to large scale power plants (1-2 g NMVOC per gigajoule; see Section 2.1).

Moreover, NO_x, PM_{10} and NMVOC emissions are high from bio-oil or (waste/animal) fat-fired stationary diesel engines and household wood stoves. To reduce the potential risks for air quality, the Dutch Government could decide to tighten the emission limit values for the relevant installations or to introduce technology standards. Prior to taking further actions on smaller to medium scale installations, detailed data need to be collected on the number and size of current and new installations, fuel types, actual emissions, existing and new emission control technologies and various costs.

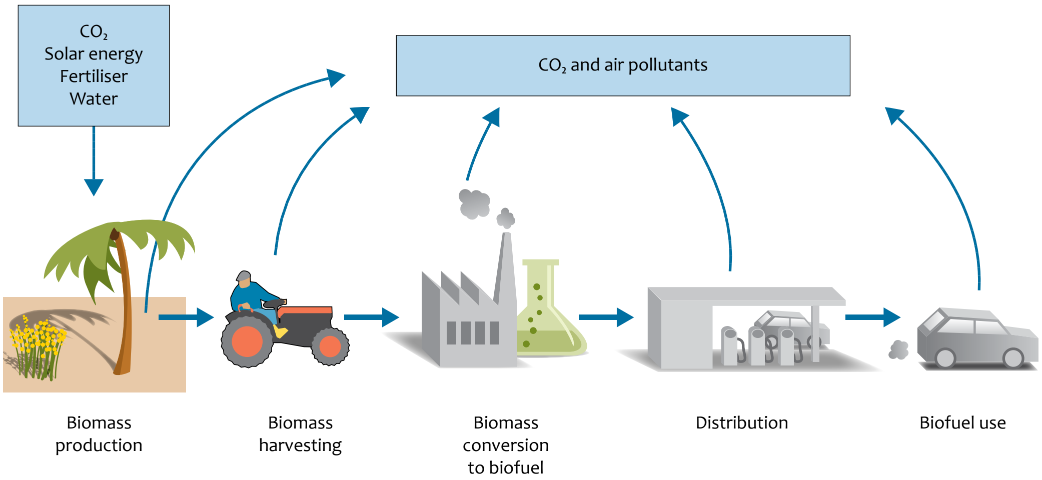
To reduce NMVOC emissions in small to medium scale installations, technical measures such as oxidation catalysts are available. But more research is needed on the effects on catalyst materials of impurities in the flue gas from biogas and biomass combustion (Kroon, 2010). The most effective measure to reduce particulate matter and NMVOC emissions from household wood burners (in residential areas) is to install certified stoves (Boersma et al., 2009).

Legislation plays a key role in reducing risks for disbenefits from biofuels.

Based on a literature review, Verbeek et al. (2008 and 2009) concluded that there is a risk of an increase in air polluting emissions from vehicles running on low or high biofuel blends. The risks are expected to be the greater with high biodiesel blends for truck engines. These high biodiesel blends are not recommended at all for passenger cars because the technical adjustments required are relatively more expensive than required for trucks. In order to reduce the risks, high biodiesel blends need to be included in type approval procedures for new dedicated trucks with advanced emission control (EGR, SCR, diesel particulate filters) that are build to run on high biodiesel blends.

Guidelines could be given, for example, that include a selection of trucks that are properly modified for high biodiesel blends. Such modifications include adjusted fuel storage and pump systems, increased lube oil storage and oil filter size, and dedicated software for the emission control devices. Moreover, truck fleets running on high biodiesel blends need to be monitored on emission control system performance, failure rates and durability. The fuel quality (low and high blends) needs to be monitored extensively.

CO_2 and air polluting emissions from biofuel production chains **Figure 6**



The risks are generally lower for vehicles running on ethanol blends, because high blend ethanol (E85) has already been included in the type approval procedure for flexi-fuel vehicles. For the low blends, E5 has been implemented and the manufacturers have made a commitment to levels up to E10 for new vehicles. Ethanol blend quality - both low and high blends - needs to be monitored including the long-term durability of fuel systems, engines and emission control devices.

Air polluting emissions from the bioenergy production chain may need attention

The contribution of bioenergy production chains (biomass, biogas and biofuels) to total Dutch air polluting emissions in 2020 is estimated to be limited. The renewable energy targets for electricity and heat production and road transport require that only a limited part of the fossil fuels to be replaced by bio-energy fuels. If renewable energy targets are increased requiring more bioenergy to be produced, more changes can occur in parts of the bioenergy production chains for some air pollutants in and outside the Netherlands. This means that air pollution from bioenergy production chains needs to be considered in the development of renewable energy strategies. These strategies may include tighter emission limit values for parts of the production chain of biomass, biogas and biofuels.

Need to monitor air polluting emissions in CCS pilot projects

Air pollutant emission profile of power plants and industries equipped with CCS are difficult to estimate. Many studies are based on assumptions on technological configurations and performances rather than on measurements. Little information is available on technologies in the laboratory or pilot phase and environmental performance is often discussed qualitatively, if at all. For more accurate estimates, measurements in demonstration projects using carbon capture technologies are required. These measurements are needed to improve analysis of the effects on air pollutants from the future application of CCS in power and industries for 2020 and beyond.

Current legislation does not prevent disbenefits from CCS

A issue emerging from this study is that current legislation does not always prevent the risk of an increase in absolute emissions, for example of NO_x emissions with CCS application in the power sector. Current European and Dutch legislation for power plants (e.g., the European Industrial Emission Directive and the Dutch NO_x emission trade system) sets relative emission limit values for air pollutants per unit flue gas (M^3) or per unit primary energy used. Because both flue gas quantities and primary energy use increase in a fossil fuel installation equipped with CCS, absolute emissions of some air pollutants may also increase. This could affect local air quality and the attainability of national emissions ceilings or sectoral targets for air polluting emissions.

Note

1 The Dutch and the European target (10%) are the same for the share of renewable energy in road transport energy consumption in 2020. However, the feasibility of a mandatory 20% biofuels share is being explored by the Netherlands.

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Understandings

1

Policy and scientific context

What are the synergies and trade-offs between climate and air pollution policies and why have they become important issues in Europe? How are they related to recent developments in both climate and air pollution policies?

Firstly, the synergies and trade-offs are introduced (Section 1.1), and then, the key developments in climate and energy policies are presented (Section 1.2). Special attention is given to the flexible instruments and renewable energy targets in the European Climate and Energy Directives, and the potential consequences for air polluting emissions. An outlook is given of potential co-benefits in the longer term of stricter climate policies (2050-2100).

Secondly, the key developments in air pollution policies are described (Section 1.3). One of the key issues is how to include the co-impacts (co-benefits or disbenefits) of European climate and energy into the ongoing revision of national emissions ceilings for 2020. Finally, European and national integrated assessment methodologies are described briefly that are used to quantify the effects of the synergies and trade-offs on energy use and emissions projections (Section 1.4).

1.1 Synergies and trade-offs between climate and air quality policies

Climate change and air pollution are linked

Climate change and air pollution are linked in many ways. Greenhouse gases (GHG) and air pollutants have a number of common sources, such as combustion of fossil fuels and agricultural activities. Climate change, for example, affects atmospheric transport and air chemistry such as increasing temperatures and dry conditions (Pleijel, 2009). Climate change could thus result in changes in concentration, dispersion and deposition of air pollutants. It could also change precipitation patterns which could alter critical loads and the sensitivity of vegetation to air pollution.
However, air pollution could also have an effect on climate change. Some air pollutants (such as sulphates) have a cooling effect and others (such as ozone and black carbon) contribute to temperature increases. Air pollution could cause changes in regional precipitation patterns. Its effects on the ecosystem could also contribute to changes in the carbon cycle. Ozone damage will reduce carbon sequestration, and increased nitrogen deposition levels (in N-limited ecosystems) will stimulate carbon uptake. These physical relationships mean that policies on climate, energy and air quality policies are also linked.

Effects of climate policies on air polluting emissions

The main benefits of climate and energy policies are decreasing dependency on imported energy, reduced GHG and air polluting emissions and stimulation of technological developments. Most co-benefits for air quality originate from energy savings, improved energy efficiency and a move towards lower, carbon-based energy production. Specific measures that can be taken include switch from coal to gas and promotion of the use of renewable energy such as wind, solar and hydropower. Quite a lot is known about the co-benefits arising from such measures. However, there are also a number of important climate measures and policies where little is known about the co-benefits and where even disbenefits can emerge. Specific measures that can potentially result in disbenefits include use of biofuels in transport, use of biomass, biofuels and biogas in stationary installations, and CCS. Examples of climate, energy and air pollution mitigation measures for the Netherlands with their multiple pollutant effects are presented in Table 1.1.

Effects of air quality policies on climate change

Recent studies have revealed effects of air polluting emissions on near-term climate change (Pleijel, 2010). Aerosols and tropospheric ozone exert strong (positive or negative) radiative forcing while present in the atmosphere, and deposition of black carbon decreases surface albedo. Thus, in addition to immediate effects on human health and vegetation, air polluting emissions will influence the rate of temperature change in the near term and could accelerate melting of ice sheets in the Arctic and of Alpine glaciers. These effects are in addition to the effects of long-lived GHGs, such as CO_2.
While the precursor emissions for ozone and aerosols that cause these effects (SO_2, NOx, PM, VOC, NH_3) are currently widely controlled in Europe, there is interest in further emission reductions to improve human health and ecosystem sustainability. However, analyses of the costs and benefits of further measures do not as yet consider the near-term impacts on climate change, and thus might lead to counter-productive side-effects of air pollution control strategies on climate change.

For this purpose, the GAINS model used in the revision of the Gothenburg protocol to identify effect-based cost-effective

Control measures in the Netherlands with effects on multiple pollutants[1] **Table 1.1**

Structural measures	– Energy savings, efficiency improvements: bans all pollutants
	– Biomass: CO_2 ↓ NO_x, PM, SO_2, HC ↑
	– Nuclear power generation : CO_2, SO_2, NO_x, PM, HC ↓
	– Wind power generation : CO_2, SO_2, NO_x, PM, HC ↓
	– Solar power generation : CO_2, SO_2, NO_x, PM, HC ↓
Stationary sources	– Advanced residential combustion: CO_2, NO_x, HC ↓
	– Large co-generation (CHP): CO_2, SO_2, NO_x, PM ↓ NMVOC ↑
	– Small co-generation (CHP): CO_2, SO_2, PM ↓ NO_x, CH_4, NMVOC ↑
	– SCR, SNCR: NO_x ↓, NH_3 ↑
	– FGD: SO_2, PM ↓, CO_2 ↑
	– Biomass co-firing in gas: CO_2 ↓ NO_x, PM, SO_2 ↑
	– Biomass co-firing in coal: CO_2, SO_2, PM ↓ NO_x, NMVOC ↑
	– CCS (post combustion, coal) : CO_2, SO_2 ↓ NO_x, PM, NH_3 ↑
	– CCS industry : CO_2 ↓ NO_x, PM, SO_2 ↑
	– Heat pumps : CO_2, NO_x ↓ PM, SO_2 ↑
Mobile sources	– Euro-standards: NO_x, PM, HC ↓ NH_3 ↑
	– Road pricing : CO_2, NO_x, PM ↓
	– Road fuel taxes : CO_2, NO_x, SO_2, PM ↓
	– CO2 standards cars/trucks: CO_2, SO_2 ↓
	– Biofuels road vehicles: CO_2 ↓
	– Electric vehicles[2]: CO_2 ↓ NO_x, SO_2 ↑
Agricultural sources	– Low nitrogen cattle feed: NH_3, CH_4 ↓
	– Improved injection of manure: NH_3 ↓ N_2O ↑
	– Anaerobic digestion-biogas: CO_2, CH_4 ↓ NO_x, SO_2, NMVOC, PM ↑
	– Anaerobic digestion (CHP): CO_2, CH_4, SO_2 ↓ NO_x, NMVOC, PM ↑
	– Air scrubbers animal housings: NH_3, PM ↓ CO_2 ↑
Other sources	– Green gas landfill/sewage treatment: CO_2, CH_4 ↓ NO_x, SO_2, PM, NMVOC ↑

[1] After a concept by IIASA. The Dutch control measures are part of the Dutch Options Document, see Section 1.4 .
HC = Hydrocarbons, CH_4 = methane, PM = particulate matter.
[2] Effects based on electricity from fossil-fuelled electricity generation (66% coal-based). Net CO_2 effects are small and net PM effects are negligible.

emission control strategies is being extended to include the radiative effects of short-lived climate forcers. This would enable quantification of the near-term climate effects of air pollution control strategies that aim to protect human health and ecosystems (Maas, 2010). The model can also be used to develop an optimal strategy for both air quality improvement and climate change mitigation.

Climate change, air pollution and health

Climate change may influence health effects related to air pollution in many ways. Higher temperatures can lead to increased levels of air pollutants, such as ozone and secondary inorganic particles. Air pollution may interact directly with temperature, such as during heat wave-related mortality episodes. Furthermore, there is evidence of interactions between traffic-generated air pollution and pollen exposure in relation to allergy, particularly in children (Bellander, 2009). In general, the anticipated climate changes are mostly expected to aggravate the adverse health effects of air pollution. Thus, preventive action focusing on air pollution exposure would be expected to reduce some of the climate-related health effects and vice versa.

Climate change and air pollution are closely connected not only with regard to interactions in causing health effects. Some measures against climate change may strongly influence air pollution levels and vice versa. For example, greater use of solid biomass fuels in domestic heating will increase emissions of air pollutants without adequate protective technology. A change in particulate matter levels in the atmosphere is expected to change its greenhouse properties, but in which direction may depend on the type of particulate matter. Health effects need to be adequately considered in prioritising climate measures.

Climate policy will decrease the cost of air quality policies

An analysis by Amann et al. (2007) has shown that EU climate policy aiming at 20% CO_2 reduction in 2020 will decrease the cost of additional air pollutant mitigation measures to achieve the ambition of the EU-Thematic Strategy for Air Pollution from 7 to 2 billion euros per year in 2020. Moreover, the cost of current air pollutant legislation will decrease from 75 to 65 billion euros (Figure 1.1). The preliminary analysis also indicates that the cost of climate policies within the EU (that reduce GHGs by 20% in 2020) is of the same order of magnitude as the cost of the air quality policies in 2020.

The benefits for the Netherlands of reduced air pollution mitigation costs were also estimated in the first integrated report of the Dutch Research Programme (Hammingh et al., 2008). An update of these cost benefits estimates is given in Section 3.3.

1.2 Developments in climate policies

New short- and long-term targets in European climate and energy policies

Climate and energy targets for Europe differ under international and European agreements. In the short term, Europe has a Kyoto protocol target of 8% reduction in GHG emissions in the 2008-2012 period on the Kyoto base years. A recent report concluded that the EU is on track to meet its Kyoto protocol commitments (EEA, 2009).

Photo 3 Preventive action in the town Bac Giang, Vietnam, to reduce the population's exposure to dust and heat (© P. Hammingh)

On the way to longer term targets, European leaders have adopted a climate and energy package in various Directives in 2009 that contain actions and ambitious targets for 2020 (EC, 2009a; EU, 2009a; 2009b; 2009c; 2009d). Europe is now committed to cutting GHG emissions to at least 20% below 1990 levels by 2020 and this commitment will rise to 30% if other industrialised countries agree to do the same. To achieve this level of reduction, targets have been set to boost energy efficiency by 20% by 2020; to increase the share of renewable energy in energy production to 20% on average across the EU by 2020; and to derive 10% of energy used in transport from renewable sources by the same year. The package also includes specific targets for each Member State. These targets will contribute to decreasing EU dependence on imported energy, to reducing GHG and air polluting emissions, and to stimulating technological developments.

EU-ETS and flexible mechanisms in N-ETS lead to uncertainty in timing and location of co-impacts on air polluting emissions

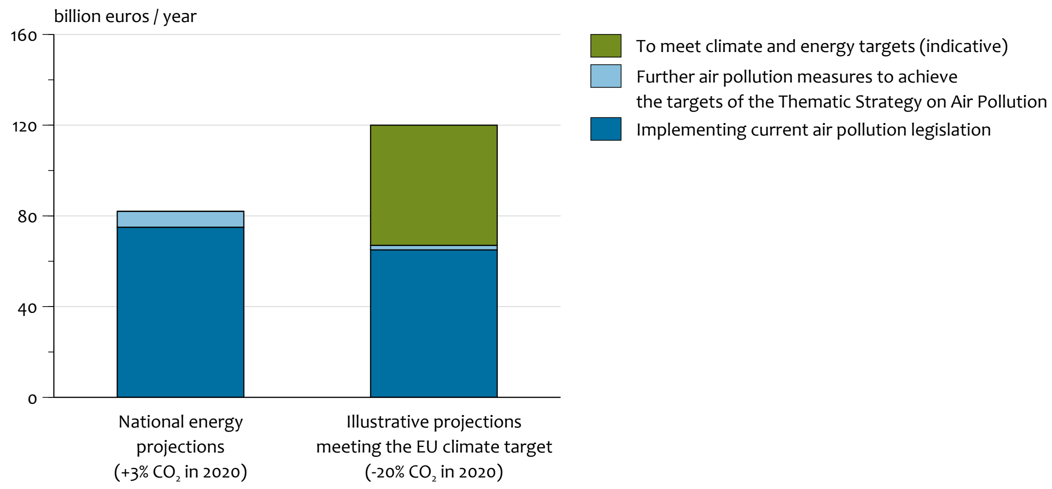
The EU climate and energy package strengthens the European CO_2 Emission Trading System (EU-ETS Directive; EU, 2009a) to cover all major industrial emitters and aviation by 2012 and introduces more auctioning. About 43% of total GHG emissions in Europe (EU 27) were emitted by ETS installations in 2008 (EEA, 2010). A single EU-wide cap on emission allowances will apply from 2013 and will be cut annually, reducing allowances available to businesses to 21% below the 2005 level in 2020 (or a reduction of 14% relative to 1990). The EU-ETS allows participants in the system to buy and sell allowances anywhere in Europe. So, if a business needs to reduce GHG emissions, allowances can be purchased anywhere in Europe or investment made in measures to reduce their own (and our national) emissions. Such measures include fuel switches, greater energy efficiency and an increased share of renewable energy production and CCS.

Various studies have shown that climate measures also lead to substantial reductions in air pollutants. However, the trading flexibility makes it more difficult to forecast the future location of climate measures in Europe and thus to estimate the location of co-benefits for air polluting emissions.

Participants in the EU ETS are allowed to buy CO_2 credits from GHG reduction investments in other countries through the Clean Development Mechanism (CDM) and Joint Implementation (JI). The credits available to EU-ETS sectors between 2013 and 2020 are currently limited to unused credits from the Kyoto trading period 2008-2012 in order to promote EU internal emission reductions. Due to the recession, a larger proportion of these credits is more likely not to be used between 2008 and 2012 and will be kept by operators for the 2013-2020 period (ECOFYS, 2009). The maximum unused credits for the Netherlands could be about 44 Mt CO_2 eq. If these credits were used in equal amounts every year between 2013 and 2020, about 5 Mt credits would be available in 2020 to Dutch participants in the ETS. Participants could also save more credits for later years towards 2020 (with possibly higher CO_2 prices) and a larger amount could be used in 2020. The uncertainty in the amount and timing of credits used makes it more difficult to forecast national climate measures in a certain year and thus to estimate the related co-benefits for air quality in that year.

In the sectors not covered by the ETS such as buildings, transport, agriculture and waste, EU-wide emissions are to be reduced by 10% below 2005 levels by 2020 (Effort Sharing Directive; EU, 2009b). A linear reduction has to be made

Air pollution and greenhouse gas emissions mitigation costs, 2020 **Figure 1.1**



Source: Amann et al., 2009

between 2013 and 2020 (each year, an equal amount of extra reductions) and GHG emissions in 2013 should not exceed current emissions[1]. The EU target for the non-ETS sector in the Netherlands is 16% GHG reduction in 2020 relative to 2005 (or 22% relative to 1990). Member States can decide which instruments and options to use to reduce non-ETS emissions, such as traffic management, clean transport, taxation, promotion of public transport, urban planning, and promotion of insulation.

The Effort Sharing Directive promotes cost-effectiveness through a number of flexibilities. For instance, GHG emissions can be 'borrowed' from the next year and/or extra reductions can be banked in one year for the following year. Borrowing is, however, limited to a maximum of 5% of the target level[2]. For example, in 2019 the Netherlands could bank about 5 Mt for 2020. Use can also be made of CO_2 credits from GHG reduction investments in other countries through CDM and JI. The maximum CO_2 credits through CDM and JI for the Netherlands per year is limited to 3% of emissions from the non-ETS sectors in 2005 (about 4 Mt in 2020).

Unused CO_2 credits can be banked in one year for the following year. Other flexibilities include the option for a country to transfer 5% (about 5 Mt for the Netherlands in 2020) of its annual allowed GHG emissions to another country and to trade its own CO_2 credits from CDM and JI. All of these flexibilities can affect the distribution of the necessary efforts over domestic and foreign measures in a specific year. This in turn influences the effects on domestic air pollution in that year.

Co-impacts of renewable energy depend on the energy and the design of flexible instruments

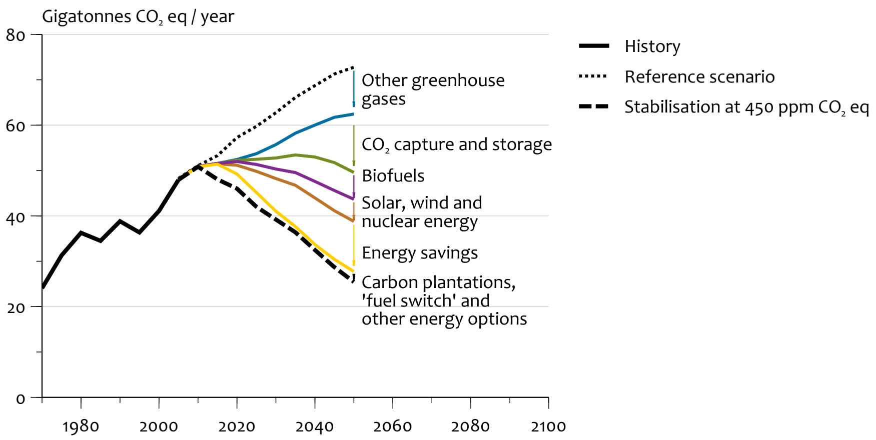
The Renewable Energy Directive (REDD; EU 2009c) establishes a common framework for promotion of energy use from renewable sources in the electricity production, heating and cooling, and transport sectors. The EU-wide target for a 20% share of renewable energy target has been set for reasons of security of supply, environmental protection and competitiveness of the renewable sector. The EU target for the Netherlands is 14% of the national energy consumption by 2020. In transport, 10% of energy use should come from renewable sources (biofuels, electricity, hydrogen) by 2020. To promote the development and use of second generation biofuels and renewable electricity in transport, their contribution to the target is multiplied by 2 and 2½ times, respectively. Several sustainability criteria apply to biofuels but have not as yet been formulated for biomass.

Flexibility mechanisms have been formulated to create opportunities for reducing the cost of achieving renewable energy targets. These mechanisms remain under Member States control in order not to affect ability to reach their national targets. They take the form of statistical transfers, joint projects by Member States and joint support schemes. Any effects on air pollutants of the flexible mechanisms depend strongly on the design of the flexible instrument and the type of climate measures involved.

Member States decide on the mix of renewable electricity, heating and cooling to achieve their renewable targets. Such measures that are also favourable from an air pollution perspective are land and sea-based wind energy, solar energy, hydropower, underground heat and cold storage. Other renewable measures such as co-firing biomass, biofuels in transport and biogas from manure fermentation have smaller co-benefits and sometimes result in disbenefits for air quality (Section 2.1 and 2.2).

Large-scale deployment of CCS potentially affects air polluting emissions

The EU Directive on the geological storage of CO_2 sets a regulatory framework for the removal of legal barriers and for environmentally safe geological storage of CO_2 (EU, 2009d). Targets are not set for the amount of CO_2 to be stored underground by a certain year. CCS is not mandatory at this stage. Eventually (Europe Commission expects in 2020), the incentive for CCS will be the carbon price resulting from the European GHG emission trading system. However, Contribution per reduction option for stabilising greenhouse gas emissions Figure 1.2



the Commission recognises that this will not happen without supporting early demonstration of CCS projects to reduce the costs.

The next step is to ensure CCS is commercially available in 2020. The European Commission has been working on a financial support programme that will demonstrate on industrial scale the full CCS chain for a representative portfolio of capture, transport and storage options across Europe. Recently, the European Commission approved six grants for CCS projects across Europe (EC, 2009b) one of which is located in the Netherlands. Capturing CO$_2$ from power plants and industries influences air polluting emissions because the capture unit has to be integrated into the plant configuration and its operation requires a considerably amount of energy. The effects on air pollution depend strongly on the combination of capture technology and combustion type and fuel chosen (Section 2.3).

Climate mitigation in the longer term could reduce some air pollutants substantially

In December 2009, the world leaders reached an accord at the Copenhagen UNFCCC 15th conference of the parties. According to science and as documented in the IPCC Fourth Assessment Report, deep cuts are required in global emissions in order to hold increase in global temperature to below 2 °C. Action is required to meet this objective consistent with science and on the basis of equity.

Scientific assessments show that to achieve the 2 °C target with a more than 50% probability, GHGs need to stabilise at less than 450 ppmv (Meinshausen, 2006). Several studies indicate that this target would correspond roughly to between 35 and 55% emission reductions worldwide in 2050 (and 70 to 85% in 2100) on 1990 levels (Van Vuuren et al., 2009). Based on certain fairness principles, these reductions could be translated into an 80-90% reduction target in 2050 for high-income countries such as the EU 27.

Reaching the targets for emission reduction to achieve the 2 °C target requires a broad portfolio of measures because the potential contribution of each option is limited by technical and other reasons. In some cases, technologies only apply to specific sectors and regions. While a broad portfolio approach has drawbacks in terms of the diffusion of research investments, there are also clear advantages. It would lead to a more resilient policy for technologies that achieve less than promised or that cannot be implemented. Excluding some options can lead to additional costs and/or the inability to reach the 2 °C target. Van Vuuren et al. (2007) provided an indication of how a 2 °C 'challenging' policy scenario could diverge from a no policy scenario as presented in Figure 1.2.

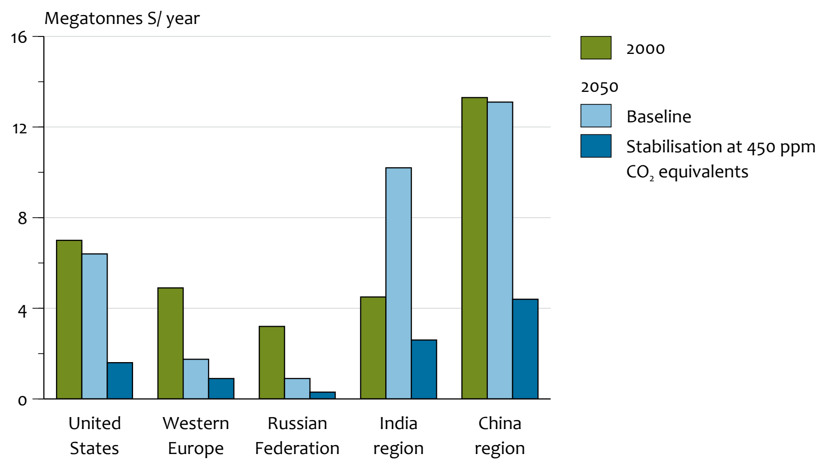
One of the most attractive forms of climate policy in terms of low cost and ease of implementation is decarbonising the central power system. This can be done with large-scale use of renewable energy in power production, such as wind power, hydropower or concentrated solar power (CSP), bio-energy, nuclear power and/or fossil-fuel fired plants in combination with CCS. Use of cleaner technologies would increase electricity prices, thus providing some stimulus for increasing efficiency and small-scale power generation by households, companies and industries. This would partly reduce demand for large-scale power plants. The main technologies are solar photovoltaic (PV) systems and small-scale wind turbines, distributed geothermal heating and cooling, and biogas-based micro combined heat and power (micro CHP).

Energy saving is an important element in all climate policy strategies. Studies show that compared to the current situation, energy saving over the next century could achieve substantial emission reductions, although the effect decreases after the first decades of this century.

The non-CO$_2$ GHG emissions include methane emissions from animals, rice cultivation, waste management and fossil-fuel operations, nitrous oxide emissions from fertiliser use, adipic and nitric acid production, and emission of fluorinated substances. Studies indicate that at least half of the non-CO$_2$ emissions could be prevented by 2050, (Van Vuuren et al. 2007).

If GHGs are reduced worldwide by 35 to 55% in 2050, air polluting emissions are also expected to reduce significantly. Most substantial reductions are SO$_2$ emissions (Van Vuuren et

Co-benefits of climate policies on SO_2 emissions **Figure 1.3**



al., 2009; Amann et al., 2009) mainly due to reduction in use of coal (Figure 1.3). Reductions of NO_x and particulate matter emissions are less substantial in this type of analysis due to the extra emissions from the assumed increased biomass use. Increased use of biomass in small to medium-scale combustion installations increases air polluting emissions, without additional measures (Section 2.1). Co-benefits are expected to be smallest for emissions of ammonia and volatile organic compounds.

Developments in Dutch climate and energy policies for 2020

The Netherlands has different climate and energy targets under international and national agreements. In the short term, the Netherlands has to comply with its Kyoto protocol target which is a 6% reduction in GHG s in the 2008-2012 period on the Kyoto base year. For the intermediate term (2020), the Dutch Government has set more stringent climate and energy targets in 2008 than those agreed in the European Union (PBL, 2009). The targets are reduction in GHG emissions of 30% on 1990 levels; a 20% renewable energy share in energy production and reduction in energy consumption of 2% per year.

The 2020 target for the renewable energy in road transport energy consumption is the same as the European target (10%). However, the feasibility of a mandatory 20% share of biofuels by 2020 is being explored. The Dutch targets imply that the Netherlands has to reduce about 21 Mt extra in 2020 compared to the EU targets (Van Dril et al., 2009; Daniels and Kruitwagen, 2010).

The EU stimulates Member States to set more stringent climate and energy targets, and Member States can decide how to meet these extra targets. The Dutch cabinet intends to do so through a combination of foreign CDM/JI credits and more stringent targets in non ETS sectors (national measures with possible co-benefits for national air quality; VROM, 2008a).

The European climate and energy package supports the Netherlands Government in achieving more stringent national targets. Measures that contribute substantially are the EU-ETS, the eco design directive for more energy efficient electrical apparatus, boilers and water heaters, the biofuels target, and the CO_2 standards for cars. The additional national climate and energy policies are presented in the work programme Clean and Efficient: New energy for climate policy (VROM, 2007). This programme contains a set of measures for each economic sector and for Dutch citizens, such as market instruments, standards, subsidies, innovation and climate diplomacy. The programme measures for key sectors are given below.

Energy sector: a new subsidy scheme is being developed for large-scale renewable energy and a stimulating regulation on sustainable energy or SDE. Large investments will be made in wind energy, and to achieve the goals set, onshore wind energy will need to be doubled in the coming four years. Offshore wind energy will also receive strong incentives. The European ETS is crucial for CO_2 reductions in this sector. Agreements have been made that new coal-fired power stations will be constructed to capture and store CO_2 underground in the future (capture ready).

Industry sector: the current agreements (covenants) on energy savings with industry (Long-Term Agreements and Benchmarking) will be further tightened. The Government wants the new long-term agreements (MJA) to include an obligation to achieve 20% improvement in energy efficiency by 2020 compared to 2005. An additional ambition is to save 10% energy throughout the rest of the chain. Programmes will be started with industrial sectors to achieve energy savings of up to 50% in the chain by 2030. The European ETS is crucial to this.

Traffic and transport: the Government is committed to the strict European standards covering CO_2 emissions for new cars. The mandatory percentage of biofuels in transport will increase after 2010 (for 2010 the goal is 4%). The feasibility of a mandatory 20% biofuels mix for 2020 is being explored. Biofuels must be produced sustainably, and these second generation biofuels count double for the target. Taxes will be greened even further. The purchase tax on new cars will be further differentiated in 2008. Cleaner, more efficient cars will be cheaper, while polluting cars will be considerably more expensive. Use of natural gas and biogas in cars will

Photo 4 The Maas tower in Rotterdam, Netherlands. The new 160 m office building uses water from the Meuse River in combination with underground heat and cold storage as sources for its climate control systems thereby reducing its CO_2 footprint.

be stimulated by extending the nation-wide pump network at filling stations. For public transport, demonstrations of hydrogen-fuelled vehicles will be promoted.

Built environment: the 'More with Less' plan aims at energy savings in existing buildings (residential, commercial and industrial buildings). The plan aims to improve energy efficiency in some 500,000 buildings by 20 to 30% in the period up to 2011, and from 2012 onwards an additional 300,000 buildings annually. The Government will make a financial contribution to this plan. A subsidy scheme has been introduced for renewable energy in existing buildings (solar boilers, heat pumps and solar electricity). For new buildings, the Energy Performance Coefficient will be tightened from 0.8 to 0.6 in 2011 and to 0.4 in 2015. The ultimate goal is for energy-neutral homes by 2020.

1.3 Developments in air quality policies

Stepwise process towards long-term ambition

Current air quality policies for ambient air in Europe consist of regulations on maximum air pollutant concentrations, product standards, emission limit values for small to large scale installations, and national emission ceilings for 2010. Both the UNECE Gothenburg Protocol (1999) and the EU National Emission Ceilings Directive (NEC Directive; EU, 2001) contain national ceiling emissions for the EU 27 for sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC) for 2010.

The emission ceilings for 2010 in the Protocol are equal to or somewhat less ambitious than those in the NEC Directive. The Protocol covers a larger geographical area with currently 51 participating countries: the EU 27, Norway, Switzerland, Turkey, Russia, other central and eastern European countries, the USA, and Canada, although not all parties have ratified the Protocol. Both regulations aim at protection of health and ecosystems by reducing deposition and concentrations of air pollutants to below critical loads and levels that harm health. In the meanwhile, both regulations follow a stepwise process that includes rules for revision of the current ceilings for 2010 and aim at stricter ceilings for 2020. Both revisions plan to include emissions ceilings for particulate matter.

New ambitions for air quality from the European Union

As part of the preparation for a revision of the NEC Directive, the European Commission set out ambitions to improve air quality in 2020 in the Thematic Strategy on Air Pollution (TSAP; EC, 2005). The ambition includes a 47% EU-wide reduction target of premature loss of life in the EU 27 due to the exposure to particulate matter between 2000 and 2020. Another target is a 31% EU-wide reduction in unprotected ecosystem areas against eutrophication. The thematic strategy assumes less stringent climate policies than those adopted in 2008. Between 2006 and 2008, the European Commission commissioned a large number of studies to derive national emissions ceilings for air pollutants in 2020 that meet their EU-wide TSAP targets. Key criteria for the national emission ceilings have been cost-effectiveness, equity and environmental progress towards the long-term environmental objectives.

The studies for the EC included energy projections, emission projections for 2020, air pollutant emission control packages and assessments of the environmental effects and cost-benefit analysis of additional air pollution mitigation (e.g., Amann et al., 2007a, 2007b; 2008; AEAT, 2008). At that time, the baselines could only take into account indications of the possible future climate and energy ambitions of the European Union. Because of the discussions on the European climate and energy ambition for 2020, and the potential implications for air pollutants (Section 1.1), the Commission has delayed revision of the NEC Directive. After the adoption of the EU climate and energy package in 2008, work on package details has continued. On 1 July 2010, the Commission announced postponement of the revision of the national emissions ceilings directive (NEC Directive) until 2013, the same year in which the EU air quality directive is to be evaluated.

New ambitions for air quality in the Gothenburg protocol

Revision of the UNECE Gothenburg Protocol started with a review of the protocol in 2007. The review concluded that to reach the ultimate goal of protecting ecosystems and human health further measures would be needed (CIAM, 2007). It concluded that the cost-effectiveness of further measures needs to be analysed in conjunction with other policy objectives, including those on climate change, energy security, transport and agriculture. After technical preparations in 2008 and 2009, the analysis started in 2010. The revised protocol will set national emission ceilings for SO_2, NO_x, NH_3, NMVOC and also $PM_{2.5}$, to be met from 2020 onwards. A new protocol is to be adopted in 2011.

The new protocol will lead to interim ceilings for 2020 and should result in a substantial step towards air pollutant levels that do not give rise to health and ecosystem problems. Further reductions in particulate matter and ozone exposure and nitrogen depositions are seen as priority (CIAM, 2007). Latest scientific findings suggest that current levels of exposure to fine particulate matter are still causing significant reductions in life expectancy (Pope et al., 2009; WHO, 2006). Secondary aerosols formed from precursor emissions of SO_2, NO_x, VOC and NH_3 constitute a significant fraction of $PM_{2.5}$ in ambient air. Nitrogen deposition remains a widespread problem in ecosystems in the Netherlands and in Europe. Despite reductions in precursor emissions (NO_x and NMVOC), no clear downward trend in ozone indicators for human health and ecosystems can be detected in Europe. Both climate and recent air pollution mitigation policies (e.g., Euro standards for Vehicles, Industrial Emissions Directive) can contribute to these priorities by reducing emissions of SO_2, NO_x and particulate matter. To reduce nitrogen deposition further, more stringent ammonia ceilings are most likely needed in some parts of Europe.

Proper estimate of co-impacts of air pollutants needed for emission ceilings

The methodology used by the UNECE and by the EC to derive ceilings uses baseline projections for 2020 for activities in the energy, industry, agriculture, transport, trading, services and construction, and the residential sectors (CIAM, 2008). These baselines should include the current climate, energy and air pollution legislation. For the revision in 2010-2011, the UNECE proposed to use the European baselines for all EU 27 countries based on the PRIMES energy system model and the CAPRI model for agriculture (Maas, 2010). These baselines are integrated into the GAINS model used in the revision to assess cost-optimal policy packages for additional air quality ambitions.

The PRIMES baseline has the advantage of being internationally consistent in the light of the most recent economic development for all countries. It provided an internationally coherent perspective comprising current legislation on climate and energy measures (except for a full inclusion of the renewable targets). However, the baseline has the disadvantage that a number of PRIMES assumptions differ from those of individual countries on, for example, economic growth and implementation of climate and energy policy measures. To assess the sensitivity of these differences, the impacts on co-benefits and the subsequent effect on the attainability of emissions ceilings, use of national energy and agricultural baseline projections is proposed as alternative in the revision.

The importance of a proper estimate of co-impacts (co-benefits or disbenefits) is underlined by previous European calculations with GAINS which showed that inclusion of co-benefits leads to more stringent ceilings for air polluting emissions in the Netherlands (Amann et al., 2007a, b, and 2008). However, the previous report of the Dutch Research Programme expressed concern about the implications for the attainability of these ceilings, and the large uncertainties resulting from the Dutch assessment of co-impacts (Hammingh et al., 2008). These include uncertainty in future CO_2 prices, uncertainties in the efficacy of European and national climate and energy measures and instruments, and the amount of imported or exported electricity. An updated analysis of the differences between the PRIMES and Dutch energy and emission baselines, and the effects on co-benefits is presented in Sections 3.1 and 3.2.

1.4 Methodologies for quantifying co-impacts

European integrated assessment methodology: GAINS & PRIMES

The European integrated assessment methodology used to derive new national emission ceilings for 2020 takes into account the co-impacts of climate and energy policies mainly through the energy baselines. Some effects of climate polices in non-energy related activities (e.g., animal numbers) in agriculture and non-CO_2 GHGs are included in the assessment methodology through different baselines that are not explored here.

The energy baselines for each of the EU Member States for future years come from the PRIMES model (NTUA, 2010). This is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU Member States. The model determines the equilibrium by finding prices of each energy form that energy producers find best to supply, and which match the quantity consumers want. The model is behavioural but is also explicit and detailed about the energy demand and supply technologies and pollution mitigation technologies. The system reflects considerations about market economics, industry structure, energy / environmental policies and regulation. These are conceived so as to influence market behaviour of energy system agents. The PRIMES energy system model has been used for analysis of the 2008 climate and energy package (EC, 2008). The model is still used to assess the impacts of tentative targets or more elaborated policies on GHG reduction, renewable, energy efficiency improvements with respect to their implications on the Member-States' energy systems and in terms of energy costs and prices.

The PRIMES energy baselines are input for the GAINS model and are the most determinant factor for the baseline levels of GHGs and air pollutants calculated by the model. The GAINS model is an integrated assessment model that brings together information on the sources and impacts of air pollutant and GHG emissions and their interactions (IIASA, 2010). The model is an extension of the earlier RAINS (Regional Air Pollution Information and Simulation) model that addressed air pollution aspects only. GAINS incorporates data on economic development, the structure, control potential and cost of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution. The model addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition on soils, in addition to the mitigation of GHG emissions. The inter relationships is described between these multiple effects and the range of pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F gases) that contribute to these effects on a European scale. More than 1000 measures to control emissions to the atmosphere are assessed for each of the 43 countries in Europe. Atmospheric dispersion of pollutants is computed and the costs and environmental impacts of pollution control strategies are analysed. In the optimisation mode, the model identifies the least-cost balance of emission control measures across pollutants, economic sectors and countries that meet user-specified air quality and climate targets.

Dutch integrated assessment methodology: Options Document & Analysis Tool

The Dutch methodology used to assess the national effects and costs of new climate and air pollution policies also integrates the synergies and trade-offs between climate policies and air pollutant emissions. It consists of different elements and steps. The first element is formed by the Dutch baseline projections for energy use, agricultural activities and GHGs and air polluting emissions. These baseline projections focus on 2020 and include current climate, energy and air pollution polices. The main baseline projection used in this study is the 2009 baseline projection (Daniels and Van der Maas, 2009).

The second element in the Dutch methodology is the Dutch Options Document for Energy and Emissions 2020. It consists of a large number of option descriptions (measures) and an Analysis Tool (Daniels and Farla, 2006). Many of the options have been recently updated (Smekens et al., 2010; CE, 2009). Most of the options are technical such as CCS at new pulverised coal-fired power plants, but there are also various non-technical options, such as reduction in the maximum speed on motorways from 120 to 100 km/h. The current option descriptions provide the reduction potentials in 2020 for more than 150 climate, energy and air pollution options.

The starting point for all options is the Dutch baseline projection 2009. Each option description includes a comprehensive fact and data sheet with specifications of the measure, its potential implementation size, the effects on levels of GHG (in megaton) and air polluting emissions (in kiloton), energy consumption (in petajoule), investment and operational costs (in euros), the possible policy instruments and additional information regarding support and barriers.

All options are inputs in the Analysis Tool which is the third element in the Dutch methodology. The Analysis Tool (Smekens et al., 2009) uses these options to produce cost-optimal option packages that start from the 2009 baseline projection and optimise towards a set of user-defined targets for CO_2, other GHG[3] and the air pollutants - SO_2, NOx, NH_3, particular matter (PM) and NMVOC. The tool provides several possibilities for managing cost-optimal solutions. For instance, the tool can either select or exclude certain measures sometimes for a certain percentage (application rate of an option). 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 an envisaged climate programme, and searches for a cost-optimal set of options required to achieve user-defined climate and air quality targets. The output is a list of options, costs, energy consumption, and effects on GHGs and air polluting emissions.

The Dutch integrated assessment methodology uses all of these elements. A hybrid analysis with the Analysis Tool and Options Document was done to assess the co-benefits and/or disbenefits of the Dutch Cabinet's climate programme Clean and Efficient. The first step in the analysis was to express the envisaged climate and energy policies and/or instruments in terms of application rates of Dutch options from the Options Document. Part of that work was done by Van Dril et al. (2009). One example is the assumption that under high CO_2 price conditions in 2020 (50 euros /tonne) about 10 Mt CO_2 will be captured from power plants and stored in empty gas and oil fields. As a result the option CCS in new pulverised coal-fired power plants with a total potential of 12 Mt CO_2 (Appendix A.4) is applied for 83%. After translating all climate and energy policies and instruments into application rates of the available options in the Analysis Tool, the total effects on energy use, GHGs and air pollutants can be calculated with the tool. No further optimisation is done. These steps are discussed in Section 3.2.

In addition, the Analysis Tool can been used to study the effects of more stringent GHG targets in addition to the envisaged policy packages. In that case, the Analysis Tool is put in the optimisation mode which generates the least cost solution to reach one or multiple emission or energy targets using the reduction potential and related costs of all remaining technical and non-technical options. At the same time, the corresponding air polluting emission reductions or increases are calculated. Application of this further step is discussed in Section 3.3.

Notes

1 Calculated as average emissions for 2008, 2009 and 2010.

2 The target of the next year is calculated by the linear reduction of the emissions in 2013 up to the N-ETS emission target in 2020

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

2

New insights into co-impacts of specific greenhouse gas mitigation measures on air pollutants

This second integrated report of the Dutch Research programme on Air and Climate builds on the results and recommendations of the first phase report (Hammingh et al., 2008). This report demonstrated a positive net effect on air polluting emissions of Dutch climate policies. This is mainly due to measures such as stimulating renewable energy (wind power) and energy savings, decommissioning older power plants, and road pricing.
However, measures such as biofuel use in road transport, bio-energy in stationary applications, and CCS in power and industrial sectors will not necessarily reduce air polluting emissions. It was therefore recommended that the Dutch situation with regard to the possible future application of these measures should be further investigated as well as the future emission factors and the estimated effects on national air polluting emissions for 2020. In addition, knowledge on emission reduction technologies needs to be updated that could compensate for possible negative effect on air polluting emissions from these climate measures.

The results of the investigation on bio-energy, biofuels and CCS is presented in the Sections 2.1-2.3, and is the basis for updating of part of the Dutch integrated assessment methodology presented briefly in Section 2.4. The updated methodology was used in the analysis of the co-impacts on national air polluting emissions arising from climate policies in the Netherlands. This is presented in Chapter 3.

2.1 Small to medium-scale bio-energy applications and fossil CHP

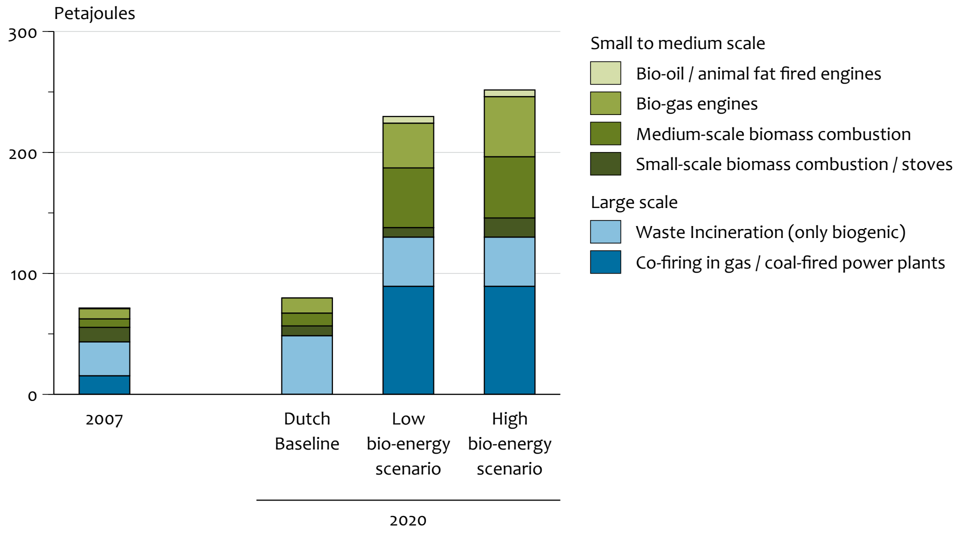
This section focuses on the air pollution effects of increased bio-energy use and energy-efficient fossil-fired combined heat and power (CHP) in small to medium stationary installations (Boersma et al., 2009). Information on the large-scale bio-energy use is included in order to present an overview of all current and possible future bio-energy applications.

Scenarios for bio-energy application

Current bio-energy activity levels (CBS, 2010), and the levels according to the Dutch baseline projections for 2020 with current legislation (Daniels and Van der Maas, 2009), contribute about 2% to the national primary energy use. Figure 2.1 shows these levels and the share of the different types of bio-energy in 2007 and three 2020 scenarios. The main

Photo 5 Medium-size power plant using waste wood in Alkmaar, the Netherlands (copyright M. Wijnbergh)

Bio-energy use in the Netherlands and projections for 2020 **Figure 2.1**



developments between 2007 and 2020 (current legislation) include an assumed stop on co-firing biomass in large-scale power plants due to the absence of subsidies and regulations, growth in biogenic waste incineration (with electricity generation), growth in medium scale biomass combustion and biogas production (from manure and co-substrate digestion), and a small decline in the of biomass use in wood burning stoves. The Dutch target for the contribution of all renewable (including wind, hydro and solar power) is a 20% share in the projected national primary energy use in 2020. The European target for the Netherlands is about 14% [1].

In order to assess the effects on air pollution on stimulating bio-energy use in small to larger scale installations, low and high scenarios for 2020 have been constructed (see Figure 2.1). Both scenarios include high application of co-firing biomass in large-scale power plants (2.2% of primary energy use) because this is one of the more substantial and cheaper biomass options. Further, moderate and ambitious assumptions have been made on the expansion of medium-scale biomass combustion, biomass use in household stoves and biogas production. These assumptions are based on rough estimates of growth rates based on developments and new plans seen in the past years, availability of indigenous biomass, and potential for manure digestion on farms in the Netherlands. The potential for biomass use in waste incineration have been adjusted slightly downwards. This is explained by the more stringent emission limit values that came into force recently and the absence of waste imports from Germany.

Under the low and high scenarios, the contributions to the projected national primary energy use are 5.5 and 6.5 %, respectively. For these scenarios to become reality, new subsidies or regulations are needed because most of these measures are currently not commercially viable. Moreover, some measures still depend on technological developments (e.g., biomass gasification).

Emissions of most air pollutants increase with increased bio-energy use

In addition to activity scenarios, the current and future emission factors for the different types of bio-energy combustion installations have been collected. A comparison of emission factors for 2007 (Appendix A.1) and those for 2020 (Table 2.1) shows a decrease in NO_x emission factors for biogas and medium-scale biomass combustion installations. This is mainly the result of enforcement of a new Dutch decree on emission limits for medium scale combustion installations (VROM, 2009) covering installations between 1 and 50 MW_{th}. Another obvious difference is that solid biomass-fired installations have higher emission factors (limit values) than do biogas-fired installations. This is due to the relatively clean combustion of biogas (lower sulphur content, low dust, availability of low NO_x combustion). The bio-oil or fat-fired diesel engines and certified and uncertified wood burning stoves have the highest emission factors for most pollutants.

In order to assess the effects of an increased bio-energy use on air polluting emissions, the types of fossil fuel being substituted and the types of installations have to be determined, together with the associated air polluting emissions. It is assumed that bio-energy substitutes are used mostly in fossil-fuelled electricity from the average (large scale) power plant park. Dutch emissions factors for coal and natural gas-fired power plants and the average values for the whole Dutch power plant park are presented in Table 2.2. A comparison of fossil emission factors from large scale plants with bio-energy emission factors from Table 2.2 shows that the fossil SO_2 emission factors are relatively high and relatively low for emission factors for NO_x, NH_3, particulate matter, NMVOC. Combined with the low and high scenarios for the additional bio-energy application in 2020, emissions of NO_x, NH_3, PM_{10} and especially NMVOC are estimated to increase (Table 2.3). Increased use of bio-energy lowers SO_2 emissions.

Emissions factors for large to small scale bio-energy installations in the Netherlands in 2020

Table 2.1

	NO_x	SO_2	NH_3	PM_{10}	NMVOC
Category	g/GJ				
Co-firing biomass with coal	37	11	5	0.9	2
Waste Incineration (only biogenic)	35	1.3	1.3	0.5	1.3
Medium-scale biomass combustion	37	10	1.7	1.7	10
Biogas from waste tips	30	2	0.15	0.5	14
Biogas from wastewater treatment	30	2	0.15	0.5	14
Agricultural biogas plants	30	2	0.15	0.5	14
Other biogas plants	30	2	0.15	0.5	14
Bio-oil/fat-fired diesel engines	130	9	4.4	17	31
Small-scale biomass combustion/stoves	130	13	0	137	620

Emissions factors for large-scale coal and gas-fired power plants in the Netherlands for 2020

Table 2.2

	NO_x	SO_2	NH_3	Dust	NMVOC
Category	g/GJ				
Coal-fired power plants	37	30	0.1	2	1.2
Gas-fired power plants	37	0	0	0	1.2
Average emission factors of the Dutch fossil fuel fired power plants in 2020	37	12.7	0.05	0.9	1.2

Change in air polluting emissions in two scenarios for increased bio-energy application in 2020[1]

Table 2.3

Scenario	Additional bio-mass use in 2020 (PJ/year)	NO_x	SO_2	NH_3	PM_{10}	NMVOC
		Kiloton per year				
Low	142	-0.2	+1.7	-0.5	-0.1	-1.1
High	172	-1.1	+1.6	-0.5	-1.2	-6.3

[1] Positive numbers refer to an emission reduction (co-benefits), negative numbers refer to an emission increase (disbenefits).

Substituting coal with biomass in power plants has neutral to positive effect on air pollution

In the scenario study, co-firing biomass in coal-fired power plants contributes about 2.2% to the renewable targets in the Netherlands in 2020. Replacing part of the coal with biomass does not change levels of NO_x and NH_3 emissions but decreases SO_2 emissions (Boersma et al., 2008). Existing extensive flue gas cleaning in these installations should clean flue gases from different type of fuels. SO_2 emissions decrease because biomass in general contains lower amounts of sulphur.

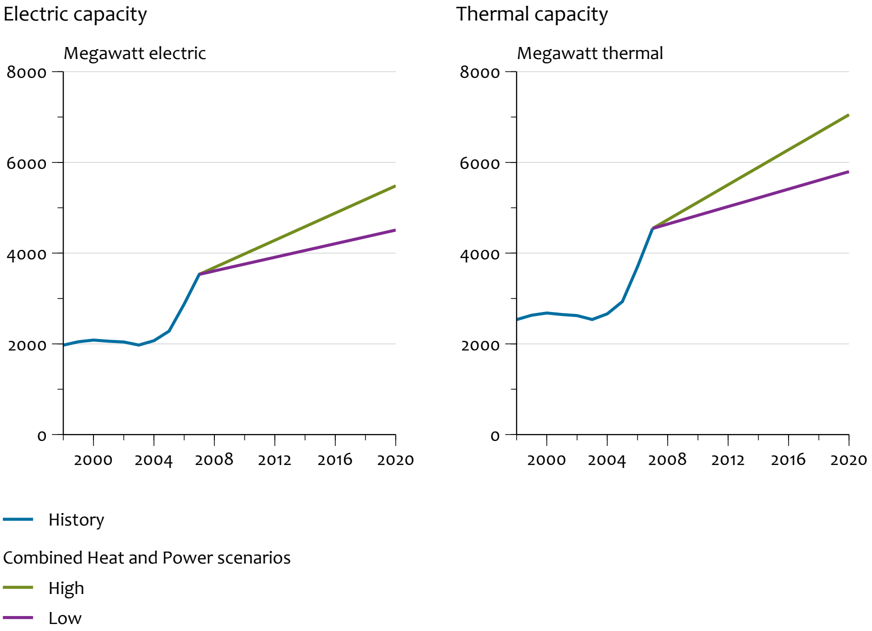
Wood burning stoves relatively large contributors to particulate matter and VOC emissions

In general, household wood burning stoves have relatively large emission factors especially for particulate matter and NMVOC (Table 2.1) but also for NO_x and SO_2. This is due to the absence of flue gas cleaning and less than optimal combustion conditions. Based on outdated statistical data, a trend towards certified household wood-burning stoves with better emission performances is observed (Boersma et al., 2009). Based on these trends and a low (8 PJ) and a high (16 PJ) scenario assumption for energy use in stoves, the effects on air polluting emissions in 2020 has been estimated. This showed that stoves in the high scenario could be responsible for 85% of particulate emissions from all bio-energy based combustion installations in the Netherlands by 2020. This corresponds to a contribution of more than 5% of the national PM_{10} emissions, or more than 10% of the national $PM_{2.5}$ emissions in 2020. These emissions occur at relatively low altitude and in residential areas. Stimulating use of certified stoves is found to be one of the more cost-effective measures with costs ranging from 30 to 50 euros/kg PM_{10}.

Increase in small-scale combined heat and power applications could increase NMVOC emissions

Stimulating combined heat and power applications (CHP) is part of the policy to increase energy-efficiency and reduce CO_2 emissions. In the period 1998-2004, the capacity of gas engines for CHP was almost stable (Figure 2.2) and then increased from about 2,000 MWe in 2004 to 3,500 MWe in 2007. The power generated by gas engine CHP plants remained almost stable (approximately 25 PJe) from 1998 to 2004 and then increased to 40 PJe in 2007. Most of the additional capacity was achieved in agriculture and horticulture (greenhouses). According to Blanken (2008), this increase in CHP based on gas engines is related to liberalisation of the energy markets and to a small extent on the subsidy in the framework of the MEP (predecessor of the SDE). To examine the effects on air pollution of an increase in fossil CHP, two scenarios have been constructed for 2020. The high scenario is based on the growth rate in the period 1998-2007 (150 MWe per year) and the low scenario assumes a growth of only half (75 MWe per year). Some studies indicate that such a growth in small-scale CHP is possible (Blanken, 2008; Davidse, 2008).The current Dutch baseline projection assumes a total installed CHP capacity of about 3700 MWe in 2020 of which 3.300 MWe is in the horticulture sector.

Small-scale combined heat and power generation in the Netherlands **Figure 2.2**



Emissions factors for small and medium-scale natural gas fired CHP, 2020 **Table 2.4**

	NO_x	SO_2	PM_{10}	NMVOC	NH_3
Category	**g/GJ**				
Gas engines CHP	>2.5 MW_{th}: max. 30 <2.,5 MW_{th}: max. 80 (intention after three years is 30)[a]	0.22 max. 67	No limit, 0.15 assumed	30 (average from monitoring)[b)]	0.15 assuming SCR

a) VROM, 2009; b) Kroon, 2010.

In terms of air pollution, natural gas and biogas are relatively clean fuels when used in gas engines (Table 2.4). They produce relatively low amounts of CO_2 per unit energy and have low emission factors for SO_2, NO_x and dust. NO_x emissions are low compared to a diesel engine running on bio-oil (Table 2.1). Current NO_x emission factors for many gas engines in greenhouses are reported to be 20 g/GJ due to use of SCR to make CO_2 fertiliser for crops. The current and future limit values are higher, which may allow for turning off SCRs temporary. One drawback of gas engines with regard to their GHG performance is their relatively high emission of volatile organic compounds. About 93% of these emissions consist of methane which is a strong GHG and difficult to oxidise with the currently available oxidation catalysts. The best way of dealing with this drawback is to purchase an engine designed with a low VOC emission profile or by optimising the engine management of existing engines (Kroon and Wetzels, 2008).

The effects on air polluting emissions of substituting fossil-based separate power and heat generation with small and medium-scale natural gas fired CHP generation is shown in Table 2.5 for the low and high scenario for 2020. The substituted electricity is assumed to be generated by the average power plant park, while heat is produced by a mix of gas and oil fired boilers (75/25 %). The substitution shows a small reduction in NO_x and SO_2, emissions and a more substantial increase of NMVOC emissions (2 to 6 kiloton) without additional control measures in the CHP installations. No noticeable change could be estimated for PM_{10} and NH_3 emissions.

Air pollutant reduction technologies available to reduce disbenefits of bioenergy

A vast number of techniques are available for reducing emissions of dust, NOx, NH_3, SO_2 and NMVOC in small to large scale stationary bioenergy plants and fossil CHP. Most of these techniques are already being used in fossil-fuel fired installations. These techniques include (for more details see Appendix A.1):

- Particulate matter: electrostatic precipitation filter, (multi) cyclones, fabric filter, ceramic filter, wet scrubber
- NO_x: Selective or non-selective catalytic reduction, flue gas recirculation, wet scrubber
- SO_2: limestone injection, wet scrubber
- NH_3: wet scrubber (acid), biofilter, active carbon injection
- NMVOC: active carbon injection, catalytic afterburner, thermal afterburner, biofilter

The investment and operational costs of these techniques vary considerably depending on the size of the installation, the fuel type and quality, process conditions, retrofit or not, presence of corrosive components in the flue gas, type of construction materials, desired cleaning efficiency and combinations with other cleaning devices. Boersma et al. (2009) present ranges in the arithmetic average and median values of costs and reduction efficiencies (expressed in

Change in air polluting emissions in two scenarios for increased CHP application in 2020[1] **Table 2.5**

Scenario	Natural CHP in 2020 [PJe/yr]/[PJh/yr][2]	NO_x	SO_x	PM_{10}	NMVOC	NH_3
		Kiloton per year				
Low	7 (e) / 10 (h)	+0.3	+0.4	0.0	-2.4	0.0
High	16 (e) / 23 (h)	+0.6	+0.8	0.0	-5.6	0.0

[1] Positive numbers refer to an emission reduction (co-benefits), negative numbers refer to an emission increase (disbenefits).
[2] e = electric, h = heat

Emissions from bio-based electricity chains and fossil reference within the Netherlands in 2020 **Table 2.6**

Emission	Palm oil (CPO)	Biogas	Natural gas reference	Wood pellets	Coal reference
	g/GJ				
NO_x	0.018	9.51	5.21	1.76	0.81
SO_2	0.003	4.41	5.86	0.84	0.19
NH_3	0.000	0.00	0.00	0.01	0.07
PM_{10}	0.000	0.42	0.22	0.14	0.05
$PM_{2.5}$	0.000	0.00	0.23	0.14	0.04
NMVOC	0.001	7.79	4.27	0.36	0.12

euro/1000 m^3 flue gas, euro/MWth and euro/GJ input). For more details on costs of reduction measures, see Boersma et al. (2009).

Limited effects of bio-energy supply chains on national air polluting emissions

For a more integrated view on the effects of bio-energy applications, estimates are made for air polluting emissions in supply and production chains of biomass, biofuels and biogas (Koper et al., 2009). These bio-energy chain emissions are compared with the chain emissions from the fossil fuels that they may replace. These estimates show, for example, that most air polluting emissions from the wood chain in the Netherlands are substantially higher than those from the coal it may replace (Table 2.6). The NO_x and NMVOC chain emissions of biogas within the Netherlands are also substantially higher than the emissions from natural gas production it may replace. Palm oil causes very low chain emissions in the Netherlands because it is produced abroad and only imported by ship.

The picture on how chain emissions from bio-energy chains compare to fossil chains change drastically when the total chain in and outside the Netherlands is considered (see Appendix A.2). Biogas and wood pellet chains have the lowest air polluting emissions compared to their fossil references (natural gas and coal) and also compared to the palm oil chain. The wood pellet chain scores better than coal on all except SO_2 emissions. The coal and palm-oil supply chains have the highest emissions of all the chains, except for NMVOC and SO_2 emissions where the natural gas chain has higher emissions. The high NMVOC and SO_2 emissions for the natural gas chain are caused by emissions in the production of natural gas (mainly in 'sweetening of natural gas').
Estimates have also been made of the effects on air polluting emissions when fossil fuels are replaced by bio-energy in low and high bio-energy scenarios (Table 2.7). These amounts represent 15 to 17% of the total projected natural gas and coal use in Dutch electricity production in 2020[2].

Changes in supply chain emissions when fossil fuels are replaced by biomass, bio-oil and biogas in 2020 are shown in Table 2.8. Only supply chain emissions of NO_x and NMVOC from bio-energy chains are a few tenths of a kiloton higher than those from fossil fuel chains. This is probably the result of the higher NO_x emissions in the transportation of wood (with a relatively low energy content) compared to coal and higher VOC emissions from biogas production in the Netherlands compared to Dutch natural gas.

Changes in the Netherlands are limited compared to the total estimated chain emissions of the projected total natural gas and coal use in large-scale electricity production in 2020. This is because only a part of the fossil fuels for electricity generation is replaced by biomass, bio-oil, and biogas. However, if renewable energy shares is increased in the future and more bioenergy has to be produced, more substantial changes could occur in air pollutant chain emissions in and outside the Netherlands unless additional measures are taken.

Uncertainties

The outcome presented here should be regarded as an initial indication of the effects because of the serious uncertainties identified. The activity scenarios presented on the future bioenergy use and medium-scale CHP should be considered as what-if scenarios and not as a best guess. The real future contributions depend strongly on subsidies and/or future obligations. Unlike large-scale fossil-fuel applications, these technologies are currently not competitive. Future policies on subsidies or obligations are currently unknown, and sometimes depend on technological (e.g., biomass gasification) and market developments (international prices of biomass).

Limited basic statistical data is available on the inventory of air pollutant emission factors in the small to medium bio-energy combusting installations with sufficient detail and correlating relevant data (air polluting emissions coupled with size, fuel type, flue gas cleaning measures, efficiency, costs). Statistical investigations and measurements could not be performed in this study and the results presented here are based on available data, public literature and estimations. Actual emission factors can be site-specific and depend on

Bio-energy use in two scenarios for power and heat production in the Netherlands in 2020 — Table 2.7

	Low scenario	High scenario
	PJ	
Palm oil for electricity	6	6
Biogas for electricity	37	50
Wood pellets for electricity	129	138

Change in supply chain emissions in the Netherlands when fossil fuels are partly replaced by bioenergy in 2020[1] — Table 2.8

	Estimated chain emissions in the Netherlands from fossil fuel use in electricity production[2]	Changes within the Netherlands Scenario		Changes within and outside the Netherlands Scenario	
		Low	High	Low	High
Pollutant	Tonne				
NO_x	3790	-251	-316	-89	-153
SO_2	3910	2	15	-31	-18
NH_3	30	8	9	-74	-74
PM_{10}	170	-19	-22	-27	-30
$PM_{2.5}$	170	-2	0	1	2
NMVOC	2840	-137	-185	-76	-124

[1] Positive numbers refer to an emission reduction (co-benefit), negative numbers refer to an emission increase (disbenefit).

[2] For comparison, the estimated chain emissions from the total coal and natural gas use in electricity production are added.

many factors such as technology, fuel, permit, scale, emission-reducing measures. Often, there is not a single identifiable emission factor for a certain technology but a range of emission factors, sometimes limited by a legal emission limit.

The above observations should be kept in mind when developing additional bio-energy policies for small and medium-scale installations that do not lead to an increase in air polluting emissions. A more detailed study may be needed to reduce the uncertainties in the estimated effects on air pollution from stimulating bio-energy applications in the Netherlands.

2.2 Biofuels in road transport

This section focuses on the air polluting effects of increased biofuel use in road transport. In 2008, biofuels contributed 2.6% to total energy consumption of Dutch road transport (CBS, 2010). The Dutch target for 2010 is a 4% (related to energy content) contribution of biofuels. The European target for 2020 for all Member States is a 10% contribution (by energy content). A 10% contribution of bio-energy to total energy consumption of road transport corresponds to 1.7% contribution to total projected primary energy use in the Netherlands in 2020.

To estimate the effects on air pollution of increased biofuel use, a scenario study was carried out with three possible biofuels mixes for the Netherlands that comply with the European target of 10% in 2020 (Verbeek et al., 2009). The emission factors of future passenger cars and trucks running on various blends of fossil and biofuels in 2020 have been estimated based on a literature study and a risk analysis. Finally, the national effects on NO_x and PM_{10} emissions from road transport have been analysed for the three biofuels scenarios.

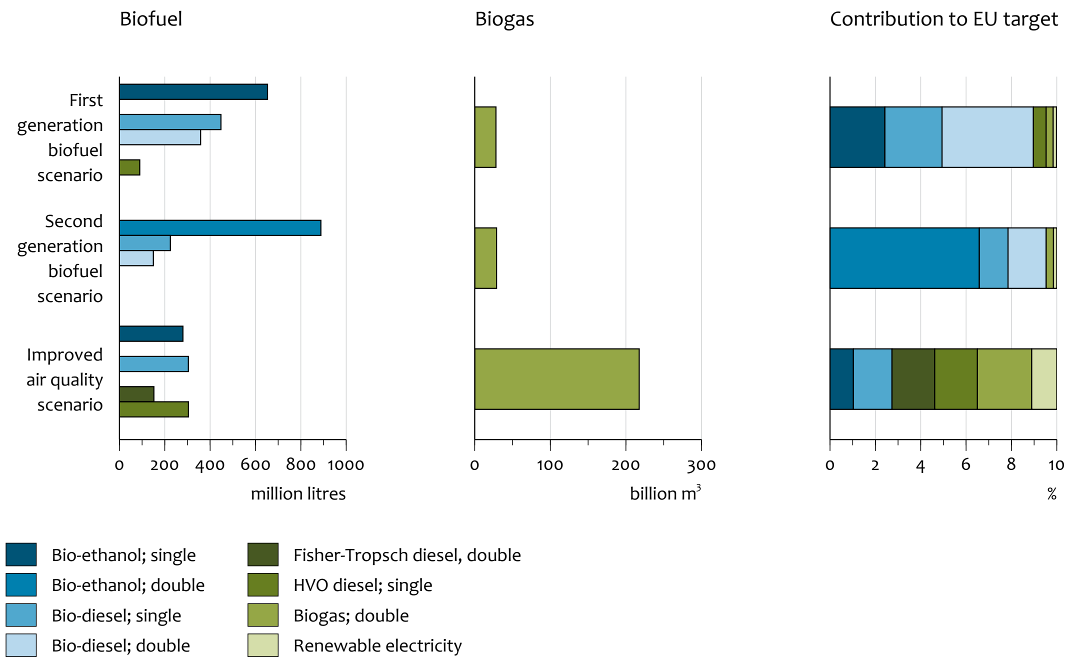
Three biofuels scenarios for exploring effects on air pollution

Three biofuels scenarios that meet the European biofuels target have been developed to explore their potential impact on air quality. Future developments are expected to be somewhere in this ‘playing field’. Verbeek et al. (2009) included in the scenarios the biofuels and biogas options that are currently envisaged to have the highest chance of maintaining or achieving a significant market share in the coming decade. The three biofuels mix scenarios are presented in Figure 2.3 and are based on the following assumptions:

1) The current biofuel scenario assumes continued use of biofuel types in 2020 that are technically mature today, and that part of the growth in biofuels volume in the coming years will come from second generation biofuels from waste and lignocellulosic biomass (2% in 2020). A relatively modest growth is assumed in electric transport. This scenario thus assumes that current biofuels and their feedstock can be developed further and made sufficiently sustainable to meet future European sustainability standards. The main share of the biofuels are blended into bulk gasoline (E10) and bulk diesel (B7) and the remainder of the biodiesel is applied as a B30 (scenario 1a) or B100 (scenario 1b) biodiesel blend in dedicated heavy duty vehicles.

2) The second generation biofuels scenario assumes that concerns about the sustainability of first generation biofuels dominate the biofuels debate in the coming years. This leads to much stronger growth in second generation biofuels (4% in 2020), and only a limited amount of the current biofuels. The second generation bio ethanol is assumed to be the only advanced second generation production process that is successful in 2020. As much ethanol will be blended into the bulk petrol as permitted. The remainder will have to be sold to niche markets as E85. A relatively modest growth of electric transport is assumed. The biofuels are blended into bulk gasoline (as E10) and diesel (as B3.6) and the remainder

Composition of Dutch biofuelscenarios that comply with EU target for 2020 **Figure 2.3**



of the bio-ethanol is applied as a E85 bio-ethanol blend for dedicated flexi-fuel vehicles or as Ethanol Diesel (ED95[3]) blend for a limited segment of special buses and trucks.

3) The improved air quality scenario assumes that the biofuels growth between 2010 and 2020 is achieved via routes that result in the least pollutant emissions from vehicles in urban areas. This includes biogas, Biomass to Liquid (BTL, also known as Fischer Tropsch Diesel), Hydrogenated Vegetable Oil (HVO), and a relatively high share of electric vehicles (assuming successful development in the coming years). HVO and BTL can be blended at higher percentages without causing problems in engines and fuel systems in the current vehicle fleet. In addition to these low-emission biofuels, the standard gasoline and diesel at the pump will contain 4% first generation bio-ethanol and biodiesel, respectively. No niche markets for high blends (B100/E85) are necessary in this scenario. The cost of this scenario is expected to be relatively high since electric and plug-in hybrid vehicles and BTL production are still very costly. It remains to be seen whether these technologies can mature sufficiently in the coming decade.

First generation biofuel production probably sufficient to meet projected Dutch consumption in 2020

Biofuels production capacities in the Netherlands up to 2008 and the planned extension of the capacities until 2012 are substantial (Figure 2.4). Biodiesel, bio-ethanol, and bio-methanol plants expected to be operational in 2012 represent a total fuel production equivalent to approximately 108 PJ/a. This is close to 20% of the projected primary energy use in transport in 2020 and nearly 3% of the total Dutch primary energy demand projected for 2020. About half of the Dutch biodiesel plants are based on rapeseed oil and cooking fats and oils. Five other biodiesel plants use rapeseed, canola, soy oil, palm oil, and animal fats as feedstock. Also, two to three bio-ethanol plants under construction or planned will use corn, grain, and waste (for second generation bio-ethanol) as feedstocks. Another biofuel plant producing bio-methanol will be based on glycerine.

Biofuels more expensive than fossil fuels

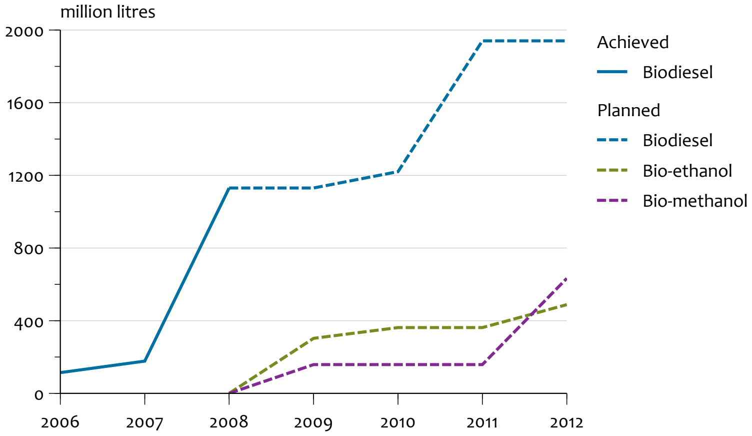
Costs of biofuels have been variable over the past few years due to changing feedstock prices, government subsidies, market forces (in times of shortages or overproduction) and fluctuations in the oil price. Cost estimates of future biofuels (Fisher-Tropsch and bio ethanol from ligno-cellulosic biomass) are even more difficult to make because these are still in an R&D, and not yet produced on a significant scale. Thus, the cost of these biofuels in the coming decade is very difficult to predict and highly uncertain. Cost reductions may be significant when technology development is successful and production volumes increase, but may remain high if these conditions are not met. Moreover, bio-energy prices could rise due to increased competition for biomass used for food and biofuel production. Tighter sustainability criteria for bio-energy production could also lead to increasing bio-energy prices.

An overview of the expected cost developments for the Netherlands of first generation biodiesel and bio-ethanol made by ECN (Boersma et al., 2009) is shown in Figure 2.5. According to this study, the cost of first generation biofuels is expected to increase in the coming decade because of rising feedstock prices. Second generation bio-ethanol and Fisher-Tropsch diesel are expected to reduce in cost significantly in the coming decades. A recent study by Wilde and Londo (2009) shows that prices of second generation cellulosic bio ethanol and Fisher-Tropsch or BTL biodiesel in 2030 could be similar to first generation bio-ethanol and biodiesel in 2020. All biofuels are expected to remain more expensive than fossil fuels in the coming decades.

Vehicles that run on high blends biodiesel or bio-ethanol, and electric vehicles are more expensive than regular cars that run

Photo 6 Rapeseed can be used as an energy crop for producing biodiesel (© P. Hammingh)

Biofuel production capacity in the Netherlands **Figure 2.4**



on straight diesel or gasoline. An overview of the additional purchase prices of special vehicles (compatible with biofuels and hybrid/electric) is given in Table 2.9. The price could increase with time if the series become larger. However, there are often additional maintenance costs that are not included here.

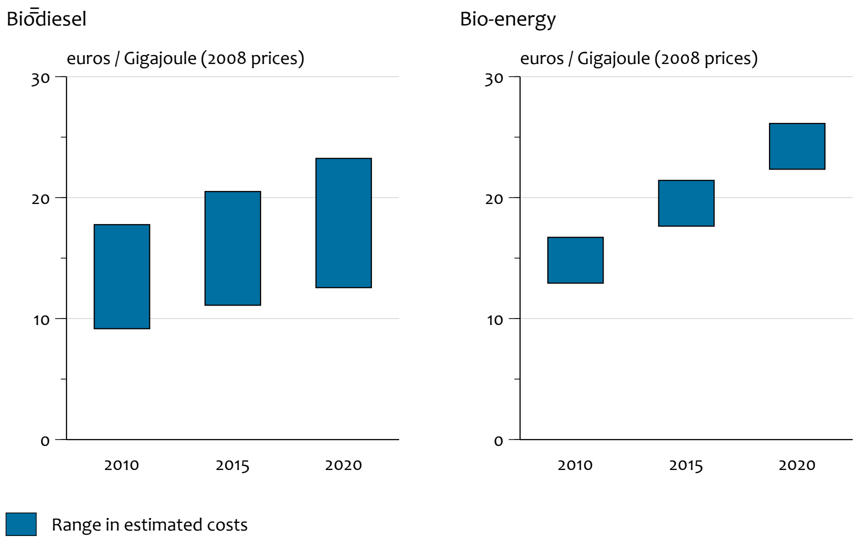
Limited monitoring data shows larger changes in exhaust emissions with higher biofuel blends

An extensive literature review on the exhaust emissions of various biofuels and blending percentages in Verbeek et al. (2008) has been updated in the Dutch Research Programme (Verbeek et al., 2009). Use of low-blend biodiesel (B7, up to 7% by volume) and bio-ethanol (E10, up to 10% by volume) in mainstream vehicles is assumed not to lead to significant effects on exhaust air polluting emissions. The argument is that current and future engines need to comply with standard emission factors (based on the Euro standards) in type approval tests where the standard reference fuels can have a maximum of 5% biofuels.

The updated information based primarily on Euro-III (HDV) engines confirms that higher blends of biodiesel in heavy duty vehicles (HDV) lead to higher exhaust pipe NO_x emissions and lower particulate matter emissions (Figure 2.6 and Figure 2.7). A regression analysis shows that a 100% biodiesel fuel could lead to an increase of about 10% NO_x emissions and a decrease of particulate matter emissions by about 40%. Monitoring data on high blends bio-ethanol applied to flexi fuel passenger cars (up to Euro-4), show that an increase in NO_x (about 30%) and PM emissions (about 35%; Verbeek et al., 2009). Since new flexi fuel vehicles need to comply with the Euro-5 standard for gasoline cars after 2012, the effects of high bio-ethanol blends are expected to disappear in the future.

Estimated production costs biofuels

Figure 2.5



Additional purchase price (euros) for special vehicles

Table 2.9

Vehicle type	2009	Projection 2020
Passenger cars / vans		
Flexible Fuel Vehicle (E85)	300- 2000	0 - 1000
Natural gas / biogas	2000 - 7500	2000[1]
Plug in hybrid	-	5000 – 6800[1]
Electric vehicle	15000	5000 – 6000[1]
Trucks		
High blend biodiesel	100 - 2000	100 - 1000

[1] Hanschke, 2009

Methodology to derive the potential effects of biofuels on exhaust air pollutants

Both studies by Verbeek et al. (2008 and 2009) show that the conventional method of deriving emission factors from monitoring data cannot be used because less emission monitoring data is available for biofuels as for fossil fuels. The emission factors for high bio-ethanol blends have been calculated by multiplying the standard fossil-fuel emission factor by a biofuel emission variation factor (Figure 2.8). For the calculation of emission factors for high biodiesel blends a failure factor is added and a failure rate (Figure 2.9). The biofuel emission variation factor represents the change in emissions due to biofuels use based on the limited monitoring data collected in Verbeek et al. (2008 and 2009). Minimum, average and maximum biofuels emission variation factors have been determined for high blends of bio-ethanol (E85) and biodiesel blends (B30/B100). For the low biodiesel and bio-ethanol blends B7 and E10 in bulk fuels, only standard fossil fuel emission factors are assumed here.

Risks for failures in future after treatment devices mainly due to higher biodiesel blends

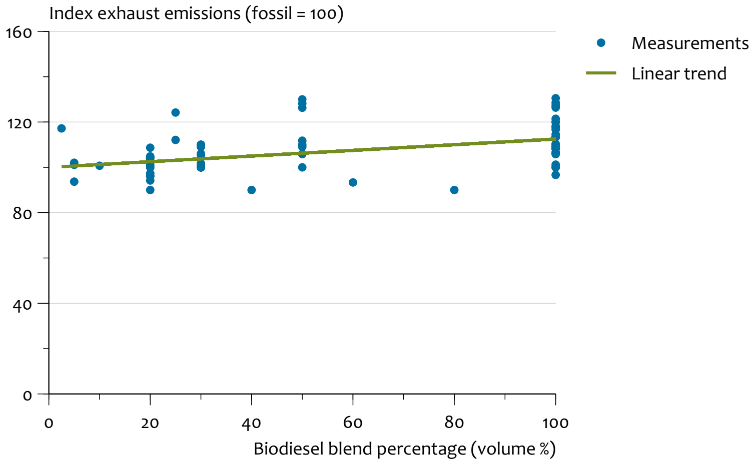
The failure factor (Figure 2.9) represents the effect of potential failures in after-treatment devices that occur due to biofuel use. Based on a literature review and a stakeholder consultation, the failure factor and the failure rate are expected for only high biodiesel blends used in dedicated heavy duty vehicles and these have been estimated. Failures of after-treatment devices are related to possible inadequate responses of catalyst and dust particulate filters due to changes in flue gas composition and/or to problems such as injector fouling and catalyst poisoning caused by impurities in biofuels. Failure factors for NO_x emissions from Euro-III to Euro-VI diesel trucks are shown in Table 2.10. For instance, if a Euro V truck faces a SCR failure due to use of a high biodiesel blends, the exhaust NO_x emissions increase from 2 to 8 g/kWh. With ethanol blends, additional failure risks in after-treatment devices are not expected to play an important role.

Expert estimates of failure frequency of after-treatment devices

Maximum failure rates for high-blend biodiesel have been estimated for Euro class III to VI trucks with after-treatment devices such as selective catalytic reduction (SCR), Dust Particulates Filter (DPF) or exhaust gas recirculation (EGR). It is assumed that 0.01% of Euro V trucks with a SCR or EGR device will fail when run on B30 biodiesel blends. The rate increases to 0.05% with B100 blends. The estimates of failure rate are based on expert views because statistical data are not available. The estimates are seen as an upper limit. To take into account the large uncertainties regarding failure rate estimates, emission factors with zero failure rates and medium failure rates (50% of the maximum estimate) have also been calculated. For natural gas or partly biogas fuelled vehicles, the LPG emission factor is used because more detailed data are not available. The assumption is that biogas used in vehicles is upgraded to natural gas quality.

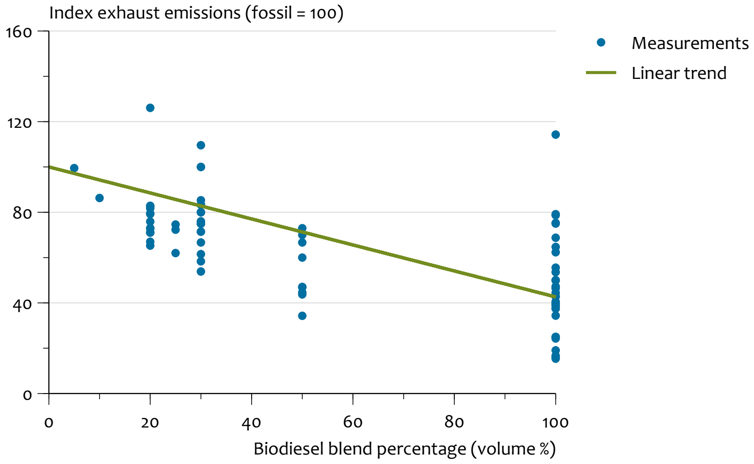
Influence from different biodiesel blends on NO$_x$ emissions from heavy-duty vehicles

Figure 2.6



Influence from different biodiesel blends on PM$_{10}$ emissions from heavy-duty vehicles

Figure 2.7



Derivation of air pollutant emission factors for bio-ethanol use in road vehicles

Figure 2.8

Emission factor bio-ethanol = Emission factor fossil fuel X Emission variation biofuel

Derivation of air pollutant emission factors for biodiesel use in road vehicles

Figure 2.9

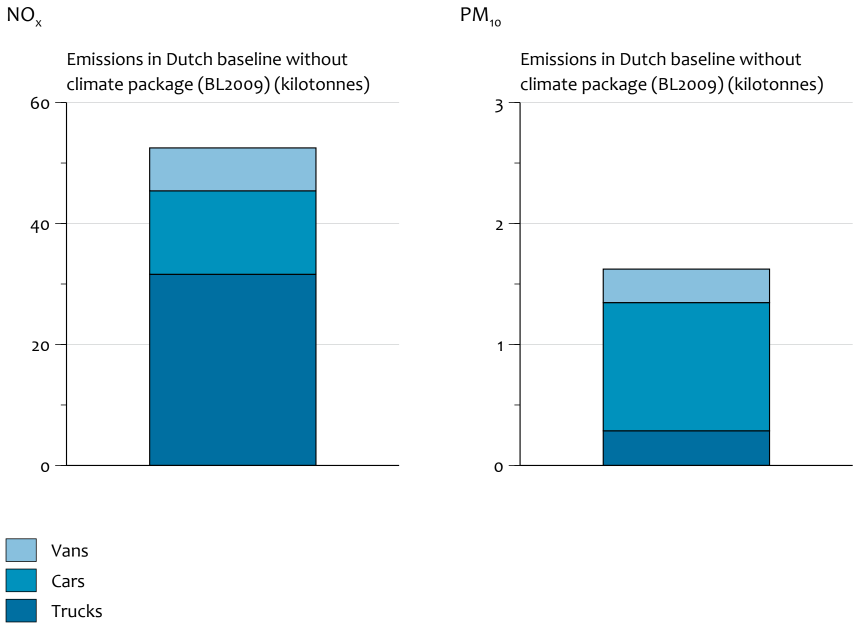
Emission factor biodiesel = Emission factor fossil fuel X Emission variation biofuel X Failure factor biodiesel X Failure rate biodiesel

Multiplying factors for NO_x emissions from trucks with failure of emission control system[1] **Table 2.10**

	Technology / failure type	NO_x limit (g/kWh)	Multiplying factor with failure
Euro III	No additional emission control	5.0	1.00
Euro IV	SCR system failure	3.5	2.27
Euro V	SCR system failure	2.0	4.00
Euro III	EGR system failure	5.0	1.25
Euro IV	EGR system failure	3.5	1.67
Euro V	EGR system failure	2.0	2.50
Euro VI	EGR + SCR + DPF		
	EGR only failure	0.4	3.40
	SCR only failure	0.4	6.67
Euro VI	SCR + DPF: SCR failure	0.4	20.0

[1] For the different engine technologies: Selective Catalytic Reduction (SCR), Exhaust Gas recirculation (EGR), Dust Particulates Filter (DPF)

Exhaust emissions from road transport in the Netherlands, by 2020 **Figure 2.10**



Co-impacts of biofuel scenarios on national projected emissions are small

The national effects on air polluting emissions of the three biofuel scenarios have been calculated with the estimates for biofuels emission factors, the amount and type of biofuels in the three biofuel mix scenarios, and additional data on projected vehicle types and their estimated performance in national reference baseline projections for 2020 (Daniels and Van der Maas, 2009). Figure 2.10 shows the baseline projections of NO_x and PM_{10} exhaust emissions from road transport in the Netherlands 2020 per vehicle category.

Compared to these baseline emissions, the estimated effects of the three biofuels scenarios (Figure 2.11) are rather small. The maximum effect is a 1 kiloton reduction in NO_x emissions and 0.03 kiloton reduction in PM_{10} emissions in the third 'local air pollution' biofuel scenario. This scenario reduces total NO_x and PM_{10} exhaust emissions from road transport by about 2% due to the substantial share of natural gas vehicles and (plug-in) electric vehicles. These estimates are based on uncertain assumptions about maximum failure rates of emission control systems due to high biodiesel blends in heavy duty vehicles. Increases in failure rates can have a substantial effect on air polluting emissions. Thus, it is recommended that these failure rates be monitored and appropriate measures taken where necessary.

Limited effects of biofuel supply chains on air polluting emissions

For a more integrated view on the effects of biofuels, polluting emissions have been estimated that occur in the biofuel supply or production chains and biogas used in road transport (Koper et al., 2009). These biofuel chain emissions are compared with the chain emissions from the fossil fuels they replace. The estimates show, for example, that domestic chains (such as biodiesel from rapeseed, biogas, ethanol from sugar beet and straw) result in higher domestic air polluting emissions than those of fossil fuels (and other biofuels such as ethanol from sugar cane, biodiesel from palm oil) which are produced mainly abroad (Table 2.11 and 2.12). The production chain of ethanol from wood results in lowest chain emissions except for SO_2 which is emitted from conversion processes

Co-impacts on exhaust emissions in scenarios to achieve EU biofuel target for 2020 **Figure 2.11**

(using sulphuric acid) for production of ligno-cellulosic ethanol from wood. The same processes also lead to lower NO$_x$ chain emissions because of the excess amount of electricity assumed to be produced from by-products in that chain.

The picture on how chain emissions from biofuel chains compare to fossil fuel chains change drastically when the total chain in and outside the Netherlands is considered (see Appendix A.2). Chain emissions from fossil fuels outside the Netherlands are substantial. The chain of Fischer-Tropsch (FT) diesel performs better than the diesel chain emissions. Chain emissions of biodiesel from rapeseed and palm oil are higher (related to their agricultural activities) than the fossil diesel chain emissions, except for SO$_2$ and NMVOC emissions. Most biofuels that could replace gasoline result in lower SO$_2$ chain emissions. Ethanol production chains result in the lowest NO$_x$ and NMVOC chain emissions. The agricultural part of the ethanol production from sugar cane and sugar beet causes relatively high NH$_3$ and NO$_x$ emissions due to fertiliser and tractor use.

Changes in supply chain emissions of 10% replacement of fossil fuels with biofuels in transport in 2020 are presented in Table 2.13 (in the three biofuels scenarios). In the Netherlands, changes in supply chain emissions of SO$_2$, NO$_x$ and NH$_3$ in the three biofuels scenarios are a few hundred ton at maximum. Most emissions tend to increase except SO$_2$, which tend to decrease except in the second biofuel scenario. In that scenario SO$_2$ is emitted in the production of lingo-cellulose ethanol from straw and wood. The same processes however, lead to lower NO$_x$ chain emissions because of the excess amount of electricity produced from by-products in that chain.

Changes in the Netherlands are relatively small compared to the total estimated chain emissions for fossil diesel and gasoline production in the Netherlands in 2020. This is because only 10% of fossil fuels are replaced by biofuels. However, if renewable energy targets for road transport increase in the future and larger amounts of high blend biofuels have to be produced, changes are more substantial in air pollutant chain emissions in and outside the Netherlands, if additional measures are not taken.

Uncertainties

The results presented include uncertainties that should be considered in using these estimates in policy development. The three biofuels scenarios for 2020, which comply with the 10% biofuel target, have been developed in order to explore their potential impact on air quality rather than to develop the realistic scenarios for the future. Future developments are expected to be somewhere in this ‘playing field’, if current policy and market conditions do not change dramatically. New impact assessments may be required for biofuels scenarios that differ substantially in the type and share of biofuels.

The study presented in this report confirms the conclusion of the previous report (Verbeek et al., 2009) that harmonised monitoring data are not available on the effect of exhaust air pollutants from biofuels in cars and trucks. The limited data for current vehicles and expert views on effects in future vehicles have been used to estimate the effects on national air polluting emissions. Based on the monitoring data and the fact that future cars need to pass type approval test while using low biofuel blends, these blends are assumed not to change exhaust emissions and that these exhaust emissions comply with the Euro standards. It remains to be seen whether this assumption holds in the future under actual conditions.

Chain emissions in the Netherlands in 2020 from biodiesel and the fossil reference

Table 2.11

	Biodiesel from rapeseed	Biodiesel from palm oil	FT diesel from wood	Biogas as transport fuel	Fossil diesel reference
Emission			**g/GJ**		
NOx	19.27	1.77	0.67	21.14	11.43
SOx	10.97	0.98	0.64	13.26	25.67
NH_3	15.39	0.01	0.00	0.23	0.04
PM_{10}	4.88	0.09	0.06	1.14	0.60
$PM_{2.5}$	1.46	0.06	0.00	0.46	1.16
NMVOC	6.29	0.63	1.13	9.71	7.26

Chain emissions in the Netherlands in 2020 from bio-ethanol and the fossil reference

Table 2.12

	Ethanol from sugar cane	Ethanol from sugar beet	Ethanol from straw	Ethanol from wood	Fossil gasoline reference
Emission			**g/GJ**		
NO_x	0.181	56.11	10.61	-13.92	13.474
SO_2	0.094	49.63	66.00	48.33	35.456
NH_3	0.003	6.79	25.17	-0.58	0.041
PM_{10}	0.013	8.97	6.24	-0.08	0.712
$PM_{2.5}$	0.011	2.88	1.56	0.98	1.408
NMVOS	0.032	41.94	13.57	4.09	7.417

Change in supply chain emissions when fossil fuels are partly replaced by biofuels in 2020[1]

Table 2.13

	Estimated chain emissions in the Netherlands from fossil fuel use in road transport[2]	Changes within the Netherlands Scenario[3]			Changes within and outside the Netherlands Scenario[3]		
		1	2	3	1	2	3
			Tonne				
NO_x	6600	-101	269	-166	519	948	502
SO_2	15800	419	-324	583	1980	1863	3236
NH_3	0	-181	-292	-103	-651	-443	-367
PM_{10}	350	-64	-62	-39	-201	-63	-69
$PM_{2.5}$	680	5	4	21	50	86	123
NMVOC	3980	-30	-20	-12	116	350	561

[1] Positive numbers refer to an emission reduction (co-benefits), negative numbers refer to an emission increase (disbenefits).
[2] For comparison, the estimated chain emissions in the Netherlands from the total fossil fuel use in road transport in 2020 are added.
[3] the numbers refer to: 1 = First generation biofuel scenario, 2 = Second generation biofuel scenario, 3 = Improved air quality scenario

Other assumptions that contribute to the uncertainty of the results presented here are the assumptions on air pollutant effects from failing individual emission control devices (due to higher blends of biodiesel use) and the occurrence of failures in the total car and truck park in 2020. Higher failure rates could result especially in increased effects on national air polluting emissions.

2.3 CCS in power generation and industry

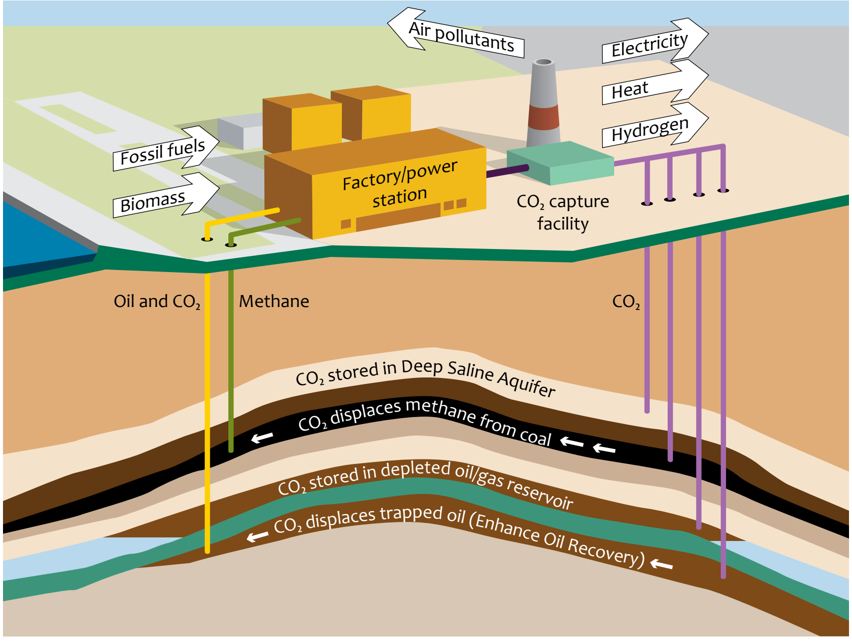
CCS application in the Netherlands in 2020 limited and more substantial in 2050

This section focuses on the air pollution effects of increased use of CCS in power and heat generation and in industry (Van Horssen et al., 2009). CCS consists of the capture of CO_2 from power plants and CO_2 intensive industries such as refineries, cement, iron and steel, the transport to a storage site and injection into a suitable underground geological formation for permanent storage (Figure 2.12). Technology for large-scale CO_2 capture is commercially available for some industrial processes such as ammonia production and is fairly well developed. However, no large-scale power plants are operating with a full CCS system. By 2020, the Netherlands is expected to have a few CCS pilot projects.

Recently, the European Commission approved a grant for a CCS pilot project in the Netherlands (EC, 2009b). The project in Rotterdam covers a demonstration of the full chain of CCS on a coal-fired capacity of 250 MW_{th} using post-combustion technology. The captured CO_2 is to be stored in a depleted offshore gasfield near the plant. The project is to be carried out by E.ON Benelux and Electrabel. This and other pilot projects are estimated to capture a few megaton of CO_2 by 2020.

To estimate the effects on CO_2 and air polluting emissions of large-scale application of CCS, a set of scenarios have been developed for 2020 and 2050 for the Dutch power sector. Options for CCS application in Dutch industry had

CO_2 capture and storage **Figure 2.12**



Source: Adapted from www.co2captureproject.org

been examined individually because there are only a few relevant industries. For 2020, low and high scenarios for the power sector have been constructed where large scale CCS is installed at two and four newly build coal fired power plants, respectively. Both scenarios include one CCS unit on a coal - integrated gasification combine cycle - power plant (IGCC) and the other units are installed on pulverised coal-fired power plants. The amount of CO_2 avoided in the low and high scenarios in 2020 is 12 and 24 MT CO_2 respectively (Figure 2.13). The avoided CO_2 is substantially lower (20-30%) than the captured CO_2 because of the extra fuel needed in to run the capture process, which partly off-sets the captured CO_2.

Scenarios for large-scale application of CCS in 2050 in the Netherlands

CCS is a climate mitigation option to reduce CO_2 emissions in the power and industrial sectors in the longer term (Section 1.2). The MARKAL energy system model (Broek et al., 2009) shows that with CO_2 reduction targets of 50% in 2050 compared to 1990, CCS will be part of a cost-optimised technology package in the future power and heat sector in the Netherlands (Figure 2.14). This model has been used to assemble three scenarios to assess the potential effects on air pollution of large-scale CCS application. The business-as-usual (BAU) scenario has no CO_2 reduction targets and the Postponed Action (PA) and the Direct Action (DA) scenarios have 50% CO_2 reduction target in 2050 on 1990 levels. Electricity demand is assumed to increase by 0.8% per year between 2020 and 2050. In the DA scenarios, action is taken directly (in 2010) whereas actions are delayed until 2020 in the PA scenario.

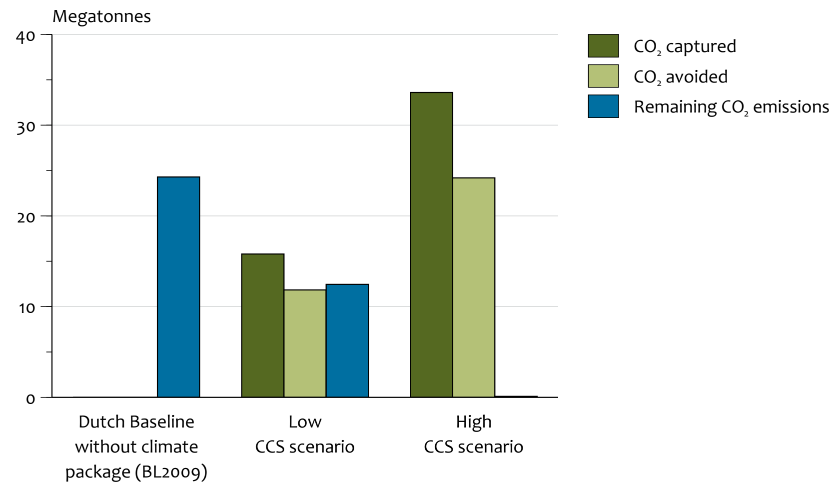
In the BAU, a large share of the sector is represented by pulverised coal (PC) power plants without CO_2 capture. In 2030, some older PC power plants will still be in operation. In the reduction scenarios, the PC power plants have disappeared and are substituted by IGCC power plants with CCS and gas-fired power plants (NGCCs) without CCS. Between 2030 and 2050, the increased demand is met by coal gasification power plants (IGCC) with CO_2 capture and also part of the gas-fired capacity is replaced by coal-fired capacity (IGCC with CCS). The two CCS scenarios show that if response to future CO2 targets is delayed (postponed action), more existing pulverised coal power plants have to be equipped with CCS instead of more new IGCC plants with CCS (direct action). Two more scenarios are presented by Van Horssen et al. (2009) which are used to assess the effects of CCS on natural gas power plants and of oxyfuel concepts on all types of power plants (for further information, see Van Horssen et al. (2009) .

Key parameters for economic and environmental performance of CCS updated

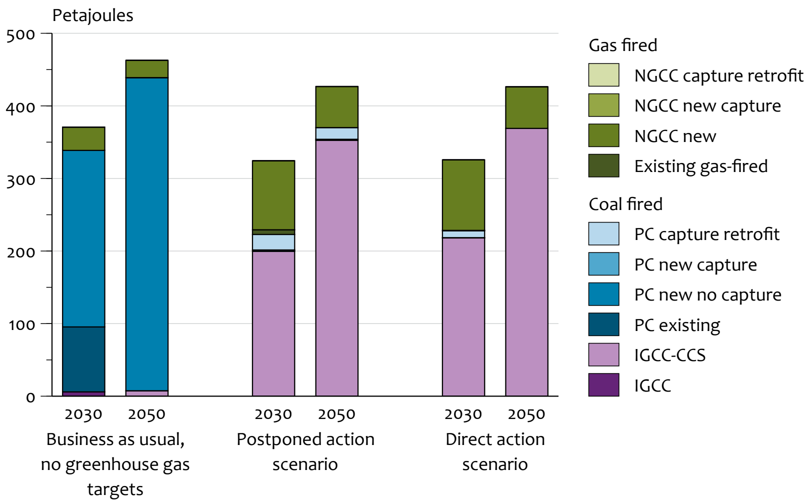
The extensive literature review on emission effects of various carbon capture technologies in the Dutch Research Programme by Harmelen et al. (2008) has been recently updated in Van Horssen et al. (2009). Key parameter values on economic and environmental performance of CCS in power and industry were standardised using parameter values representing the Dutch situation. Standardisation allows direct comparison of data from various studies, and has resulted in more robust estimates of environmental and cost performance of power plants with CO_2 capture. The new key parameter values for CCS technologies in power generation are given in Table 2.14.

An important finding is that SO_2 emission factors from coal power plants with CO_2 capture are much lower than indicated in Harmelen et al. (2008). This is mainly because the average sulphur content in the Dutch coal mix is considerably lower than previously estimated. The range of SO_2 emission factors reported by various studies is also narrower after parameter

Effects from CCS scenarios on CO_2 emissions from four new coal fired power plants, by 2020 **Figure 2.13**



Effect from CCS scenarios on electricity production, 2030 – 2050 **Figure 2.14**



NGCC = Natural Gas Combined Cycle power plant
PC = Pulverised Coal power plant
IGCC= Integrated Combined Cycle power plant (coal gasification)

standardisation. All CO_2 capture technologies result in a significant reduction of SO_2 emissions.

Standardisation of parameters to assess changes in NO_x emission factors was too complex because of the large number of factors affecting the end-of-pipe NO_x emission levels. Available data from various studies indicate that in facilities equipped with pre- and post-combustion capture, NO_x emissions increase per kWh almost proportionally with the increase in primary energy demand. This is due to the energy penalty induced by CO_2 capture. In general, NO_x emission factors from oxyfuel concepts are expected to be very low, particularly for gas fired concepts.

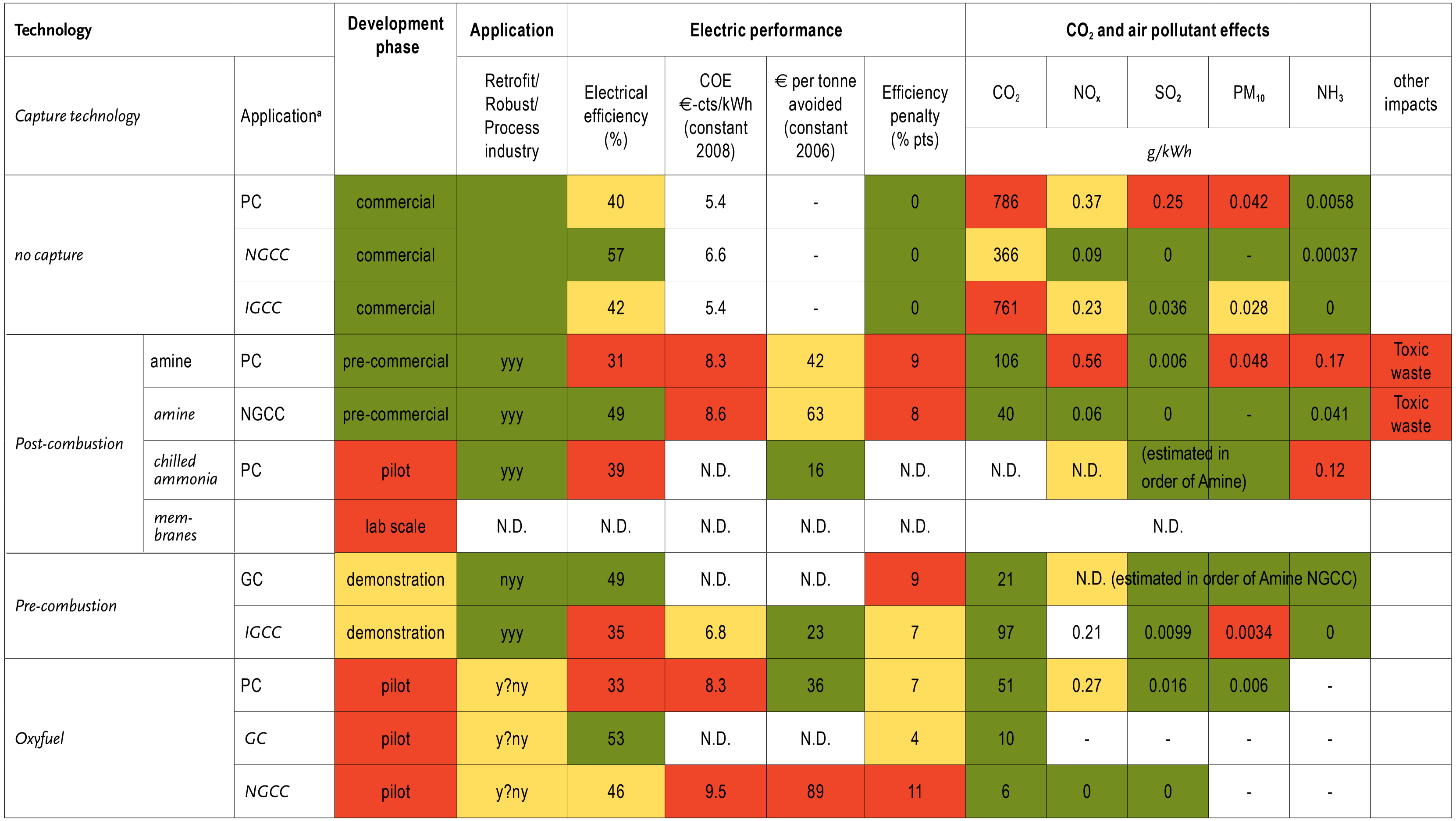
NH_3 emission factors are estimated to increase significantly with post-combustion capture by a factor of 10 to 25 compared to coal-fired power plants without capture. These emissions are caused by the slip of ammonia in the chilled ammonia concept, or by degradation of an amine-based solvent that may be used in post-combustion capture. Particulate Matter (PM_{10}) emissions may increase slightly because of the efficiency penalty in post-combustion and IGCC concepts. Whether and to what extent NMVOC emissions are affected by CO_2 capture technologies is largely unknown.

CCS with coal gasification may be the cheaper CCS option

Van Horssen et al. (2009) shows that coal gasification (IGCC) with pre combustion capture may have the lowest CO_2 avoidance cost ranging between 18 and 27 euro/tonne CO_2 avoided. This is followed by post-combustion capture and oxyfuel capture from coal power plants. Absolute costs for some CO_2 capture routes have decreased after parameter standardisation. The influential parameters are annual operation time, economic lifetime of a plant, and interest rate. Cost estimates in most studies are calculated

Emission factors of CO_2 capture technologies for power generation in the Netherlands[1]

Table 2.14



Technology			Development phase	Application	Electric performance				CO_2 and air pollutant effects					
Capture technology		Application[a]		Retrofit/ Robust/ Process industry	Electrical efficiency (%)	COE €-cts/kWh (constant 2008)	€ per tonne avoided (constant 2006)	Efficiency penalty (% pts)	CO_2	NO_x	SO_2	PM_{10}	NH_3	other impacts
									g/kWh					
no capture		PC	commercial		40	5.4	-	0	786	0.37	0.25	0.042	0.0058	
		NGCC	commercial		57	6.6	-	0	366	0.09	0	-	0.00037	
		IGCC	commercial		42	5.4	-	0	761	0.23	0.036	0.028	0	
Post-combustion	amine	PC	pre-commercial	yyy	31	8.3	42	9	106	0.56	0.006	0.048	0.17	Toxic waste
	amine	NGCC	pre-commercial	yyy	49	8.6	63	8	40	0.06	0	-	0.041	Toxic waste
	chilled ammonia	PC	pilot	yyy	39	N.D.	16	N.D.	N.D.	N.D.	(estimated in order of Amine)		0.12	
	mem-branes		lab scale	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.					
Pre-combustion		GC	demonstration	nyy	49	N.D.	N.D.	9	21	N.D. (estimated in order of Amine NGCC)				
		IGCC	demonstration	yyy	35	6.8	23	7	97	0.21	0.0099	0.0034	0	
Oxyfuel		PC	pilot	y?ny	33	8.3	36	7	51	0.27	0.016	0.006	-	
		GC	pilot	y?ny	53	N.D.	N.D.	4	10	-	-	-	-	
		NGCC	pilot	y?ny	46	9.5	89	11	6	0	0	-	-	

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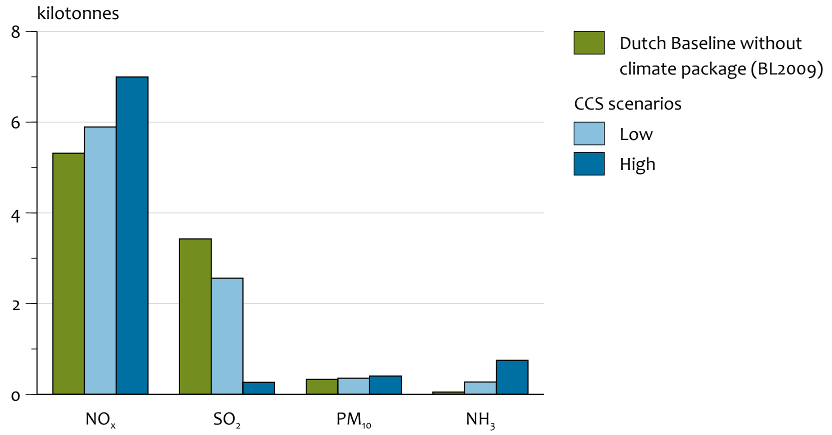
[1] The overview also shows the development phase, area of application, economic performance compared to reference technologies without carbon capture. Green is better than average, yellow is average and red indicates worse than average. PC = pulverised coal, NGCC = natural gas combined cycle, IGCC = integrated gasification combined cycle, GC = gas cycle, n.a. = not available (Source: Horssen et al., 2009; Harmelen et al., 2008).

Effects from CCS scenarios on air pollutants from four new coal fired power plants, by 2020 **Figure 2.15**



on an assumption that the technology is mature. The results presented, therefore, do not mean that IGCC with pre-combustion CO_2 capture would be the cheapest technology in the short to mid-term future. "First-of-a-kind" plants are likely to be significantly more expensive than indicated by the results presented in this report. Moreover, the costs presented in this study do not include CO_2 transport and storage that may add a further 5 to 10 euros/t CO_2 avoided. This will depend on the amount of CO_2, availability at nearby storage sites, and the maturity of CO_2 transport infrastructure.

CCS in 2020: higher NO_x, NH_3 and PM_{10} emissions, lower SO_2 emissions

Using the updated emissions factors (Figure 2.14) and the two Dutch scenarios for 2020, the effects on national air polluting emissions of CCS have been estimated. The results (Figure 2.15) show that CO_2 capture increases NO_x, NH_3 and PM_{10} emissions without additional measures. NO_x and PM_{10} emissions increase because of the additional energy consumption of the CO_2 capture units.

NH_3 is emitted as a result of degradation of CO_2 solvents (amines). Research is ongoing on ways to reduce solvents degradation and thus also emissions from solvents. With improved solvent technology, NH_3 emissions can be strongly reduced. Other standard NO_x and NH_3 emission reduction measures are available to abate the estimated increases (Appendix A.1). Van Horssen et al. (2009) estimate that the additional costs of those measures are relatively small compared to the cost of the currently obligatory air pollution mitigation measures for Dutch power plants.

The analysis further shows that SO_2 emissions decrease dramatically. As previously described, SO_2 concentrations in flue gases have to be reduced before CO_2 capture can take place because of the reaction of SO_2 with the amine solvent. Van Horssen et al. (2009) calculate that the costs of this extra SO_2 reduction prior to the capture is less than 0.5 euros per tonne of CO_2 which is less than 1% of the total CO_2 capture costs.

CCS in 2050: major reductions in CO_2 and air-polluting emissions possible

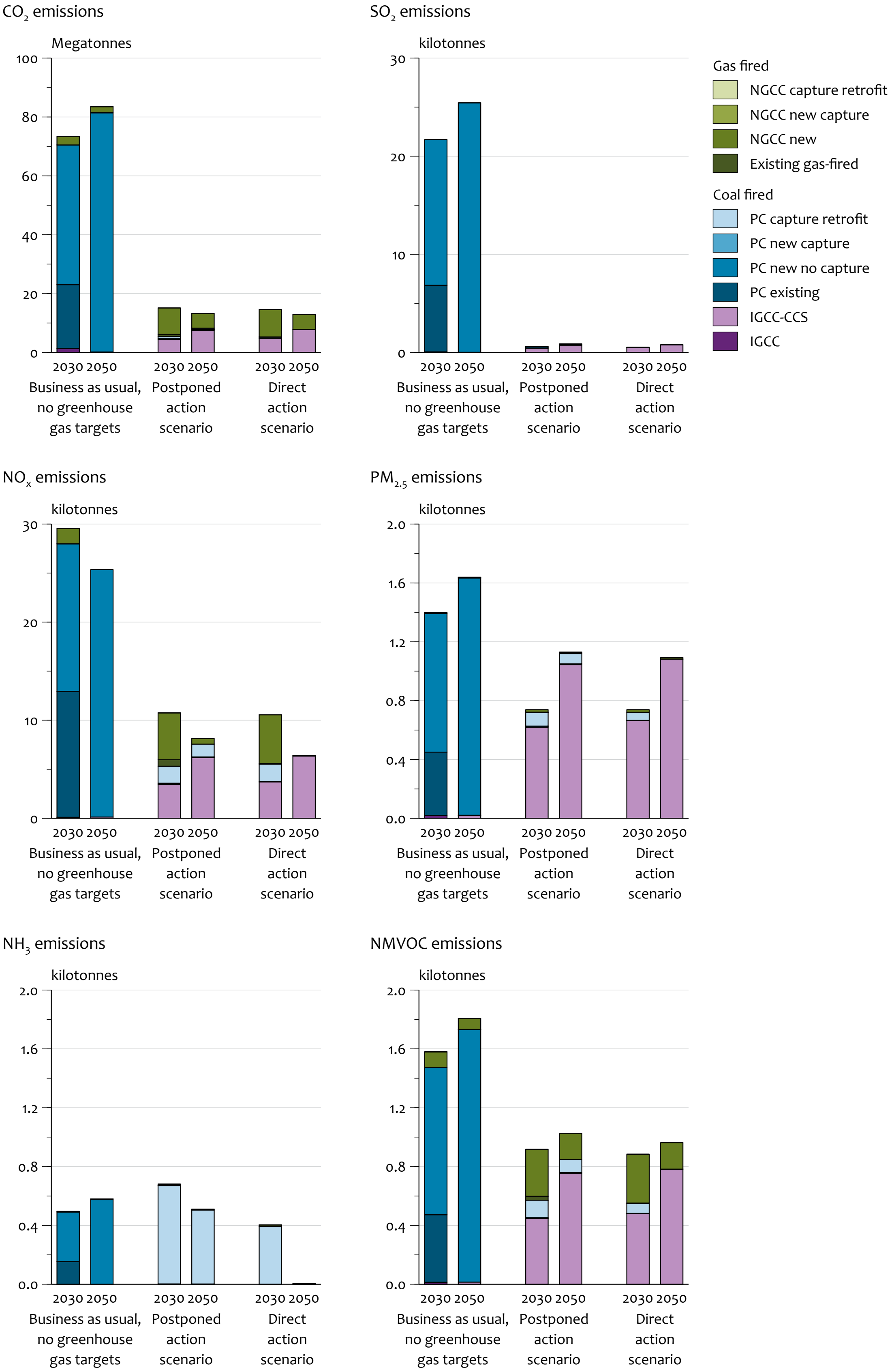
CCS scenarios for 2030 and 2050 estimate substantial reductions in emissions of CO_2 (>80%), SO_2 (>90%), NO_x (>65%), NMVOC (>40%) and particulate matter (>30%) compared to the Business-As-Usual (BAU) scenario (without CO_2 targets), see Figure 2.16. This is mainly caused by substitution of pulverised coal power plants without CCS in the BAU scenario by IGCC power plants with CCS and NGCCs without CCS. SO_2 emissions are estimated to decrease the most. NO_x emissions do not decrease as much because of the energy penalty from the capture units. The difference between 2030 and 2050 is mainly the result of the increase in electricity demand and hence more power plants. NH_3 emissions could increase in the 2030 and 2050 scenarios because few pulverised-coal power plants are equipped with post-combustion CO_2 capture, which are absent in the BAU scenarios. An increase in NH_3 emissions can be prevented with standard emission reduction measures (Appendix A.1). If no more pulverised-coal power plants with post-combustion capture are build (as in the direct action scenario in 2050), NH_3 emissions are reduced to almost zero.

Limited reductions of air pollutant through CCS in industry

Cost-effective CO_2 capture of about 8 Mt per year may be possible in 2020 in ammonia and hydrogen production process and especially in iron and steel plants. Amine-based CO_2 capture from industrial processes such as cement production, ethylene production and petroleum refineries were found to be relatively expensive. Table A3.1 (Appendix A.3) presents a detailed overview of key parameters such as emission factors for CO_2 capture applied to Dutch industries.

The effect of CO_2 capture in industry on air polluting emissions is expected to decrease emissions of SO_2 (a few hundred kiloton maximum) and particulate matter. NH_3 emissions are not expected to change. Changes in NO_x emissions will largely depend on the combination of blast furnace type and CO_2 capture technology that can be applied in the Dutch iron and steel plant. NO_x emissions are likely to decrease with the use of oxygen blast furnaces and to increase with conventional blast furnaces.

Effects from CCS scenarios on emissions, 2030 – 2050 **Figure 2.16**



NGCC = Natural Gas Combined Cycle power plant
PC = Pulverised Coal power plant
IGCC= Integrated Combined Cycle power plant (coal gasification)

No major risks of air pollution expected with bio-energy and CCS (BECS)

All three approaches to CCS technology under consideration for fossil fuels systems could be applied to bio-energy systems. If a power plant is optimised to use biomass for co-firing, the fuel mix is not expected to affect the performance of the CO_2 capture unit significantly. However, there is little experience as yet with the combination of the two innovative technologies of co-firing biomass and CCS.

Another issue is that co-firing biomass reduces the efficiency of a (coal) power plant by 0 to 10% on average due to the lower energy content of biomass. This efficiency loss combined with the energy loss due to energy consumption (penalty) of the CO_2 capture process constitutes the main drawback to co-firing biomass in combination with CCS. To generate the same electrical and/or heat output as a standard coal power plant, a plant equipped with BECS must have a larger design. With regard to air polluting emissions, co-firing biomass with coal is expected to reduce SO_2 emissions compared to pure coal firing. Changes in emission of the other air pollutants are less significant.

Uncertainties

The many technological, economic and legal barriers constitute uncertainties about the timing and extent of future application of CSS in the Netherlands and other countries. Large-scale application in the Netherlands is not very realistic before 2020. Thus, any substantial effects on national air polluting emissions from this technology may only be expected in the longer term. The uncertainty regarding the emission factors used in this study is high. They are based on limited monitoring data and desk top (model) studies. Even though the available emission data have been harmonised, uncertainties still persist. Variables causing uncertainty that have not been controlled for all substances in this study include the technical configuration and performance of a power plant, the CO_2 capture technology, and the exact fuel composition.

The emission factors from current studies (mainly up to 2030) have also been used in this study to estimate air polluting emissions in 2050. This brings large uncertainties. In this long time horizon, new conversion and CO_2 capture technologies may emerge that could not be taken into account here. For example, research and development is ongoing to find more stable and energy efficient CO_2 solvents. This may lead to more favourable effects on NO_x and NH_3 emissions. The emission factors presented in the scenario studies for 2020 and 2050 should are considered to be conservative, in this respect.

2.4 Integrating new insights into option descriptions

New information on the effects on air polluting emissions of the application of biofuels in transport, bio-energy in stationary installations and CCS has been presented in Section 2.1 to 2.3. The relevant information has been used by ECN to update the Dutch Options Document (see also Section 1.4). An overview of the updated options, their potential effects on GHGs and air pollutants and the associated costs are listed in Appendix A.4.

Seven new options for bio-energy in small to large installations

Based on the study on bio-energy in stationary installations (Section 2.1), seven options were updated. The largest adjustments were made to emission factors for stand-alone, medium-scale biomass combustion. Air polluting emission factors for these types of installations increase because of the higher emission factors of the small-scale installations and the lower efficiency compared to fossil-fired power plants. Substituting part of the coal with co-firing biomass lowers SO_2 and particulate matter emissions.

Green gas options (biogas) and synthetic natural gas options were updated with respect to potential and air polluting emissions. For all processes generating green gas or synthetic natural gas, air polluting emissions are observed to increase. For manure digestion, sewer gas and landfill gas production, a reduction in methane emissions is observed.

Two options for reducing PM_{10} emissions from residential wood-burning stoves and open fire places were formulated based on information from Boersma et al., 2009, namely replacing stoves with new certified stoves, and use of dust filters (Electros Static Precipitation filter-ESP). Both options substantially reduce dust emissions but stove replacement also substantially reduces NMVOC emissions and some NO_x emissions. Moreover, newer and certified stoves are more energy efficiency, thus reducing fuel use.

Three new options for biofuels in road transport

Based on the study on biofuels in road transport (Section 2.2), three biofuel options for road transport have been formulated based on the three different scenarios that cover specific mixes of biofuels and electric vehicles. All options show a small increase in SO_2 emissions which result from the additional electricity consumption by electric vehicles. This has to be generated by the average power plant park mix, which consists mainly of both coal and gas-fired power plants. NO_x and particulate matter emissions increase as well due to electricity consumption but are counterbalanced by decreasing (exhaust) emissions from conventional fuels and biofuels. The second generation biofuel option shows the best air pollutant performance because NO_x emissions decrease somewhat in this scenario.

Ten new options for CCS in power and industry

Based on the study on CCS in power and industry (Section 2.3), several CCS options were updated or formulated: four options for CCS in coal-fired power plants, four options for CCS in CO_2 pure streams in the oil and chemical industry and three options in CO_2 diluted streams in the industry. In the options CCS in coal-fired power plants SO_2 emissions decrease. NO_x emissions increase because of the additional fuel required for running the CO_2 capture unit. NH_3 emissions are enhanced with CCS at pulverised coal plants because of the amine degradation (ammonia slip).

Pure CO_2 streams contain virtually no contaminants and therefore no direct NEC effects are associated with these options. For diluted CO_2 streams, contaminants may have to be removed prior to CO_2 capture, thereby decreasing NEC emissions. Since CO_2 sources may vary, NEC effects are not always known in advance. For CO_2 capture in the iron and steel industry, reduction potential for the SO_2 emissions has been estimated. For many CCS options in industry, extra electricity consumption has been assumed to run the CCS process, which may substantially increase NEC emissions of the power sector.

Notes

1 The target of 14% has been calculated by the European Commission using a definition based on final energy. With the definition based on primary energy, the European Commission's renewable target for the Netherlands would be several percent points higher (Van Dril et al., 2009).

2 The baseline energy projections in Daniels and Van der Maas (2009) show that in 2020 about 490 PJ coal and 651 PJ natural gas use in large-scale power and heat generation.

3 ED95 is ethanol diesel that is expected to be used in a very small niche market of HD vehicles. The fuel contains about 93% ethanol, ignition improver and water. It is used in specially developed engines that generally comply with the EEV emissions level (Euro V with somewhat reduced particulate matter emission standard). Emission factors are assumed to be the same as for standard diesel vehicles.

3

Analysis of co-impacts of climate policy packages on air polluting emissions

The estimated co-impacts of the European and national climate and energy packages on baseline projections for energy and GHGs are presented in Section 3.1 and air polluting emissions in Section 3.2. The estimates are based on European analysis, and on the Dutch analysis which includes the new insights described in Chapter 2. Because the current Dutch implementation of the climate and energy package delivers only part of the necessary GHG reductions, energy savings and share of renewable, an additional analysis was carried out. This comprises cost-effective policy packages that meet European or Dutch climate and energy targets. These target packages and the resulting effects on air pollutants are presented in Section 3.3.

3.1 Impacts of climate policies on energy and greenhouse gas emissions

The GAINS-PRIMES baselines for the Netherlands

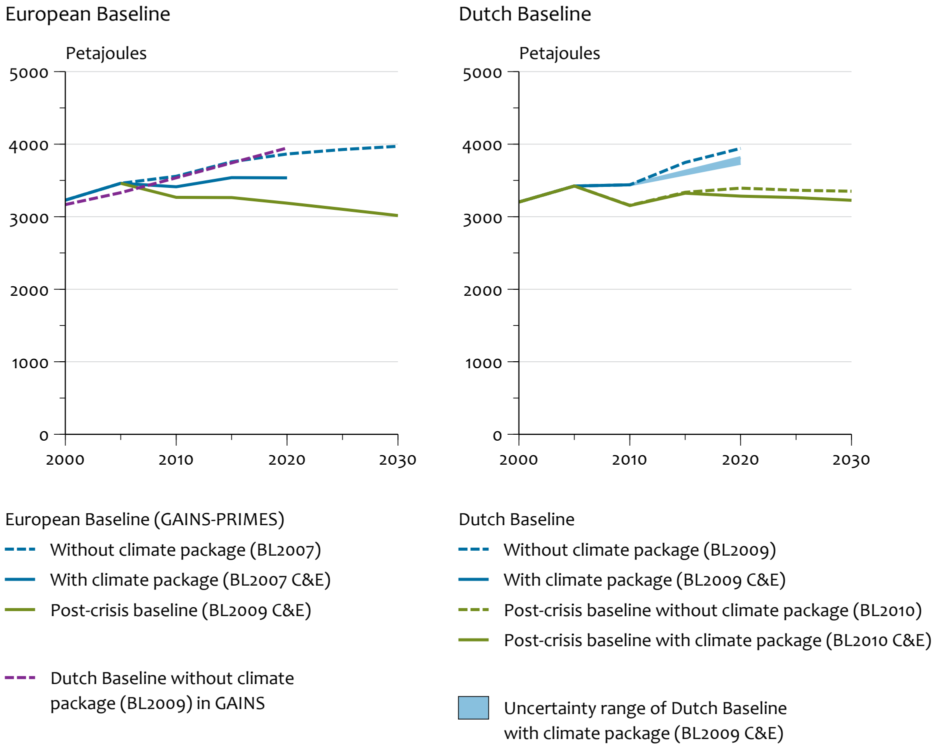
The methodology used by UNECE and the European Commission to revise the national emissions ceilings in baseline projections for 2020 for energy use and agriculture activities is presented in Section 1.4. The energy baselines are the main determinant factor for the baseline levels of GHGs and air pollutants calculated with the GAINS model (Section 1.4). At the start of the revision of the Gothenburg protocol in 2007, UNECE proposed an initial European energy baseline for all the 27 Member States based on the 2007 PRIMES energy system model (CIAM, 2008). Agricultural activities were based on national baselines.
One of the PRIMES energy baselines included preliminary implementation of the European climate and energy package (C&E) as of January 2008. This baseline is referred to in this report as GAINS-PRIMES BL2007-C&E. The other baseline without this package is referred to as GAINS-PRIMES BL2007. The key parameters of these and other baselines available in the GAINS online model are presented in Table 3.1 together with various PRIMES data sources (Capros et al., 2008a, b). The assumptions on energy efficiency improvements, aggregated on a national level in the 2007 scenarios by PRIMES are not publicly available and could not be compared with the Dutch assumptions.

The 2007 baseline with C&E shows a reduction in primary energy use of about 8% (328 PJ) in 2020 on the 2007 baseline without C&E (Figure 3.1-left). The reduction in GHG emissions due to C&E is about 13% in 2020 (Figure 3.2-left). The two GAINS-PRIMES baselines with and without C&E enable assessment of the co-benefits for air pollution reduction (see Section 3.2). Figure 3.1 (left) also shows the Dutch energy baseline projection from 2009 (Daniels and van der Maas, 2009) that was integrated into the GAINS model in 2009 (GAINS-NAT BL2009). This Dutch baseline assumes limited C&E policies (to meet the Kyoto targets) and shows a similar increase in primary energy use as the GAINS-PRIMES BL2007 (without the EU climate and energy package). The resulting GHG emissions differ little between these two baselines (Figure 3.2-left). This Dutch scenario is described in more detail under Dutch baselines.

In February 2010, UNECE proposed to use an updated version of the PRIMES baselines (from December 2009) as the central energy baseline in the revision, and new baselines for agricultural activities based on the CAPRI model (Maas, 2010). The new PRIMES energy baseline included new post-crisis assumptions on economic growth and updates for the implementation of European climate, energy and air pollution legislation. Some policies from the Directives on Renewable Energy, End-Use Energy Efficiency and Energy Services, Fuel Quality, and the Large Combustion Plant directive could not be included fully in the baseline because Member States are still working on the national implementation of the Directives (Klaassen, 2009). A preliminary version of the baseline (dated August 2009) is publicly available through GAINS online (IIASA, 2010) and is referred to here as GAINS-PRIMES BL2009 C&E.

The lower economic growth (and lower projected levels of activity) and the more stringent climate and energy policies (Table 3.1) decrease substantially primary energy use (Figure 3.1-left) and GHG emissions (Figure 3.2-left). This baseline almost reaches the indicated GHG target of the European Union. This target includes the EU target for the Dutch non-ETS sector of 22% (compared to 1990 levels) and also assumes a reduction in the Dutch ETS sector equal to the

Primary energy use Figure 3.1



Key parameters of the GAINS-PRIMES energy baselines for 2020 Table 3.1

	GAINS-PRIMES			GAINS-NAT
	BL2007	**BL2007 C&E**	**BL2009 C&E**	**BL2009**
GDP growth (%/2005-2020)	2.1	2.1	1.4	2.9
Population growth (%/2005-2020)	0.36	0.36	0.24	0.41
Oil price (€'05/boe in 2020)[1]	61	61	59	61
CO_2 price (€'05/ton in 2020)	0	22	19	35
Renewable (% in 2020)	3.5	6.9	10,9	5
Biofuels (% in 2020)	5.5	7.5	8.9	4
Energy efficiency (%/2005-2020)			1.99	0.9
CO_2 reduction 1990-2020 (CO2 eq)[2]	-17.5	<1	18	-18

[1] boe= barrel of oil equivalent
[2] Red colour means an increase

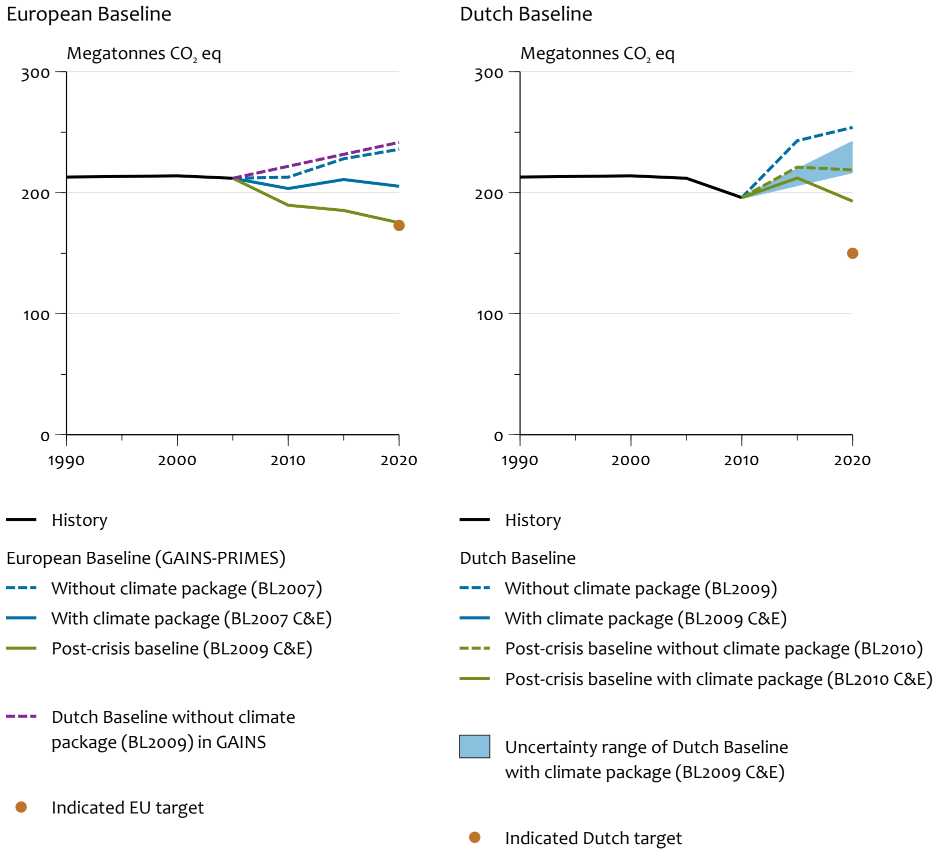
EU-wide EU-ETS target of 14% reduction (compared to 1990 levels).

Dutch baselines

In 2008 and 2009, a new baseline was made for energy use and GHGs in the Netherlands (Daniels and Van der Maas, 2009). This pre-crisis 2009 energy baseline (referred here as Dutch BL2009) assumes relatively high economic growth and includes the limited climate and energy measures implemented as of December 2008 (Table 3.2). In addition to this baseline, the additional effects on energy use and GHGs from the envisaged policies in the Dutch climate programme Clean and Efficient (Section 1.2) have been assessed (Van Dril, 2009). This is called here the envisaged climate package. The assessment was carried out using a range in assumptions on CO_2 prices (20 to 50 euros), biofuel shares (10-20%) and the effectiveness of European and Dutch climate and energy policy instruments (high and low effectiveness). The high CO_2 price and the highly effective policy instruments are included in the High estimate and the low CO_2 price and the less effective policy instruments in the Low estimate.

The assessment showed that when the envisaged climate package (Section 1.2) is taken into account (see Dutch BL2009 C&E and its range), the shares of biofuels and energy efficiency improvement could increase substantially (Table 3.2). The package leads to a net lower primary energy use (127-206 PJ; Figure 3.1-right) and GHG emissions (Figure 3.2-right). The envisaged climate package results in moderate GHG reductions, between 13 and 36 Mt CO2 eq in 2020 (Figure 3.3). Most of the reductions in the high estimate (C&E-H) are achieved with CCS (10 Mt), energy savings (~15 Mt including tighter CO_2 standards for passenger cars) and biofuels in road transport (5 Mt). In the low estimate (C&E-L) 70% of reductions are achieved with energy savings (Figure 3.3). According to the Options Document (Section 1.4), the costs of the envisaged climate and energy policies are between 2 and 6 billion euros per year (in euros at 2000).

Greenhouse gas emissions **Figure 3.2**



Key parameters of the Dutch energy baselines for 2020 **Table 3.2**

	Dutch baselines			
	BL2009	**BL2009 C&E (low – high)**	**BL2010**	**BL2010 C&E**
GDP growth (%/2005-2020)	2.9	2.9	1,6	1.6
Population growth (%/2005-2020)	0.41	0.41	0.3	0.3
Oil price (€'05/boe in 2020)[1]	61	61	67	67
CO_2 price (€'05/ton in 2020)	35	20-50	19	19
Renewable (% in 2020)	5	5.8-7.3	6.3	15.5
Biofuels (% in 2020)	4	8-20	8.5	8.5
Energy efficiency (%/2005-2020)	0.9	1.4-1.6	1.4	1.5
CO_2 reduction 1990-2020 (% CO2 eq)[2]	-19	-13 to -2	-3	9.5

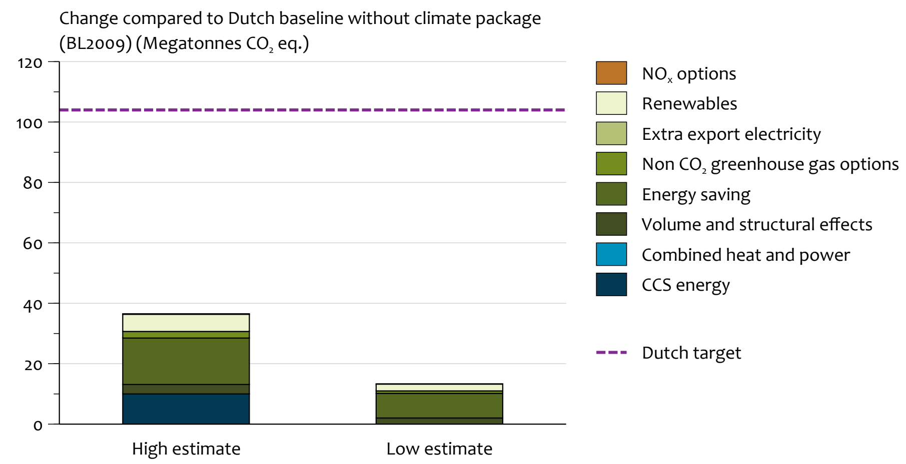
[1] boe= barrel of oil equivalent
[2] Red colour means an increase

This 2009 baseline with the envisaged climate package does not meet the Dutch targets for 2020 for reduction of GHG emissions (150 Mt CO_2 eq), energy savings (2%/year) and renewable energy (20% share). It also does not meet the European targets of 20% reduction in GHG emissions (172 Mt CO_2 eq) and 14% renewable energy. The effects on air pollutants from cost-optimal climate packages that meet all the European and Dutch targets are presented in Section 3.3.

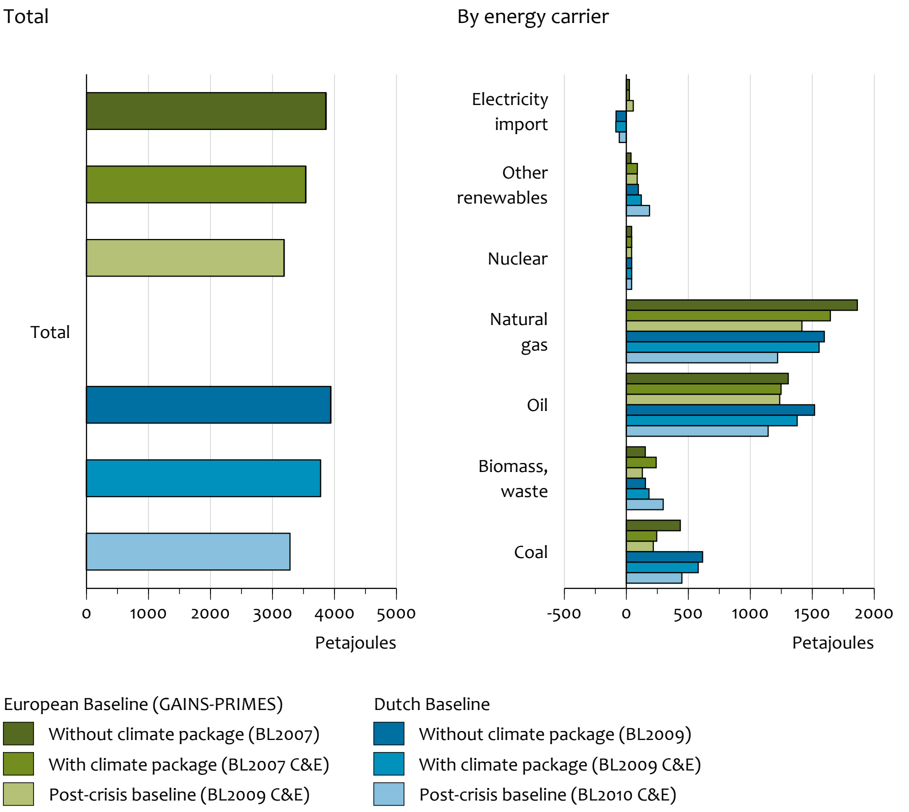
The Dutch pre-crisis baseline assumes somewhat higher economic growth than that of the GAINS-PRIMES 2007, and thus estimates more energy consumption and higher GHG emissions (Figure 3.2). The maximum change in GHG emission reductions from the envisaged climate packages are about the same in both baselines. However, with the lower assumptions in the Dutch baseline for the CO_2 price and the efficacy of the climate and energy policies, GHG emission reductions and co-benefits for air quality are substantially lower (Figure 3.3).

Recently, new Dutch baselines have been constructed for energy use, GHGs and air pollutant emissions in the Netherlands. The update was made because of the expected substantial effects of the economic crisis and the latest developments in current and envisaged climate and energy policies (Daniels and Kruitwagen, 2010). The post-crisis 2010 energy baseline (Dutch BL2010) assumes relatively moderate economic growth and includes more climate and energy

Reduction of greenhouse gas emissions by Dutch climate package, 2020 **Figure 3.3**



Primary energy use, 2020 **Figure 3.4**



measures implemented than the 2009 baseline (Dutch BL2009; Table 3.2). This leads to lower primary energy use (Figure 3.1-right) and GHG emissions (Figure 3.2-right).

When the envisaged climate package 'Clean and Efficient' (Section 1.2) is taken into account (see Dutch BL 2010 C&E), the share of renewable energy (mainly bio-energy in small and large installations and wind on sea and land) is estimated to increase substantially (Daniels and Kruitwagen, 2010). The new baseline does not expect substantial application of CCS in 2020 and a maximum share of only 10% biofuels in total road transport fuel consumption. Also, the 2010 baseline with envisaged measures of the Dutch climate programme does not meet the Dutch target for GHG emission reductions in 2020 (150 Mt CO_2 eq). In the new baseline study, the co-impacts on air pollutants of the envisaged climate package have not as yet been updated.

Different assumptions on coal use and export of electricity in the baselines

To gain better insight into the differences between the GAINS-PRIMES and Dutch energy baselines, all the energy projections have been examined according to fuel type (Figure 3.4). With climate policies (extension C&E), the amount of biomass and other renewable energy increases in all the baselines, and coal, oil and natural gas decreases. With

Emissions and (co-)impacts in the GAINS-PRIMES baselines for the Netherlands, 2020

Table 3.3

	GHG	SO_2	NO_x	NH_3	$PM_{2.5}$	PM_{10}	NMVOC
	Mt	Kiloton					
GAINS-PRIMES BL2009 C&E	175	33	166	130	16	37	156
GAINS-PRIMES BL2007	236	50	196	130	18	40	161
GAINS-PRIMES BL2007 C&E	205	45	178	130	18	39	161
(Co-)impacts BL2007 C&E [1]	31	5.5	18.4	0.1	0.1	0.9	0.3

[1] Positive number refers to emission reductions (co-benefits) and negative numbers to emission increases (disbenefits).

Emissions and co-impacts in the Dutch baselines, 2020[1]

Table 3.4

	GHG	NO_x	SO_2	NH_3	PM_{10}	NMVOC
	Mt	kiloton				
Dutch BL2009	254	199	48	129	35	165
Dutch BL2009 C&E [2]	218-242	192-195	42-47	129-132	34-35	165
Co-benefits BL2009 C&E [2]	12-36	4-7	1-6	0 to -2.5	0.4-0.6	0 to -0.1

[1] Positive number refers to emission reductions (co-benefits) and negative numbers to emission increases (disbenefits).
[2] The range covers the effects of an assumed modest and more stringent European climate policy and low and high assumptions on efficiency of national climate instruments (Van Dril, 2009).

climate and energy policies, coal and gas use is more strongly reduced in the GAINS-PRIMES baseline (BL2007 C&E). This is because most existing coal-fired power plants and a number of new gas fired plants are assumed to have been decommissioned. The coal and gas use in the Dutch baseline (BL2009 C&E) with climate and energy policies do not reduce dramatically because decommissioning is not expected to be large scale in 2020. This is also related to the assumption based on the Dutch analysis of the north-west European electricity market (Daniels, 2008; Daniels and Van der Maas, 2009) that the Netherlands will become a net exporter of electricity in 2020.

This export effect can also be expressed in terms of increased national air polluting emissions. If exported electricity is assumed to be generated by coal power plants, national NO_x and SO_2 emissions could be 5% and 18% higher respectively (~10 kiloton NO_x and ~8 kiloton SO_2) than the GAINS-PRIMES projections (which assume some import).

With regard to oil use, larger reductions are seen in the Dutch baseline (BL2009 C&E) than in the GAINS-PRIMES baseline (BL2007 C&E). This is because the Dutch baseline includes a stricter CO_2 standard for cars (95 g CO_2/km) in 2020 and a 20% share of biofuels.

3.2 Co-impacts of envisaged climate packages on air polluting emissions

GAINS-PRIMES baselines for air pollutants in the Netherlands

The pre-crisis GAINS-PRIMES 2007 baselines show significant co-benefits for national NO_x emissions (9% reduction or 18 kiloton) and SO_2 emissions (10 % reduction or 5 kiloton) from the envisaged European climate and energy policies (Table 3.3). A similar comparison for the post-crisis GAINS-PRIMES 2009 baseline is not possible because only a 2009 baseline with climate and energy policies is publicly available. However, emission levels in this post-crisis 2009 baseline are substantially lower than the 2007 baseline because of the combined effect of the assumed lower economic growth and more stringent climate and energy policies (Table 3.1). The low use of coal (Figure 3.4) leads to relatively low SO_2 emissions.

The role of baseline emissions in the revision of the national emission ceilings is very important for the Netherlands. These baselines, and their estimated effects on air quality, are the starting point in the revision. Subsequently, a number of ambition levels for an improved air quality, will be translated with the GAINS model into indicative national emission ceilings for all the countries under the GP and the NECD. That information will be used within the negotiation processes towards a new GP and NECD.

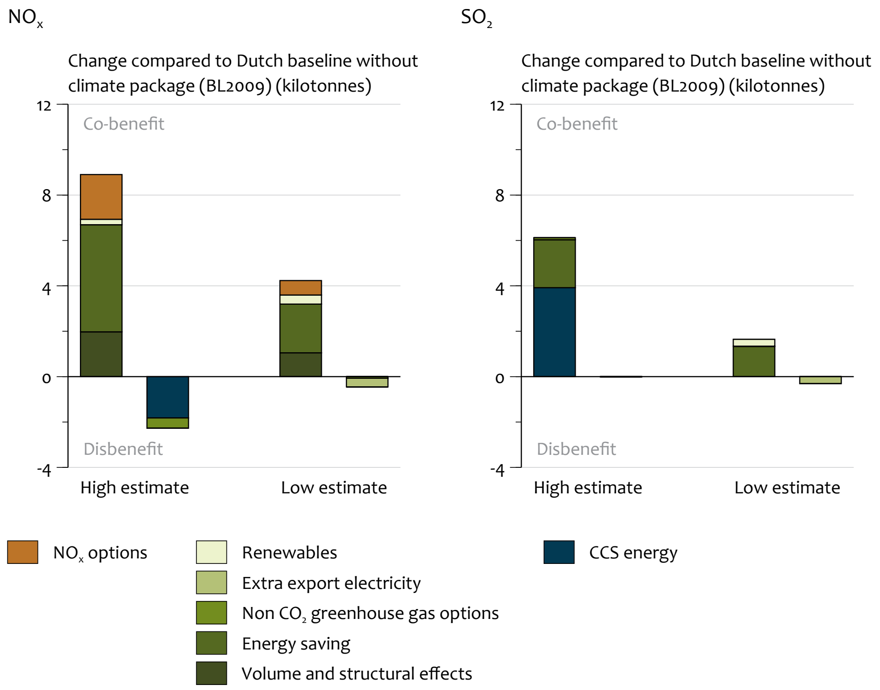
Dutch baselines for air pollutants

The pre-crisis Dutch 2009 baselines reveal limited net co-benefits for national NO_x emissions (maximum 3.5% reduction or 7 kiloton) and SO_2 emissions (maximum 12.5 % reduction or 6 kiloton) from the envisaged Dutch climate package (Table 3.4). The NO_x co-benefits are dominated by reductions from energy savings mainly in stationary energy use and volume effects mainly in transport (Figure 3.5). The co-benefits for SO_2 emissions result from energy savings, CCS in power generation and use of renewable energy (Figure 3.5). The limited co-benefits for PM_{10} result from volume effects in transport. No significant co-impacts are expected for NMVOC emissions.

Some disbenefits (emission increases) can occur under climate measures of CCS in power and the non-CO_2 GHG option being co-digestion of manure. NH_3 emissions can increase in a few options, namely CCS in power plants and biomass. However, these increases can be mitigated with the options for ammonia reduction (Section 2.1, Appendix A.1).

Co-impacts of Dutch envisaged climate package on air pollutants, by 2020

Figure 3.5



Co-impacts ratios of kiloton air pollutants reduced per megaton CO_2 reduction, 2020

Table 3.5

	GHG	NO_x	SO_2	NH_3
Co-benefits	**Mt**		**Kt**	
Dutch BL2009 C&E[1]	1	0.3-0.2	0.2-0.1	0 to -0.1
GAINS-PRIMES BL2007 C&E	1	0.6	0.2	0

[1] The range covers the effects of an assumed modest and more stringent European climate policy and low and high assumptions on efficacy of national climate instruments (Van Dril, 2009).

Co-benefits for NO_x emissions higher with the GAINS-PRIMES methodology

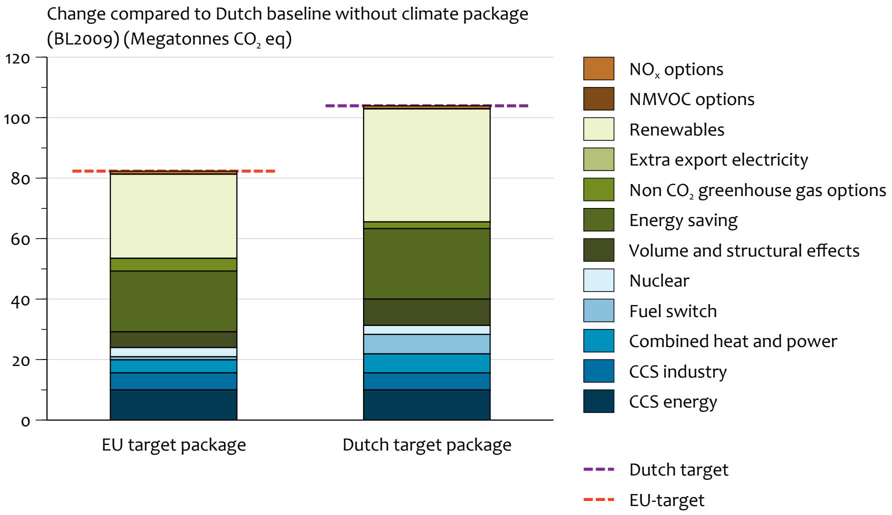
Both the GAINS-PRIMES methodology (2007) used by UNECE and the Commission, and the Dutch methodology (2009) estimate net co-benefits from envisaged climate packages, mainly for SO_2 and NO_x emissions (Table 3.3 and Table 3.4). Only the Dutch methodology estimates net disbenefits for ammonia due to extra emissions from assumed CCS application in a few coal fired power plants. A further comparison shows that the co-benefit ratios of especially NO_x (but also SO_2) emission reductions (in kiloton) per megaton CO_2 reduction are higher in the GAINS-PRIMES estimates (Table 3.5).

This difference is explained largely by the GAINS-PRIMES estimates, which assume larger decreases in coal and gas use. As explained above, most existing coal-fired power plants and a number of new gas fired plants are assumed to have been decommissioned in the GAINS-PRIMES estimates. Co-benefit ratios for NO_x and SO_2 emissions per megaton CO_2 reduction are relatively high in power generation. In the Dutch estimates (BL2009 C&E), coal and gas use do not decrease considerably because the Dutch expect an increase in electricity export towards 2020. Growth in the export of electricity results from the projected decrease in inland demand due to climate policies and the construction of new power plants (Daniels, 2008; Daniels and Van der Maas, 2009). The viability of the new power plants is explained by the competitive advantage of the Dutch (fossil) electricity sector. This is due to easy access to cheap cooling water from the North Sea, the low cost of coal supply because of the proximity to harbours, and the relatively easy access to geological CO_2 storage capacity in empty gasfields.

Another explanation for the smaller co-benefits for NO_x emissions in the Dutch estimates is the assumed application of CCS[1], which decreases the co-benefits for NO_x emissions in the Dutch estimates. CCS does contribute to the net co-benefits for SO_2 emissions. The co-benefits for SO_2 emissions do not differ greatly between the GAINS-PRIMES and Dutch estimates, but have different causes.

Yet another explanation for the smaller co-benefits for NO_x emissions in the Dutch estimates is that these estimates include larger reductions in oil use in road transport. This is due to stricter CO_2 standards (95 g CO_2 per km) in 2020 and a higher share of biofuels (20% [2]). However, both measures have little effect on emission of air pollutants (e.g., NO_x) from road transport. Tail pipe air pollutants from cars and trucks are regulated by the Euro standards.

Reduction in greenhouse gas emissions to achieve targets for 2020 **Figure 3.6**



Co-impacts of climate target packages in the Netherlands, 2020[1] **Table 3.6**

	GHG	NO_x	SO_2	NH_3	PM_{10}	NMVOC
	Mt	kiloton				
Dutch BL2009	254	199	48	129	35	165
Reductions from the European target package	82	14	10	-2.5 to 0	1	-3
Reductions from the Dutch target package	104	15	11-16	-2.5 to 0	1	-4

[1] Positive number refers to emission reductions (co-benefits) and negative numbers to emission increases (disbenefits)

3.3 Co-impacts of climate target packages on air polluting emissions

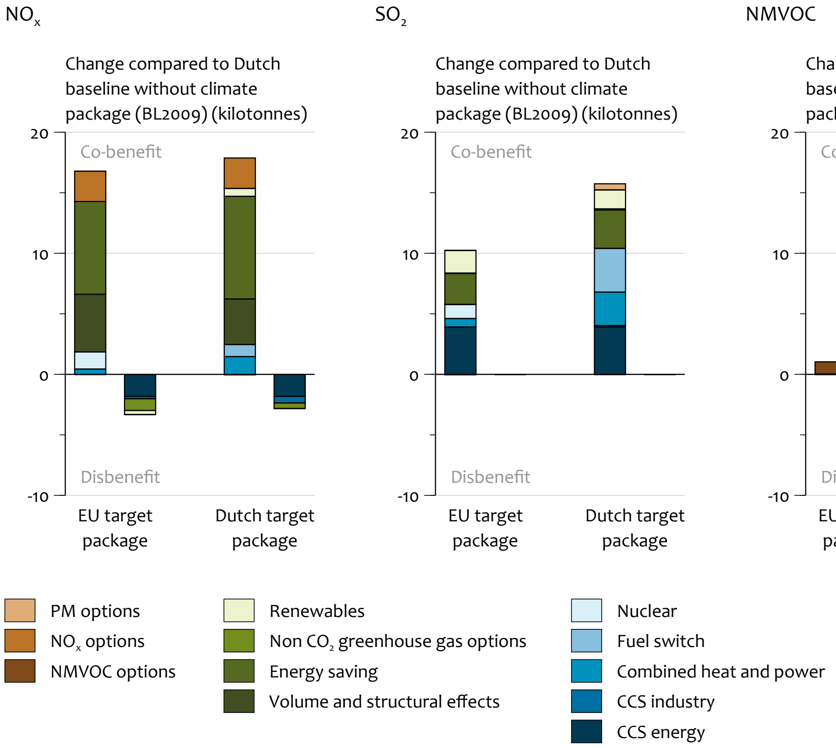
As shown before, the Dutch 2009 baseline with strict implementation of the envisaged Dutch climate package does not meet either the European or and the Dutch targets for reduction of GHG emissions and energy targets in 2020. To close the gap between projections with envisaged packages and the GHG gas and energy targets, the Netherlands needs to develop additional national climate and energy policies. The Netherlands could also decide to combine additional national policies with the purchase of CDM/JI credits abroad (to a maximum of about 25 Mt CO_2 eq, see Section 1.2). However, buying a large amount of credits abroad makes it more difficult to achieve national renewable and energy efficiency targets. Any co-impacts associated with these credits would also occur abroad.

To estimate the co-benefits on air pollutants of an additional Dutch climate and energy package to meet either European or Dutch climate and energy targets, two cost-optimal packages of climate and energy measures have been constructed using the Dutch Options Document and the Analysis Tool (Section 1.4). These are referred to as the European and Dutch climate target packages. These target packages are based on the Dutch baseline with the most stringent implementation of Dutch envisaged climate policies (Dutch BL2009 high scenario; see Figure 3.3). The two packages that meet the European and the Dutch climate and energy targets are presented in Figure 3.6. However, the Dutch renewable energy target cannot be met with the options currently available and the maximum feasible share is about 18%.

More energy savings and renewable measures are taken in the target packages than in the Dutch envisaged climate packages. The energy saving measures include more savings in electric appliances in households and service sectors, reduced heat demand in the residential and services sectors and a trading system for transport fuels. The renewable energy measures include more wind energy generation at sea and on land, 10% extra biofuels (total 20% biofuels), biogas from co-digestion of manure, green gas from biomass gasification, and co-firing biomass in power plants. As a result coal use decreases by about 70% under the Dutch target package compared to the Dutch 2009 baseline without the Clean and Efficient programme. Other major contributions come from CCS in power (10 Mt) and industry (about 6 Mt from purer CO_2 streams where less efficiency losses occur than CCS in the energy sector), combined heat and power (CHP), and fuel switch (mainly coal to gas). According to the Options Document (Section 1.4), the cost is 3.5 to 6.5 billion euros per year for the EU target package and 8 to 10 billion euros for the Dutch target package (in euros at 2000).

The net co-benefits for air pollutants of the European and the Dutch target packages (Table 3.6) are larger than those of the envisaged Clean and Efficient programme (Table 3.4). The NO_x co-benefits mainly result from energy savings measures, and volume and structural effects (Figure 3.7). Some disbenefits for NO_x emissions (emission increases) can be seen with implementation of CCS, renewable energy (biomass in small-

Co-impacts of the climate target packages on air polluting emissions, by 2020 **Figure 3.7**



medium scale installations and co-firing in gas power plants), and green or synthetic gas production. The SO_2 co-benefits result from CCS in power and industries, various switches from coal to gas and bio-energy (in centralised power plants and in CHP), more renewable energy and more energy savings resulting in less electricity consumption and hence less (coal fired) production (Figure 3.7).

The disbenefits for ammonia emissions originate mainly from the increase in emissions due to increased use of post-combustion CO_2 capture. These increases can be mitigated with reduction measures (Section 2.1, Appendix A.1). The disbenefits for NMVOC emissions originate from an increase in combined heat and power installations (CHP) with gas engines (without NMVOC mitigation measures) and from increased use of biomass. The effects of the target packages on PM_{10} are expected to be relatively small.Co-impacts of climate target packages in the Netherlands, 20201

Foreign credits may be needed to achieve Dutch GHG targets if CCS is not available in 2020

CCS application was included in the previous analysis of the envisaged Dutch climate packages and the EU and Dutch target packages. However current insights indicate that CCS may not be available on a large scale in 2020 in the Netherlands. Therefore, an additional analysis was carried out to show the effects on what options can be taken (and the associated costs and co-impacts) of excluding CCS in power and industries. The implication is that the reduction achievable from a storage potential of about 16 Mt CO_2 in 2020 needs to be compensated by other options. The Analysis Tool shows that without CCS, the Dutch GHG target of -30% by 2020 is not achievable with the other domestic measures available in the Options Document. Instead, the option of buying CDM/JI credits at 28 euro/ton for about 16 Mt is necessary. This amount is still below the maximum of about 25 Mt credits that the Netherlands is allowed to buy (Section 1.2). If the CCS reduction potential is replaced by foreign CDM/JI credits, the costs of achieving the Dutch target for reduction in GHG emissions may decrease. This is because the price per ton GHG for CDM/JI credits in 2020 is assumed to be below the cost of reduction by CCS at that time.

Excluding CCS means that the disbenefits of CCS in power and industries (NO_x and NH_3 for up to 2.5 kiloton each) and the co-benefits (SO_2 for up to 4 kiloton) do not occur in the Netherlands (see Figure 3.7). Any co-impacts related to the foreign credits thus occur outside the country.

Climate packages lead to net cost reduction for air pollution mitigation

The co-benefits of the European and Dutch target packages on air polluting emissions (Table 3.6) can be monetised in terms of avoided or extra costs for air pollutant mitigation. The net co-benefits on NO_x and SO_2 emissions are expressed as costs avoided for air pollutant mitigation and net disbenefits for NH_3 and NMVOC emissions as the extra cost of compensating measures.

Data on the potential and cost of many options for SO_2 and NO_x emission mitigation are based on recent information (Smekens et al., 2010), and for PM_{10} mitigation options on the Dutch action plan on particulate matter reduction in industry (VROM, 2008b).

Based on these data, the SO_2 co-benefits (10 to 16 kiloton) represent a total value of 15-30 million euros per year (in euros at 2000) in terms of avoided air pollutant mitigation options. The co-benefits of 14-15 kiloton NO_x represent a value of 10-45 million euros per year. The lower end of this range includes also a number of policy measures and the higher end mainly technical measures. The co-benefits of 1 kiloton PM_{10} represent a value of about 50 million euros per year.

To compensate for the disbenefits for NH_3 emission due to CCS, mitigation options in power and industry may be available at reduction costs of about 1.8 million euros per kiloton (Van Horssen et al., 2009). This means that the maximum disbenefits of 2.5 kiloton may be reduced at the total cost of 4.5 million euros per year. Based on older information from the Options Document, the disbenefits for NMVOC of 3 to 4 kiloton may be compensated for at a cost of up to 4 million euros.

The co-impacts of the European and the Dutch target packages lead to net co-benefits in terms of avoided additional options for air pollutant mitigation at a maximum value of over 100 million euros per year. These cost savings are small compared to the indicated costs in 2020 of current Dutch air quality policies of about 3 billion euros in 2020 (CIAM, 2010; IIASA, 2010) or the additional Dutch climate packages of about 3-9 billion euros in 2020 (Smekens et al., 2010; Wijngaart & Ros, 2009).

Notes

1 A substantial amount of energy is needed to run a CO_2 capture unit for which can result in extra NO_x emissions depending on the type of the combustion - capture technology combination and any additional measures.

2 The Dutch target for the share of renewable energy in road transport in 2020 is the same as the European target (10%). However, the feasibility of a mandatory 20% biofuels share is being explored.

4

Optimising co-benefits and reducing disbenefits

To optimise the co-benefits of climate policies on air polluting emissions and to prevent disbenefits, climate and air quality policymakers need to work closely together (Section 4.1). This study provides information for that process. It provides estimates for the potentially substantial co-impacts of climate policies in the Netherlands on air polluting emissions. In addition, it appoints the large uncertainties that surround the estimates for those co-impacts (Section 4.2). Recommendations are given how to reduce or prevent disbenefits of specific climate measures (Section 4.3).

4.1 Develop long-term vision and harmonised strategy on air and climate

In many countries and institutions, climate and air pollution policies tend to have been developed more or less independently. Climate policy also in the Netherlands tends to focus heavily on CO_2 reduction with little attention to the effects of policies on, for instance, air pollution. Air quality policy does not always take into account climate policy processes. For instance the European revision of national air pollutant emission ceilings started initially without consideration of the implications for the ongoing process on EU policy on climate and energy. Another emerging issue is the potential effects of air pollution measures on short-term global warming.

This lack of coordination has a number of drawbacks from both an economic and an environmental standpoint. Industry, for instance, may be faced with situations in which in one year carbon reductions have to be made and in the next reductions in conventional air pollutants (Climate Institute, 2010). This reduces the opportunities for industries (under coordinated policies) to take more cost-effective measures in reducing CO_2 emissions and air pollutants simultaneously. According to Eurelectric (2010), uncoordinated climate and air policies are a hindrance to long-term planning and investments in industry.

Lack of coordination can also lead to climate policy packages with measures that are neither beneficial nor optimal for air pollutants. This study confirms that a number of important climate measures have disbenefits for air quality including use of bio-energy in small to medium scale installations, stimulating small to medium scale combined heat and power, and introducing certain types of CCS. These trade-offs imply that climate policies and targets for the short or long term alone are not sufficient to guarantee a decrease in air polluting emissions. Clear intermediate air pollution targets, such as national emission ceilings, are a better guarantee of an intended decrease in air polluting emissions. With better coordination, climate packages can be chosen that contribute (partly) to an intended decrease in air polluting emissions, and thus reduce the cost of air pollution policies. These benefits in turn are valuable incentives in developing climate policies.

Lack of coordination on climate and air quality policy yields less overall environmental protection for the societal resources expended and does not contribute to the societal support for climate and air policies. The lack of coordination may result from a lack of shared long-term vision and harmonised strategy to achieve short- to long-term targets (Maas et al., 2009). Thus, it is recommended that a Dutch vision and strategy be developed on climate change and air-pollution mitigation.

4.2 Co-impacts, uncertainties, and revision of national emission ceilings

In the ongoing revision of the national emission ceilings in the UNECE and the European Commission for 2020, co-impacts of the European climate and energy policies on air polluting emissions are to be incorporated in the baselines. The role of baseline emissions in the revision of the national emission ceilings is very important for the Netherlands. These baselines, and their estimated effects on air quality, are the starting point in the revision. Subsequently, a number of ambition levels for an improved air quality, will be translated with the GAINS model into indicative national emission ceilings for all the countries under the GP and the NECD. That information will be used within the negotiation processes towards a new GP and NECD.

UNECE and European Commission propose using the GAINS and PRIMES models to construct these baselines. The comparison of the GAINS-PRIMES and Dutch baselines without and with climate and energy policies made in this report (Section 3.1 and 3.2) has shown that the GAINS-PRIMES co-benefits per megaton CO_2 reduction are higher especially for NO_x emissions (but also SO_2), and no disbenefits are estimated for NH_3. Thus, including these GAINS-PRIMES co-benefits into national emissions ceilings for 2020 may lead to a number of relatively strict ceilings in the Netherlands.

This comparison with regard to air pollutants could only be made for the GAINS-PRIMES 2007 and the Dutch 2009 baselines. The newer post-crisis PRIMES 2009 baseline (Klaassen, 2009; Amann et al., 2010) is only available with the agreed EU climate and energy policies (and not without). The newer Dutch post-crisis 2010 baseline (Daniels and Kruitwagen, 2010) for air pollutants is currently only available without the envisaged Dutch climate and energy policies.

In February 2010, UNECE proposed using a PRIMES 2009 baseline, which includes most of the agreed European climate and energy policies and also takes into account the post-crisis effects on economic growth. Relatively low economic growth is assessed for the Netherlands of 1.4% up to 2020 (Maas, 2010). This scenario meets the EU climate and energy targets for the Netherlands. It leads to relatively low baseline emissions especially for SO_2 (33 kiloton) and NO_x (166 kiloton) in 2020. It remains to be seen whether additional air quality ambition levels are defined that lead to even lower national emissions ceilings for the Netherlands (lower than the baseline).

The Dutch analysis of the co-benefits of the EU target package (Section 3.3) indicates that SO_2 and NO_x baseline emissions could decrease to about 40 and 190 kiloton, respectively, in 2020. With the stricter Dutch climate and energy targets, the baseline SO_2 and NO_x emissions could decrease a further few kilotons. These estimated co-impacts are indicative and should be interpreted with care.

The first argument for caution is that the co-benefits of the target packages are not based on a complete and agreed Dutch climate and energy policy plan that meet the targets. Such a plan does not as yet exist. Instead, a theoretical potential analysis was carried out using assumptions on (mostly technical) options and a cost-optimal order of the options. The list of options can never be complete because different technical measures may emerge or new policy measures with different costs and effects may be developed. Also, the cost-optimal order of options may be quite different in reality because arguments other than cost-effectiveness could play a determining role, for instance, energy security or a distribution of reduction efforts over sectors or GHGs.

The second argument is that in the Dutch potential analysis only additional national climate and energy measures in the ETS and non-ETS sectors have been included. In reality, the Netherlands could decide to combine additional national policies with the purchase of CO_2 credits abroad to meets non-ETS targets. These credits can be purchased through the Clean Development Mechanism (CDM) or Joint Implementation (JI). To meet the EU greenhouse gas target, the Netherlands is allowed to buy credits for about 4 Mt CO_2 equivalents per year in 2020. For the more stringent national target, the Netherlands is allowed to buy a maximum of about 25 Mt CO_2 eq. per year. A disadvantage of buying a large amount of credits (abroad) is that it is more difficult for the Netherlands to achieve national renewable and energy efficiency targets. With regard to the ETS sector, the Dutch participants in the EU-ETS are not forced to take measures themselves (in the Netherlands), but are free to buy credits in the EU-ETS. Moreover, some credits may be bought through CDM and JI. Thus, any co-impacts associated with foreign credits will also occur abroad.

The third argument for caution is that the Dutch analysis in this report was carried out with a baseline using relatively high economic growth of 2.9% up to 2020. Velders et al., (2009) show that a lower economic growth could have substantial impacts on future emissions, because of fewer activities and less energy use. If the Dutch economic growth is reduced from a pre-crisis assumption of 2.5% per year to a post-crisis assumption of 1.5% per year between 2010 and 2020, national NO_x and SO_2 baseline emissions reduce by about 10 and 2 kiloton respectively. The volume effects of lower economic growth also affect the climate and energy measures needed to meet the targets. Probably, fewer measures will be needed to achieve GHG and energy targets in 2020, and subsequently there are fewer co-benefits.

To understand the net effects on baseline emissions of air pollutants, a national baseline for air polluting emissions should be prepared that integrates lower post-crisis economic growth and all necessary climate and energy measures to meet the European or Dutch targets.

4.3 Reducing air pollution risks from specific climate measures

4.3.1 Bio-energy use in stationary applications

Air pollutant reduction technologies available to reduce bio-energy disbenefits

The number of small to medium sized (bio-energy) installations is expected to grow as a result of climate policies. This includes, for instance, installations that produce biogas from co-fermentation of manure, medium-scale biomass combustion installations and combined heat and power installations. While this leads to CO_2 emission reductions, it also leads to higher emissions of most air pollutants, except for SO_2. SO_2 emissions decrease because biomass generally contains less sulphur than the fossil fuels used in the Dutch power plants.

In general, small to medium-size installations (up to several megawatt thermal [MWth]), including those using biomass, biofuels or biogas, emit higher amounts of air pollutants (per unit of heat or electricity) that do large installations. This is because small installations use less advanced combustion technologies and flue gas cleaning systems. Moreover, the emission limit values are less strict for small installations.

To limit the risk of the potential increase in air pollutants, the Netherlands Government has enforced a new decree with more stringent emission limits for existing and new medium-scale combustion installations including those using bio-energy (VROM, 2009). Despite this decree, an increase in small to medium scale installations carries a risk of an increase in most air polluting emissions. Emission factors for NMVOC in small to medium scale biomass and biogas combustion (14-60 g NO_x per gigajoule) are relatively high compared to those of large-scale power plants (1-2 g NO_x per gigajoule; see Section 2.1). Moreover, NO_x, PM_{10} and NMVOC emission factors are rather high for bio-oil or fat-fired stationary diesel engines and (household) wood-burning stoves. To reduce the potential risks, the Netherlands Government could decide to tighten the emission limit values for the relevant installations.

To reduce NMVOC emissions in small to medium installations (e.g. CHP with gas engines), technical measures such as oxidation catalysts are available. But more research is needed on the effects of catalyst materials from impurities in the flue gas if biogas and biomass are used as fuels (Kroon, 2010). The same type of oxidation catalysts can be used to reduce NMVOC emissions from bio-oil or fat-fired stationary diesel engines. Reducing NO_x emissions from these types of diesel engine/fuel combinations beyond the current emissions limit values (130 g NO_x per gigajoule) is a challenge because the current limit values require a selective catalytic reduction (SCR) unit with a reduction efficiency of about 90 to 95%.

The best measure to reduce particulate matter and NMVOC emissions from household wood-burning stoves (in residential areas) is to require the installation of certified stoves. The cost-effectiveness of this measure (about 30 to 50 euro per kg PM_{10} avoided) is within the cost-effectiveness range used in the Dutch Action Plan Industrial Particulate Matter Emissions (5 to 90 euros per kg PM10 avoided; VROM, 2008b). Other more expensive reduction measures for household stoves are electronic precipitators and oxidation catalysts. These techniques require more maintenance and/or specific operation procedures. The use of certified pellet stoves may lead to less air pollution because of the more constant combustion conditions than in wood log combustion in simple stoves.

Air polluting emissions from the production chain of bio-energy may need attention

Currently, bio-energy chains (biomass, biogas and bio-oil) are expected to have limited effects on total air polluting emissions in the Netherlands in 2020. This is because only a limited proportion (<20%) of the fossil fuels is replaced by bio-energy fuels. However, if renewable energy targets for transport, electricity and heat production are increased and more bio-energy has to be produced, substantial changes in air pollutants could occur in parts of the bio-energy production chain in and outside the Netherlands. This means that air pollution from bio-energy production chains is one of the aspects to be considered in developing renewable energy strategies. Tighter emission limit values for parts of the production chain of biomass, biogas or bio-oil may be part of those strategies.

Limited knowledge about air pollution from smaller scale (bio-energy) installations

In general, there is reasonable amount of activity data, emission factors and applied emissions reduction technologies on bio-energy use in large-scale combustion installations (over 50 MW_{th}). This is because such installations have rather strict monitoring and reporting requirements, which is not the case with small to medium scale (bio-energy) installations. As a result, basic statistical data are either rather limited or sometimes outdated (numbers and type of current bio-energy installations, their air polluting emissions coupled with size, fuel type, flue gas cleaning measures, efficiency, costs).

The activity scenarios presented on the future bio-energy installations and medium-scale CHP should be considered as what-if scenarios and not as a best guess. The real future contribution depends substantially on subsidies and/or future obligations. These technologies are currently not competitive with large-scale fossil applications, future policies on subsidies or obligations are as yet unknown, and sometimes depend on technological (e.g., biomass gasification) and market developments (international prices of biomass).

These observations imply that the conclusions in this report on the effects of increased bio-energy use in small-scale installations should be interpreted with caution. It also emphasizes the need for careful consideration of air pollution in developing additional renewable policies that include increased application of bio-energy in small to medium scale installations.

4.3.2 Biofuel use in road transport

Legislation plays a key role in reducing risk of air pollution from biofuels

Based on a review of recent studies, Verbeek et al. (2008 and 2009) concluded that all types of vehicles running on low or high biofuel blends pose risks of increased air polluting emissions. The risks are expected to be largest with high blends of current biodiesel in heavy duty vehicles. These blends are not recommended for passenger car diesel engines because the necessary adjustments are less cost-effective than in heavy duty vehicles. To reduce the risks, guidelines are needed for truck fleets running on high biofuel blends and with advanced emission control (EGR, SCR, diesel particulate filters). The guidelines would need to include a selection of trucks that are adequately prepared for this type of biodiesel. Such vehicles need to have modifications such as adjusted fuel storage and pump systems increased lube oil storage and oil filter size and dedicated software for the emission control devices. Moreover, fleets with trucks running on high biodiesel blends need to be monitored for emission control system performance, failure rates and durability. In addition, the quality of the biodiesel blends needs to be monitored extensively.

The risks are generally lower for vehicles running on low biodiesel blends, because blends of up to 5% have already been implemented in the type approval procedures. However, impurities in biodiesel can lead to problems with fuel and emission control systems over time. Therefore, the quality of low biodiesel blends needs to be monitored and also the long-term durability of engines and emission-control devices.

Similarly, the risks are generally lower for vehicles running on ethanol blends because high blend ethanol (E85) has

Photo 6 Emission testing of cars running on biofuels blends is important in monitoring effects on air polluting emissions. Test facility for light duty vehicles at Joint Research Centre in Ispra, Italy © EC (2009)

been implemented in the type approval procedure for flexi-fuel vehicles. E5 has been implemented for low blends and manufacturers are committed to levels of up to E10 for new vehicles. The ethanol blend quality (both low and high blends) needs to be monitored as well as the long-term durability of engines and emission control devices.

The risk of increased air pollution in vehicles running on natural gas and/or biogas can be reduced by purchasing vehicles with factory-installed fuel systems. The type approval system needs to be improved for vehicles with retrofit systems. This also applies to vehicles with LPG systems. Fleets with cars on biogas (or a mixture of natural gas and biogas) need to be monitored, including their emission control system performance, failure rates and durability. Only biogas upgraded to natural gas quality should be used and the quality of the biogas monitored regularly.

Air polluting emissions from biofuel production chains may require attention

Currently, biofuels chains are expected to have limited effects on total air polluting emissions in the Netherlands 2020. This is because biofuels replace only a small proportion (<10%) of fossil fuels used in transport. However, if renewable energy targets for transport are increased and more biofuels have to be produced, more substantial changes could occur in air pollutant chain emissions in and outside the Netherlands. This means that air pollution from biofuel production chains should be considered in the development of renewable energy strategies. Tighter emission limit values for part of the production chain of biofuels may be part of those strategies.

4.3.3 CCS in power generation and industry

Need for monitoring air polluting emissions in CCS pilot projects

Before large-scale application of CCS, a number of technical (e.g., upgrading to large scale application, energy penalty, air pollutant aspects, real CO$_2$ storage capacities and leakage risks), legal (e.g., post-closure liability) and societal barriers (e.g., not in my backyard) need to be overcome and confidence is required on the environmental performance (IPCC, 2005; Harmelen *et al.*, 2008). The reports on CCS of the Dutch Research Programme on Air and Climate (Van Horssen et al., 2009; Harmelen et al., 2008) have contributed to knowledge on the environmental performance of CCS application with regard to estimated costs and effects on air polluting emissions in the Dutch power and industrial sectors. However, it is difficult to accurately estimate the air pollutant emission profile of power plants equipped with CO$_2$ capture.

Reported emissions are mostly based on assumptions (and not on measurements) about the technological configuration and performance that vary considerably. For technologies currently in the laboratory or pilot phase, less information is available and environmental performance is often discussed qualitatively, if at all. For more accurate estimates, measurements in demonstration projects using capture technologies are required. This information on emission factors for SO$_2$, NO$_x$, PM$_{10}$ NH$_3$, NMVOC and other degradation products of amines is needed to improve the scenario analysis of this study for 2020 and beyond.

Legislation for BECS and co-sequestration needs further elaboration

To improve analysis of future environmental effects of CCS, clarification is needed on the position of CCS in European and Dutch legislation, in particular on CO$_2$ and – Biomass with Carbon Storage (BECS) - accounting in emission trading, combustion of waste in combination with CCS, and storage of pollutants other than CO$_2$ (co-sequestration). Treatment of BECS under EU ETS is currently unknown and still under discussion. BECS will only become attractive if allowances are given to the negative emissions from biomass with CCS. Currently, negative GHG emissions are not acknowledged.

Insights in co-impacts of CCS on air pollution expected to evolve rapidly

The research and development on CCS is progressing rapidly throughout the world, with the implication that analysis under the Dutch Research Programme could be refined in the future. The following aspects should be considered in a new analysis:

- CCS and novel technologies including new solvents which are under development;
- CCS and other environmental aspects such as waste and emissions to water;
- CCS and co-firing biomass: impact on air polluting emissions of different forms and qualities of biomass, based on experience in power plants.
- economic and environmental impacts of strategies for utilities and industry to mitigate CO_2 emissions by using biomass co-firing and/or CO_2 capture separately or in combination.
- CCS scenario analysis of both GHGs and air polluting emissions for the long term.

Appendices

A.1 Biomass activities, emissions factors and emission control technologies

Use of biomass, biogas and bio-oil in stationary applications in 2007 and projections for 2020 (Units: PJ primary energy input per year)

Table A1.1

	2007	Dutch baseline Projections 2020	Scenario Low 2020	Scenario High 2020
Co-firing gas/coal fired power plants	15	0	89	89
Waste incineration (only biogenic)	28	48	41	41
Small-scale biomass combustion/stoves	12	8	8	16
Medium-scale biomass combustion	7	11	49	51
Large-scale biomass combustion	0	0	0	0
Biogas (engine) from waste tips	*2*	*0*		
Biogas (engines) from waste water	*2*	*8*		
Agricultural biogas plants	*2*	*2*		
Other biogas plants	*1.5*	*2*		
Total anaerobic digestion	7	13	37	50
Bio-oil/fat-fired engines	0.5	0	6	6
Cement industry	-	0	0	0
Total bio-energy input	**71**	**80**	**224**	**252**
National primary energy input	**3353**	**3942**	**3942**	**3942**
Contribution of bio-energy to the national primary energy input (%)	**2,1**	**2,0**	**5,7**	**6,4**

Use of medium scale fossil-fired combined heat and power in 2007 and projections for 2020 (Units: PJ primary energy input per year).

Table A1.2

	2007	Dutch baseline Projections 2020	Scenario Low 2020	Scenario High 2020
Gas engines	97	102	123	150
Gas turbines	3	5	5	5
Total	100	107	129	156

Dutch emission factors for small- to large-scale bio-energy applications in 2007 (Units: g/GJ)

Table A1.3

Category	NO_x	SO_2	NH_3	PM_{10}	NMVOC
Co-firing	40	11	5	0.9	2.0
Waste incineration (only biogenic)	35	1.3	1.3	0.5	1.3
Medium-scale biomass combustion	130	10	1.7	5	60
Biogas from waste water	195	0.5	0.0	0.5	14
Biogas from waste tips	195	0.5	0.0	0.5	14
Agricultural biogas plants	195	0.5	0.0	0.5	14
Other biogas plants	195	0.5	0.0	0.5	14
Bio-oil/fat fired engines	130	9	4.4	17	31
Small-scale biomass combustion/stoves	111	15	N/A[1]	181	748

[1] information not available

Emission reduction techniques for dust, NO_x, SO_2, NH_3 and NMVOC. Table A1.4

Pollutant	Emission reduction technology	Capacity range [m^3/hr]	Conversion technique			Remarks
			W	A	O	
Dust	Cyclone	100-100,000 (<100 kWth-70 MW$_{th}$)	X			Not suitable for very small particles Not suitable for low dust concentrations Often used in combination with other dust removal system
	Fabric filter (Baghouse filter)	No limitations	X			Achievable: 10 mg /m^3 Often used in combination with limestone or active carbon injection
	ESP 1-stage	> 20,000 (> 15 MW$_{th}$)	X			
	ESP 2-stage	< 100,000 (< 70 MW$_{th}$)	X			
	Ceramic filter	2,000-500,000 (1-350 MW$_{th}$)	X			Achievable: 1 mg/m^3
	Wet scrubber	< 200,000 (< 150 MW$_{th}$)	X			Waste water production
	Rotating particle separator		X			
	Settling chamber	100-100,000 (< 100 kWth-70 MW$_{th}$)	X			Low efficiency
NO_x	SNCR	No limitations	X			
	SCR	< 1,000,000 (< 700 MW$_{th}$)	X	X	X	NH_3 slip < 5 mg/Nm^3 Achievable: 50 mg NO_x/Nm^3
	Flue gas recirculation	No limitations	X			
	Wet scrubber	< 2,000,000 (< 1,400 MW$_{th}$)	X			Waste water production
SO_2	Limestone injection	10,000-300,000 (7-350 MW$_{th}$)	X			In combination with dust removal; also removal of Cl (35-80%) and F (95%)
	Wet scrubber	50-500.000 (< 350 MW$_{th}$)	X			Also can remove dust (> 50%), VOC (50-99%), NH_3 (> 99%), HCl and HF (99%)
NH_3	Wet scrubber (acid)	50-500,000 (< 350 MW$_{th}$)		X		
	Bio-filter	No limitations		X		Also removal of NMVOC
	Active carbon injection			X		Also removal of H_2S and NMVOC
NMVOC	Active carbon injection	100-100,000 (<100 kWth-70 MW$_{th}$)	X			
	Catalytic afterburner	1,000-30,000 (1-20 MW$_{th}$)	X	X	X	
	Thermal afterburner	1,000-30,000 (1-20 MW$_{th}$)	X	X	X	
	Bio-filter	No limitations		X		Also removal of NH_3

W = wood combustion, A = anaerobic digestion, O = oil combustion. Bold = detailed in this study [VITO/Infomil, 2009]

A.2 Air polluting emissions from bio-energy production chains

Air polluting emissions in 2020 from biomass, bio-oil and biogas chains in electricity generation and the fossil reference (in and outside the Netherlands)

Table A2.1

Emission	Unit	Palm oil	Biogas	Natural gas reference	Wood pellets	Coal reference
NO_x	g/GJ	37.22	9.51	21.72	18.23	67.50
SO_2	g/GJ	24.80	4.41	24.40	16.28	15.84
NH_3	g/GJ	20.75	0.00	0.02	0.17	5.91
PM_{10}	g/GJ	4.93	0.42	0.93	1.14	3.80
$PM_{2.5}$	g/GJ	1.76	0.00	0.97	2.17	3.58
NMVOC	g/GJ	5.05	7.79	17.80	7.57	9.82

Air polluting emissions in 2020 from biodiesel chains and the fossil diesel reference (in and outside the Netherlands)

Table A2.2

Emission	Unit	Biodiesel from rapeseed	Biodiesel from palm oil	FT diesel[1] from wood	Biogas as transport fuel	Diesel reference
NO_x	g/GJ	42.88	46.08	17.18	21.14	42.80
SO_2	g/GJ	21.60	30.86	10.16	13.26	96.29
NH_3	g/GJ	51.10	23.14	0.07	0.23	0.14
PM_{10}	g/GJ	14.81	5.82	0.95	1.14	2.24
$PM_{2.5}$	g/GJ	3.89	2.18	1.38	0.46	4.36
NMVOC	g/GJ	13.74	7.45	13.32	9.71	27.09

[1] Fisher-Tropsch second generation synthetic biodiesel

A2.3 Air polluting emissions in 2020 from bio-ethanol chains and the fossil gasoline reference (in and outside the Netherlands)

Table A2.3

Emission	Unit	Ethanol from sugar cane	Ethanol from sugar beet	Ethanol from straw	Ethanol from wood	Gasoline reference
NO_x	g/GJ	130.60	56.11	10.61	-8.15	50.53
SO_2	g/GJ	40.79	49.63	66.00	53.82	133.07
NH_3	g/GJ	3.77	6.79	25.17	-0.58	0.16
PM_{10}	g/GJ	9.08	8.97	6.24	0.45	2.67
$PM_{2.5}$	g/GJ	1.62	2.88	1.56	0.98	5.29
NMVOC	g/GJ	39.95	41.94	13.57	13.83	27.75

A.3 Key parameters of CO_2 capture in the Dutch industrial sector

Figure A3.1 Overview of industrial emission sources, potentially feasible CO_2 capture technologies and performance. Green indicates better than no capture, yellow is the same as no capture, and red indicates worse than no-capture case. Cost figures are for 2020, assuming that the technologies are fully commercialised. The cost figures do not include CO_2 transport and storage. N.D. = no data.

Sector	**Annual total emissions in NL**	**CO_2 conc.**	**CO_2 capture**	**Additional process gas treatment?**			**Other additional facilities**	**Appli-cation**	**CO_2 reduction potential**	**Economic performance**	**Environmental performance**						
	$MtCO_2$/ year		Application	de-NOx	de-SOx	Dust filter		Retrofit?	$MtCO_2$/ year	€ per tonne avoided (constant 2008)	Unit	CO_2 emissions	NO_x emissions	SO_2 emissions	PM_{10} emissions	NH_3 emissions	Other impacts
Cement	0.6	13%, 0.13 bar	No capture	-	-	-	-	-	-	-	g/kg cement	443	0.92	0.26	0.011	0.056	
			Chemical abs. (MEA)	No	Yes	No	CHP[1]	y	0.51	110		-60	0.89	0.002	0.004	0.169	Toxic waste
Steel	10.3	25%, 0.25 bar	No capture					-	-	-	kg/ton crude steel	1560	0.83	0.48	0.51	Negligible	
			Oxyfuel + VPSA	No	No	No	ASU[2]	y	5.2	40		780	N.D.	0.37	N.D.	No change	
Hydrogen (high purity)	0.66	15-35%, 3-11 bar	No capture	-	-	-	-	-	-	-	g/MJ H_2 LHV	80	0.035	Negligible	Negligible	Negligible	
			Chemical abs. (MDEA)	No				y	0.37	40		35	N.D.	No change	No change	No change	
Ethylene	5.7	12%, 0.12 bar	No capture	-	-	-	-	-	-	-	g/kg ethylene	1560	1.05	0.00015	0.67	Negligible	
			Chemical abs. (MEA)	No	No	Yes	CHP[1]	y	5.1	110		177	1.03	-0.001	0.36	0.33	Toxic waste
Refineries	7.5	8%, 0.08 bar	No capture	-	-	-	-	-		-	Relative change	-	-	-	-	-	
			Chemical abs. (MEA)	Yes?	Yes?	Yes?		y	4.5	110		60%	-	-	-	N.D.	Toxic waste

[1] Combined head and Power
[2] Air Seperation Unit

A.4 Updated Dutch climate and energy options

Option	**Status**	**Max CO_2 reduction potential (Mton)**	**Associated national cost eff. (€/ton CO_2)**	**Associated major emission reduction (minus symbol = increase)**
CO_2 capture at existing coal-fired power plants	Updated	6.8	32.4	2.5 kton SO_2 -1.6 kton NH_3 -0.9 kton NO_x
CO_2 capture at invested coal-fired power plants[1]	Newly formulated	8.4	35.1	3.3 kton SO_2 -2.2 kton NH_3 -1.5 kton NO_x
CO_2 capture new coal-fired power plants post combustion	Updated	11.5	35.1	4.5 kton SO_2 -2.9 kton NH_3 -2.1 kton NO_x -0.1 kton PM10
CO_2 capture new coal-fired IGCC power plants	Updated	11.5	42.3	4.1 kton SO_2 -2.1 kton NO_x 0.1 kton PM10
CO_2 capture ethylene oxide production	Newly formulated	0.2[2]	16.0	-
CO_2 capture hydrogen plants at refineries	Updated	0.6[2]	7.7-8.9	-
CO_2 capture (bio) ethanol	Newly formulated	0.4[2]	11.0	-
CO_2 capture ammonia production	Updated	1.2[2]	7.5	-
CO_2 capture primary iron and steel industry	Updated	4.5	32.1	-1.2 kton NO_x 0.2 kton SO_2
CO_2 capture refineries	Newly formulated	6.0	31.3	-0.2 kton NO_x -0.1 kton SO_2
CO_2 capture hydrogen plants (high purity H_2)	Newly formulated	0.7	27.3	-
Biomass co-firing in power plants	Updated	7.4	40.1	1.5 kton SO_2 -0.5 kton NH_3 -0.4 kton NO_x -0.2 kton NMVOC 0.1 kton PM10
Biomass power plants (stand-alone)	Updated	0.8	244	-0.4 kton NMVOC -0.2 kton SO_2 -0.2 kton NO_x -0.1 kton NH_3 -0.1 kton PM10
Green gas from landfill and sewer gas	Updated	0.3	-64.6	1.9 Mt CH_4 (CO_2eq) -0.1 kton NO_x -0.1 kton NMVOC
Green gas from manure (and biomass) digesters	Updated	3.2	189	7.4 Mt CH_4 (CO_2eq) -4.4 kton NO_x -2.0 kton NMVOC -0.3 kton SO_2 -0.1 kton PM10
Green gas from biomass gasification	Updated	0.6[3]	108	-0.3 kton NO_x -0.1 kton SO_2
Emission requirements existing stoves	Newly formulated	-	-	1.1 kton PM10 1.0 kton PM2.5 2.1 kton NMVOC 0.1 kton NO_x
Obliged ESP application existing stoves	Newly formulated	-	-	1.0 kton PM10 0.9 kton PM2.5
Biofuels in transport – Scenario 1	Newly formulated	1.4	375	-0.1 kton SO_2
Biofuels in transport – Scenario 2	Newly formulated	0.5	481	0.2 kton NO_x -0.1 kton SO_2
Biofuels in transport – Scenario 3[4]	Newly formulated	-0.3	-	-0.6 kton SO_2

[1] These are coal-fired power plants where the necessary investment decisions have been made and construction has already started

[2] This is an average of two Dutch companies. CO_2 capture at the company with the largest potential would be cheaper.

[3] According to the scenario with the highest probability

[4] This option results in increasing GHG and SO_2 emissions because most of the electricity used to charge the hybrid and plug in electric vehicles is generated with fossil (coal/gas) fuels. Because of the negative effects and the positive costs, a negative cost-effectiveness is calculated that has no meaning here.

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Colophon

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Improving air quality in the Netherlands also depends on choices in climate policy

Measures to prevent climate change could contribute to improving air quality in the Netherlands. In 2020, climate policy in the Netherlands could reduce emissions of sulphur dioxide (SO_2) from 48 to about 32 kiloton, and emissions of nitrogen oxides (NO_x) from 199 to about 184 kiloton. In addition, the cost of climate and air quality policies could be reduced by a few percent provided policies are more closely attuned.

Energy savings and use of wind energy both contribute to improving air quality. However, the benefits to air quality are likely to be less if the Netherlands purchases CO_2 credits from abroad. Furthermore, measures such as carbon capture and storage and increasing small-scale production of bio-energy may also increase air pollution but could be prevented by setting more stringent air quality limit values.

This study has been carried out in the framework of the Dutch research programme on Air and Climate (BOLK). This programme was set up by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) to investigate the extent to which climate policy can contribute to improving air quality in the Netherlands in 2020. The Ministry uses this information in the preparation of climate and energy policies and strategies and in setting the Dutch position with regard to the revision of national emission ceilings under EU air policy for 2020.

PBL Netherlands Environmental Assessment Agency, November 2010