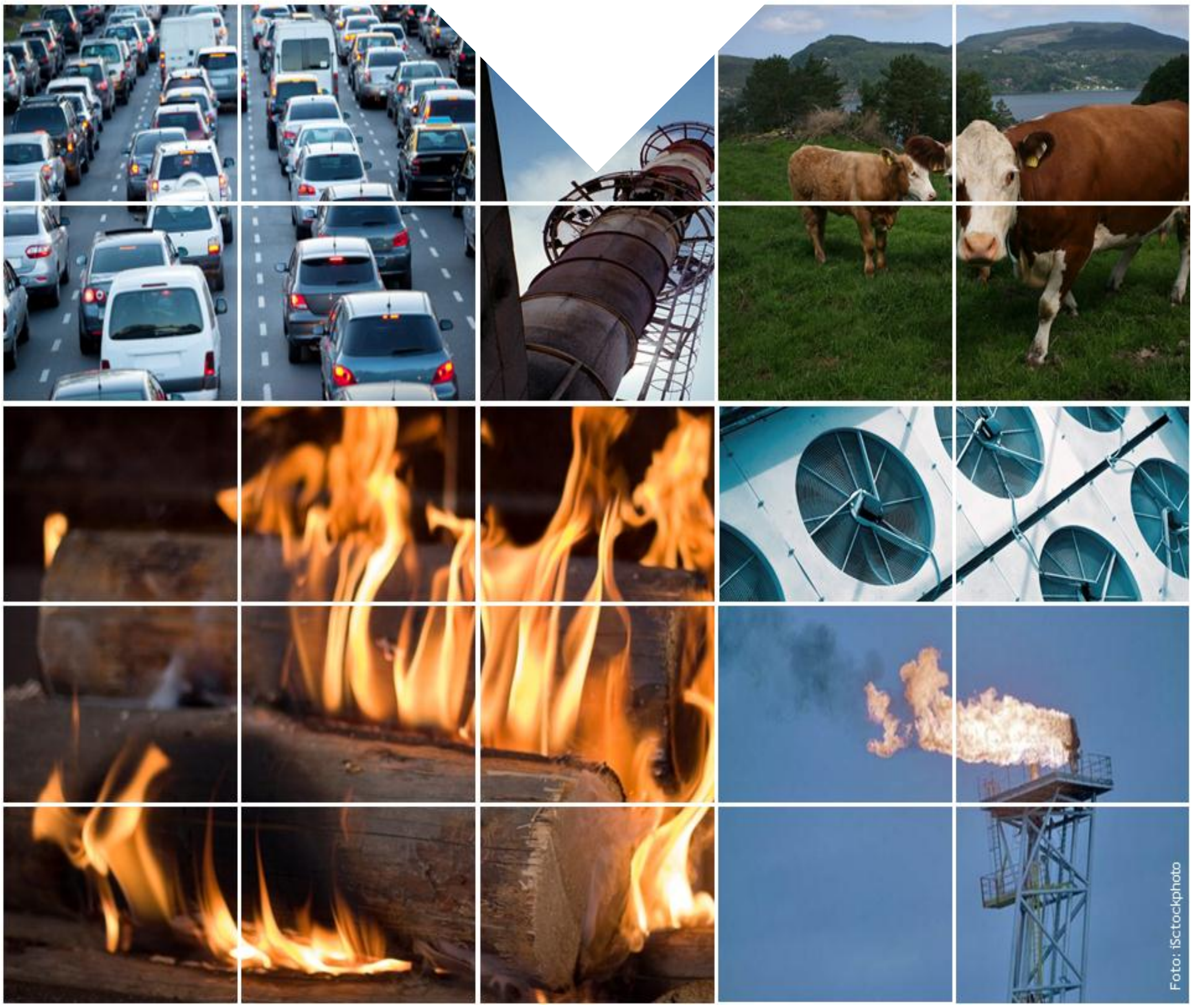
NORWEGIAN ENVIRONMENT AGENCY

REPORT

M135/2014

Summary of proposed action plan for Norwegian emissions of short-lived climate forcers



Preface

The Norwegian Environment Agency, on behalf of the Ministry of the Environment, has prepared a proposal for an action plan to reduce short-lived climate forcers by 2030.

The objective of the assignment has been to give an integrated assessment of climate, health and environmental effects of Norwegian emissions of short-lived climate forcers, propose measures and instruments for reducing such effects by 2030 and evaluate the need for additional monitoring of these components.

The interdisciplinary project team of the Norwegian Environment Agency has been managed by Solrun Figenschau Skjellum. Vigdis Vestreng has been the scientific supervisor of the project. We have cooperated with several external organisations, but the Norwegian Environment Agency is sole responsible for the content of the report.

We would like to thank all contributors for useful input!

Oslo, December 2013

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Summary

In recent years, the climate, health and environmental benefits of reducing emissions of short-lived climate forcers have received increasing international and national attention.

The Norwegian Environment Agency, on behalf of the Ministry of the Environment, has performed an integrated assessment of climate, health and environmental effects of Norwegian emissions of short-lived climate forcers, proposed measures and instruments for reducing such effects by 2030 and evaluated the need for additional monitoring of these components (Norwegian Environment Agency, 2013a).

In this proposed action plan, short-lived climate forcers are defined as gases and particles that contribute to warming and that have a lifetime of a few days to 15 years. These include black carbon (BC), tropospheric ozone (O_3), methane (CH_4) and some hydrofluorocarbons (HFCs). Methane and HFCs are regulated under the Kyoto Protocol.

Organic carbon (OC) and sulphur dioxide (SO_2), which contribute to cooling, are co-emitted with short-lived climate forcers from some emission sources and have therefore also been included here. A characteristic of the climate effects of the short-lived climate forcers, with the exception of the HFCs and to a certain extent CH_4, is that it matters where in the world the emissions are released.

In this analysis, climate effects are defined as global warming or cooling of the atmosphere. Health effects are defined as effects on public health caused by given concentrations of one or more pollutants. Environmental effects are defined as effects on crops and forests caused by given concentrations of one or more pollutants.

The study of short-lived climate forcers is a relatively new field in public administration. The basis of scientific knowledge is still immature and has developed in parallel with work on the action plan. A great deal of the work has therefore consisted of monitoring the research front and developing methods, emission inventories, projections and assessment of uncertainties, so as to analyse the measures. As far as we are aware, no corresponding analyses have been performed in other countries.

BOX 1 Global climate, health and environmental effects of short-lived climate forcers

A report from the UN Environmental Programme shows that a set of emission-reducing measures aimed at short-lived climate forcers could reduce global warming by 0.5°C by 2050 in relation to a reference scenario prepared by IIASA, on the basis of information from the World Energy Outlook 2009 from the IEA (UNEP/WMO, 2011). According to this study, the reduced rate of warming caused by a cut in short-lived climate forcer emissions would itself be short-lived. In order to prevent warming in the longer term, emissions of long-lived greenhouse gases such as CO_2 must be reduced. By implementing measures aimed at both short-lived climate forcers and long-lived greenhouse gases, a more rapid climate benefit could be obtained, thereby increasing the chances of achieving the 2°C target that the world's leaders have set for preventing dangerous climate change.

The study also shows that at a global level, reduction of short-lived climate forcers could prevent 2.4 (0.7-4.6) million premature deaths a year from 2030 onward from BC and 0.04-0.52 million from ozone, as well as reducing losses of wheat, rice, maize and soya crops by 52 (30-140) million tonnes a year, or approximately 1-4% of the global production of these foods after 2030, when a set of 14 measures is implemented (UNEP/WMO, 2011).

First Norwegian emission inventories for black carbon and organic carbon

In connection with this work, we have established both the first Norwegian emission inventory for black carbon as well as for organic carbon. In the proposed action plan, black carbon (BC) is defined as the light-absorbing part of fine particles ($PM_{2.5}$) and is mainly created by the incomplete combustion of fossil fuels, biofuels and biomass. Organic carbon (OC) is the reflective proportion of fine particles ($PM_{2.5}$). Together with black carbon, organic carbon represents the dominant proportion of carbonaceous particles.

Figure S.1 shows the emission sources of black carbon in Norway. The dominant sources are diesel engines and wood burning for residential heating. The dominant source of OC emissions is residential wood-burning stoves. This source represents 83% of the national OC emissions. The uncertainty estimates for BC and OC emissions have not been quantified, but are assumed to be considerably higher than for the other components included in the proposed action plan.

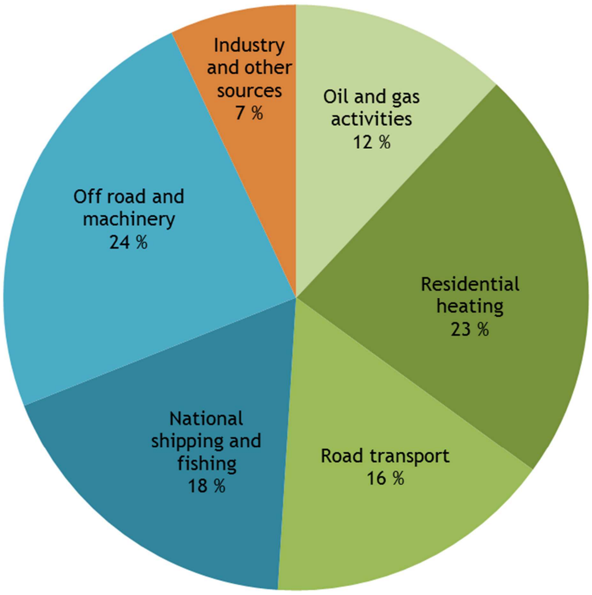

Figure S.1: Distribution of sources for Norwegian 2011 emissions of black carbon. Source: Klif/Statistics Norway (2013), Statistics Norway (2013)

Calculation of climate effects in the action plan

Climate effects are defined here as global warming or cooling of the atmosphere. The combined climate effect, that is to say the sum of the warming and cooling effects, has been calculated for all the measures that have been assessed in this proposed action plan. This has not previously been done in Norwegian climate analyses.

The climate effects of the different components can be compared and summarised after conversion into so-called CO_2 equivalents. This can be done by multiplying emissions in tonnes by a factor that states the climate effect of the relevant component relative to the climate effect of a tonne of CO_2 with certain given assumptions. The three key assumptions are 1) the method for calculating the climate effect, typically global warming potential (GWP) or global temperature change potential (GTP); 2) the period of time over which the climate effect is calculated; and 3) the region where the emissions occur. This factor is called an emission metric. Global warming potential is the total climate forcing over the entire period, while temperature change potential is the temperature response in the last year of the period. Thus GWP reflects all the effects on the climate that an emission has had during the period, while GTP gives a snapshot of the temperature response in the last year. The metrics are based on model studies. Calculating climate effect based on metrics represents a simplification compared to the application of models that explicitly include emissions as well as chemical and physical processes every time climate effects are to be analysed and assessed.

There is no international consensus over which metrics are most suitable for analysing short-lived climate forcers, but IPCC (2013) and several others state that the choice of metric depends on the purpose of the analysis. During the first commitment period of the Kyoto Protocol under UNFCCC, GWP calculated over a hundred-year period was used, regardless of where the emission occurred ("GWP100, global"). The Kyoto gases are methane, HFCs and several long-lived gases, including CO_2.

Our objective is to analyse the climate effects of short-lived climate forcers in the short term. As we have assessed it, "GTP10, Norway", i.e. global temperature change potential calculated ten years after the emission occurred in Norway, is the most appropriate metric for analysing measures for Norwegian emissions of short-lived climate forcers in the short term. This metric gives a snapshot of the temperature response 10 years after the emission and reflects both the short lifetime of short-lived climate forcers and the fact that the emissions occur in Norway.

A risk in using metrics to compare different climate forcers is that this creates the impression that it does not matter which component is reduced, as long as the estimated climate effect in CO_2 equivalents is the same. It is particularly important to bear this in mind when the climate effect of black carbon, which only stays in the atmosphere for a few days, is seemingly likened to CO_2 and other long-lived greenhouse gases by a metric that focuses on the properties of short-lived climate forcers. Using "GTP10, Norway", the emissions will only be "equivalent" in terms of temperature change ten years after the emissions occurred in Norway. CO_2 and other long-lived gases, on the other hand, have a lifetime in the atmosphere much longer than 10 years. The long-term effects of the long-lived gases on the climate system are thus not reflected in "GTP10, Norway". This applies for example to sustained global warming due to climate feedback of the carbon cycle, deep ocean temperature change, and other factors.

There is not one, single metric that describes the climate effects of both short-lived and long-lived components in an appropriate manner.

Significant climate effects of Norwegian emissions of black carbon and methane in the short term

The overall climate effect of Norwegian emissions of short-lived climate forcers was 35 million tonnes of $CO_{2e(GTP10,\ Norway)}$ in 2011, distributed as shown in Figure S.2. The figure also includes the climate effect of OC and SO_2 which is co-emitted with short-lived climate forcers from some sources.

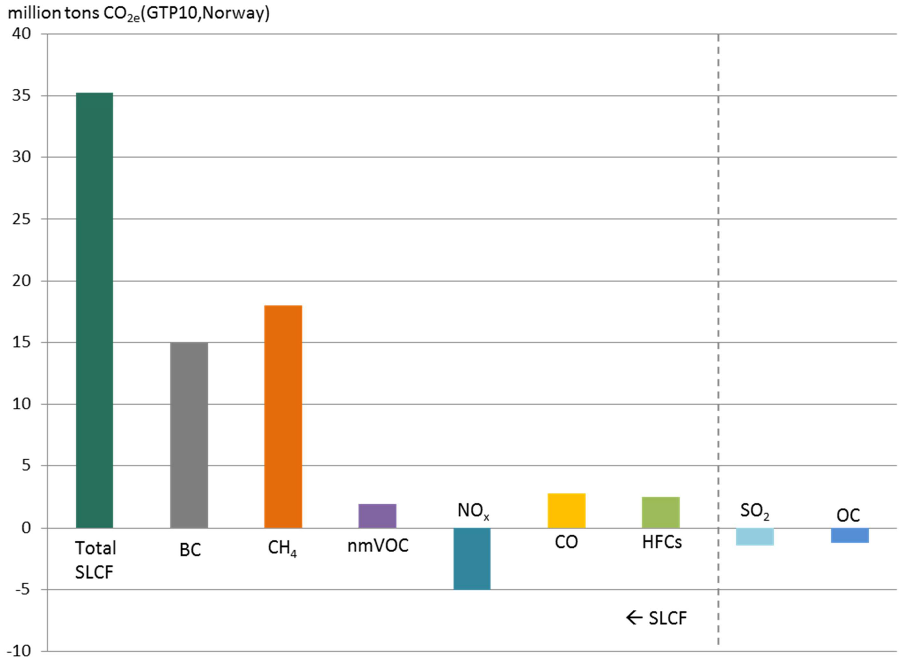

Figure S.2: Climate effect in 2011 expressed in million tonnes of $CO_{2e(GTP10,\ Norway)}$ for Norwegian emissions of short-lived climate forcers, as well as SO_2 and OC. Source: Klif/Statistics Norway (2013), Statistics Norway (2013)

Figure S.2 shows that, for the short-lived climate forcers, the warming effect of Norwegian emissions is clearly largest for methane, followed by black carbon. The warming effect of the ozone precursors CO and nmVOCs, as well as HFCs, is considerably less. The ozone precursor NO_x, like OC and SO_2, has a cooling effect. NO_x emissions have a cooling effect in a ten-year perspective primarily because NO_x leads to a reduction of CH_4 in the atmosphere. OC and SO_2 emissions form particles that cause cooling because they reflect the sunlight.

The historical development and projection of climate effect in the short term are shown in Figure S.3 for long-lived gases, short-lived climate forcers, OC and SO_2. We can see that there is a reduction or little change for all components apart from CO_2 over the period 1990-2011, and that this trend is expected to continue to 2030.

The reductions are assumed to reflect measures already implemented and policies adopted. If we compare Norway's emissions of all climate forcers (both short- and long-lived), we can see that in the short term, only CO_2 has a higher climate effect than methane and black carbon. This has been the case since 1994. The combined climate effect given in $CO_{2e(GTP10,\ Norway)}$ for methane and BC in 2011 was approximately 70% of the climate effect of Norwegian CO_2 emissions.

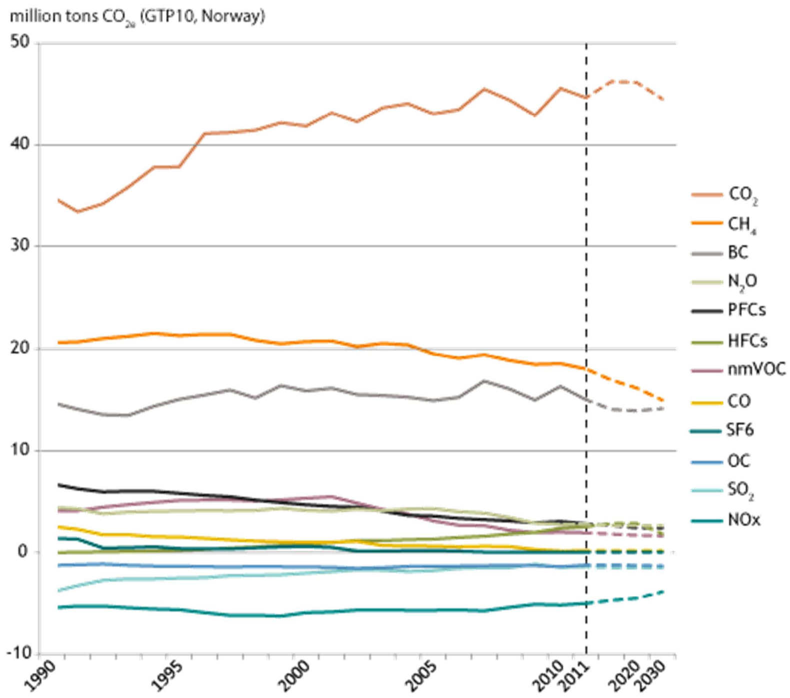

Figure S.3: Historical development and projection of the climate effect of all components in the reference scenario in $CO_{2e(GTP10,\ Norway)}$. Source: Klif/Statistics Norway(2013), Statistics Norway(2013), FIN(2013)

Important to reduce both short-lived climate forcers and CO_2 in the short term

Achievement of the 2°C target that the world's leaders have set for preventing dangerous climate change requires a long-term reduction in warming. In a 100-year perspective, CO_2 and other long-lived greenhouse gases dominate the climate effect. The climate effect of the short-lived climate forcers is limited in a 100-year perspective. In order to avoid a warming of more than 2°C, it is therefore most important to reduce the emissions of CO_2 and other long-lived greenhouse gases.

In a ten-year perspective, the climate effect of short-lived climate forcers is considerable (Figure S.4), but even in a short-term perspective, the climate effect of Norwegian CO_2 emissions in 2011 alone was greater than the overall climate effect of all Norwegian emissions of short-lived climate forcers. This indicates that CO_2 reduction is also important in the short term. Rapid CO_2 reduction could help to limit the rate of warming in the short term. It is therefore important for Norway to implement CO_2-measures quickly.

Measures aimed at short-lived climate forcers cannot replace CO_2 measures in either the short or long term. But reduced Norwegian emissions of short-lived climate forcers, and especially methane and BC, will reinforce the global climate benefits of rapid reductions in CO_2 emissions.

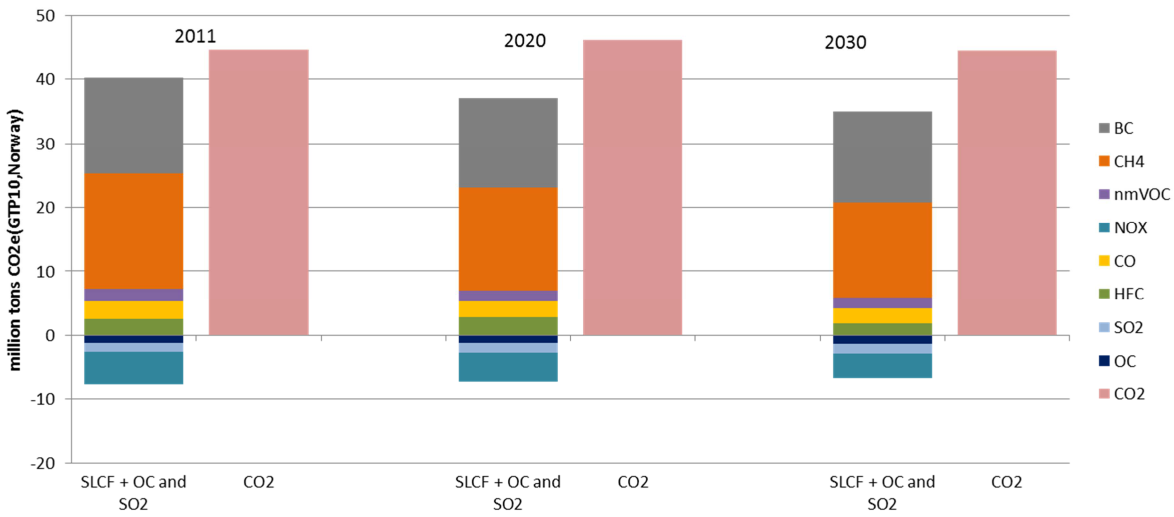

Figure S.4: Global climate effect of short-lived climate forcers (SLCFs), OC and SO_2 compared with that of CO_2 in 2011, 2020 and 2030

Norwegian BC emissions are of significance for the Arctic

Norwegian BC emissions have approximately a 1.5 times higher climate effect per tonne than the global average (Figure S.5) and may contribute to melting in the Arctic. This is because the albedo effect of Norwegian emissions is high compared to the global average due to our proximity to the Arctic. The same applies to other countries close to the polar regions or other snow- and ice-covered areas such as the Himalayas.

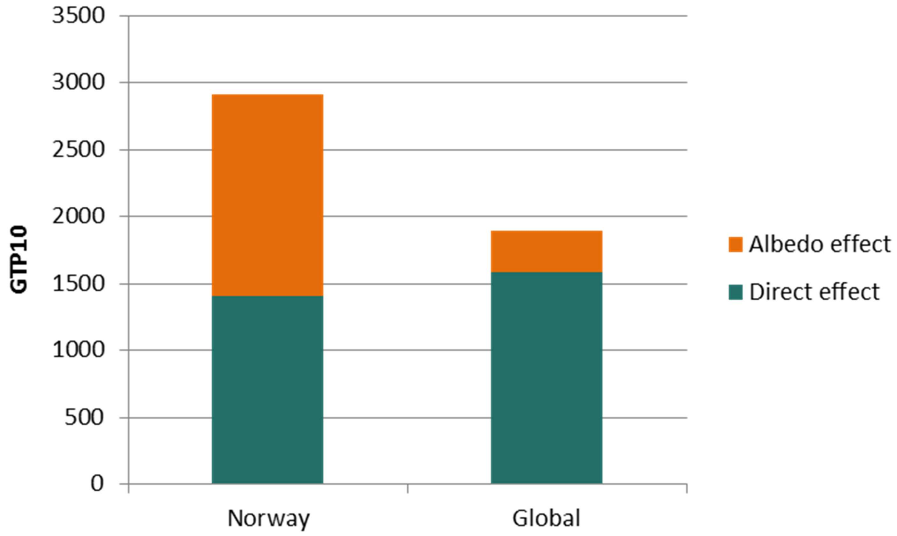

Figure S.5: The climate effect of a tonne of Norwegian BC emissions, compared to the global average climate effect per tonne of emissions. The metric is divided into the contribution from the direct effect (atmospheric absorption) and the albedo effect on snow and ice. Source: Hodnebrog et al. (2013)

A reduction in Norwegian BC emissions could give positive health effects in Norway

Reducing Norwegian BC emissions could also give health benefits, since the current high level of fine particles ($PM_{2.5}$ which BC is part of) in cities and urban settlements may be detrimental to public health.

Due to black carbon's climate effects in the Arctic and its negative health effects, reduction of these emissions should be given special consideration.

No climate benefit from NO_x reductions

In a short-term perspective, reducing emissions of the ozone precursor NO_x will contribute to warming. In the longer term, e.g. 100 years, NO_x emissions have a minimal climate effect.

NO_x reductions will however give health and environmental benefits in Norway. In cities and urban settlements, the levels of NO_2 may be detrimental to public health. NO_x also contributes to the creation of ozone, which is hazardous to health. The environmental effect of nationally produced ozone is limited.

International collaboration is important for reducing levels of NO_x and ozone in Norway, since a high proportion of these components are long-range transboundary air pollutants. Norway must also meet its own obligations, and measures to reduce NO_x emissions for health and environmental reasons are already being assessed by the Norwegian Environment Agency (Norwegian Environment Agency, 2013b).

Framework for analysing measures and instruments

The objective of this part of the study is to perform an integrated assessment of climate, health and environmental effects of Norwegian emissions of short-lived climate forcers and propose measures and instruments for reducing effects by 2030. No target for emission reductions has been defined.

The analysis is limited to emissions covered by the Norwegian emission inventory as published by the Norwegian Environment Agency and Statistics Norway.

A number of "CO_2 measures" will reduce emissions of short-lived climate forcers. These include for example traffic-reducing measures or a transition to more environmentally-friendly vehicles or renewable energy. Such measures are generally not covered in this analysis and were last assessed in Climate Cure 2020 (Klif, 2010). The focus of the current analysis is therefore to identify emission reductions that are in addition to the reductions that follow from CO_2 measures. Thus, the analysis does not give an overview of the complete reduction potential for Norwegian emissions of short-lived climate forcers.

We have targeted our measures at emission sources where the reduction potential for short-lived climate forcers is large. Most of our measures are aimed at BC and CH_4, which are the short-lived climate forcers with the largest short-term climate effect (Figure S.2). The reduction potential of the measures is described in relation to the emission developments we expect on the basis of adopted policies, a so-called reference scenario.

For some measures, there may be a trade-off between desired climate benefit and positive health and environmental effects. As mentioned above, for example, NO_x reductions cause short-term warming, but give health and environmental benefits. Our objective has been to reduce short term warming without significant, adverse health and environmental effects.

Within this framework, the intention has been to identify all measures with a significant reduction potential, and we have considered the reduction potential for all emission sources in the Norwegian emission inventory. In practice, however, the available basis of data and knowledge has been a limitation in terms of which measures it has been possible to assess. A detailed description of the measures in different sectors is given in the sector report (Norwegian Environment Agency, 2013c) accompanying the main report (Norwegian Environment Agency, 2013a).

The lack of data and knowledge has been a particular challenge for the petroleum sector, where we have only been able to assess two measures. These two measures are not necessarily the best measures for this sector, and more information should be obtained, so as to be able to assess further measures.

Since our analysis cannot give a complete overview of the reduction potential for Norwegian emissions of short-lived climate forcers, the work is intended to illustrate mitigation options targeting short-lived climate forcers. Further work may be necessary to identify the best measures, as well as to design the assessed measures appropriately.

Results of the analysis of measures

The combined climate effect, i.e. the sum of the warming and cooling effects, has been calculated for all measures. Emissions of NO_x, OC and SO_2 lead to a cooling of the atmosphere, and cause warming when they are reduced. This is particularly important to take into account for emissions that contain a high proportion of cooling components, such as organic carbon from burning wood. The share of OC in a tonne of particles from road transport emissions for example is much lower than from wood burning, so that the combined climate benefit of reducing a tonne of BC emissions from road transportation is larger than for a tonne of BC emissions from burning wood and other biomass. The implication is that measures aimed at emission sources that also emit large quantities of cooling components are not necessarily good climate measures under all circumstances.

We have assessed the combined climate effect, as well as health and environmental effects, for 18 non-overlapping measures, that is to say measures that genuinely complement each other because they reduce different emissions. Measures have been identified in six sectors (petroleum, industry, residential heating, transport, agriculture and HFCs in products) that together accounted for 83% of all Norwegian emissions of short-lived climate forcers in 2011.

The transport and agricultural sectors have the highest emissions of short-lived climate forcers measured in $CO_{2e(GTP10,\ Norway)}$. In the transport sector, BC emissions from diesel engines dominate. Emissions of short-lived climate forcers from the agricultural sector consist exclusively of methane, most of which (87% in 2011) comes from enteric fermentation produced in digestive systems of ruminants and the remainder from manure management.

There are significant emissions from residential heating, which primarily comprise BC from wood burning. The petroleum sector has considerable BC emissions, from flaring and the use of diesel, and methane from cold venting and process leakages.

The sector HFCs in products covers all the HCF emissions which originate entirely from the use of HFCs in products such as heat pumps and refrigerants. Norway has comprehensive legislation to limit HFC emissions, and these emissions are now relatively limited. Even stricter requirements are being evaluated in the EU, however. In the industrial sector, BC and CO emissions have been more than halved since 1990 as a result of lower production and improved technology, and emissions of short-lived climate forcers are now rather limited in the industry sector.

The climate effects of the 18 measures are shown at component level in Figure S.6a. We can see from the figure that the calculated reduction potential that could theoretically be triggered by the assessed measures is 4.3 million tonnes of $CO_{2e(GTP10,Norway)}$ on average per year, i.e. approximately 12% of the combined emissions of short-lived climate forcers in 2011 which is 35 million tonnes of $CO_{2e(GTP10,\ Norway)}$ (Figure S.2). The reduction potential in Figure S.6 includes both the warming components (positive climate effect) and the cooling components (negative climate effect) that are reduced.

The largest emission reductions are BC reductions, followed by methane and HFC reductions, both of which are regulated under the Kyoto Protocol (Figure S.6a). The combined effect of BC and OC reductions corresponds to 40% of the reduction potential of the 18 measures (Figure S.6b). Correspondingly, the combined effect of the reduction of the Kyoto gases methane and HFC is also 40%.

The final 20% comes from the long-lived greenhouse gases CO_2 and N_2O (13%) and the remaining short-lived climate forcers and SO_2 (7%). The NO_x and SO_2 reductions are too small to be visible in Figure S.6a.

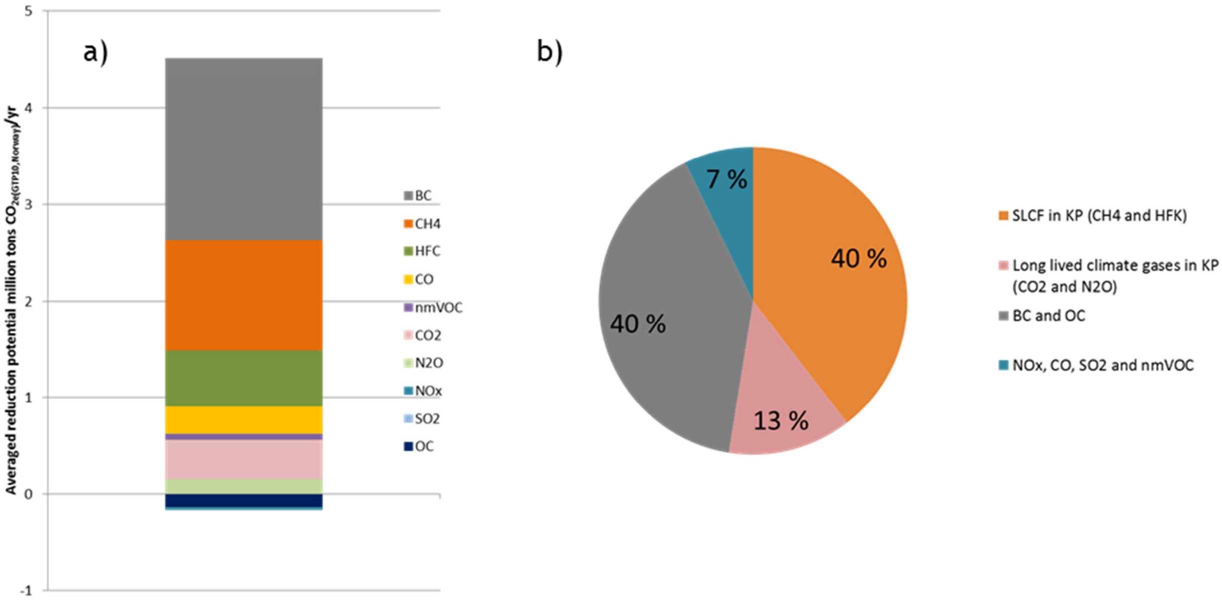

Figure S.6a: Average emission reductions in million tonnes of $CO_{2e(GTP10,Norway)}$ per year for each component of the 18 non-overlapping measures. Note that the emission reductions for NO_x and SO_2 are too small to be visible in the figure. Figure S.6b: Percentage distribution of emission reductions for the 18 measures

In assessing these 18 measures, we have emphasised the cost per reduced tonne of $CO_{2e(GTP10,\ Norway)}$, so-called cost effectiveness. The cost effectiveness of the measures has been calculated in line with the Ministry of Finance's guidelines for socio-economic analysis[1].The cost of the measures includes valued health effects when relevant, i.e. health benefits measured in NOK have been deducted from the cost of the measure. Eight of the 18 measures have health effects. The combined health benefits of these 8 measures average NOK 1.6 billion a year.

We have not had the data required to value the effects on forest and crops (environmental effects) in the same way as for health effects, but these are believed to have negligible significance for the conclusions of the analysis.

[1] The calculation of cost effectiveness is explained in Norwegian Environment Agency (2013) and is in line with the Ministry of Finance guidelines, the climate benefit of the measures has not been valued.

In Figure S.7, the measures have been ranked by increasing cost per reduced tonne of $CO_{2e(GTP10, Norway)}$, i.e. by declining cost effectiveness. The annual reduction potential for the measures is summarised along the first axis (*x* axis). Thus the figure shows what reduction potential can be achieved for a given cost effectiveness (*y* axis). The cost effectiveness is also shown without health benefit (red dots) to demonstrate the significance health benefits have for cost effectiveness. The ranking of most measures changes when the health effect is no longer included.

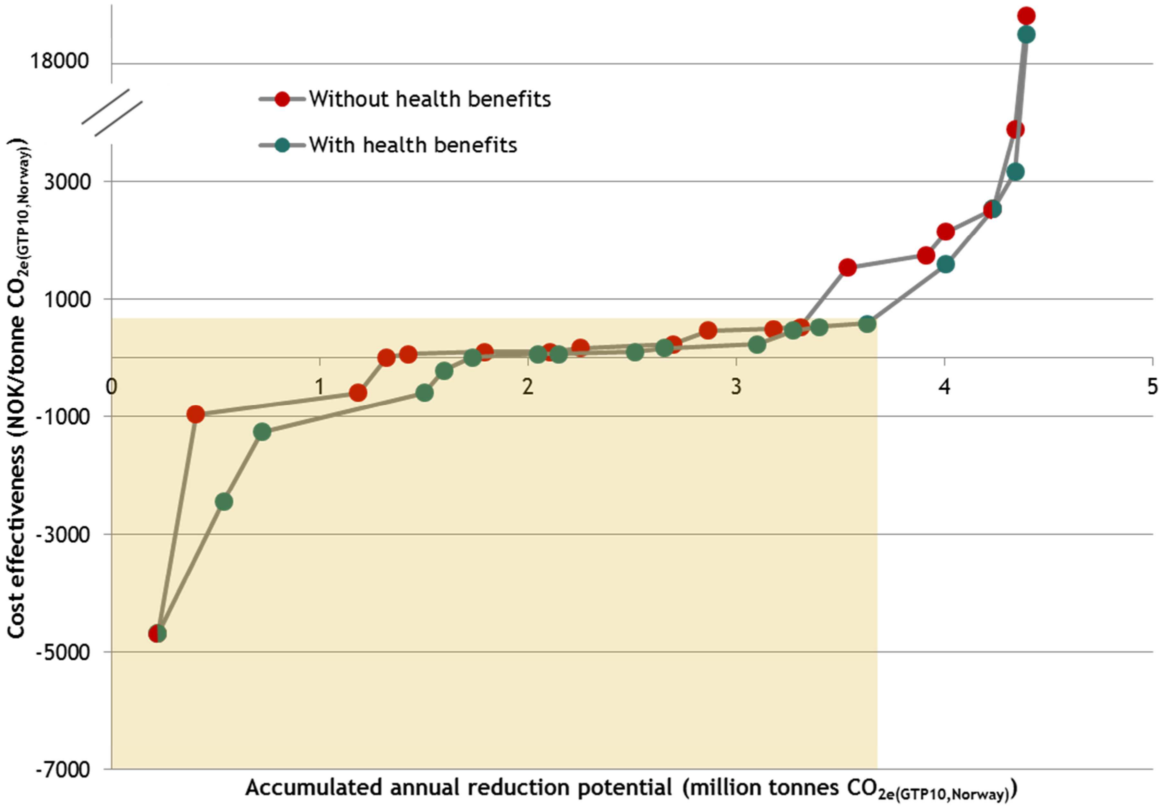

Figure S.7: Cost effectiveness and cumulative annual reduction potential for the 18 non-overlapping measures. The green dots show the cost effectiveness of the measures when health effects are taken into account. The red dots show cost effectiveness when the health effects are not considered

Figure S.7 indicates that cost effectiveness becomes significantly poorer from around NOK 600 per reduced tonne of $CO_{2e(GTP10,Norway)}$ for the curve that includes health benefits (green dots). Four of the measures are calculated to have cost effectiveness considerably poorer than NOK 600 per tonne of $CO_{2e(GTP10,Norway)}$ and are outside of the yellow zone.

The figure also shows that the 8 measures with health effects become considerably more expensive if the health effects are not included (i.e. the line with the red dots lies above the line with the green dots).

Five measures have been calculated to cost less than NOK 0 per reduced tonne of $CO_{2e(GTP10, Norway)}$. For two of the measures (wood burning) this is due to the large health benefits. For the other three measures, this is primarily due to cost savings.

Integrated assessment of the measures

In addition to considering the cost effectiveness including health effects, we have qualitatively and based on expert judgement assessed how realistic it is to achieve the estimated emission reductions through the most relevant instrument or combination of instruments. This is called emission reduction effectiveness. Emission reduction effectiveness is ranked qualitatively as high, moderate or low. In general, regulatory requirements are considered to be effective instruments, while raising awareness through public information and outreach are typically considered to be less effective. A combination of instruments is often necessary to trigger a measure. For example targeted information about financial support schemes could increase the emission reduction effectiveness of financial instruments.

In Table S.1, we list the cost effectiveness and the emission reduction effectiveness of all measures. Cost effectiveness includes both climate effect and health effect. Whether it is the climate effect or the heath effect that has the largest impact on the calculation of the cost effectiveness of the different measures varies greatly. The climate effects of the measures differ a lot, and only 8 of the 18 measures have a health effect. We have therefore also listed the climate and health effects in the table.

Cost effectiveness and climate and health effects of the measures have been assessed as high, moderate or low on the basis of an interrelated evaluation[2]. No consideration has been given to whether the values for cost effectiveness and climate and health effects are low, moderate or high in relation to other analyses.

The assessment of all measures has been based on the measures as they have been designed here. It is possible to scale the measures differently. All of the measures are associated with uncertainties. These are discussed after the assessments.

The characteristics of the different measures are summarised in Table S.1 below.

[2] Cost effectiveness (NOK/tonne $CO_{2e(GTP10,\ Norway)}$): H < 0, M = 0-600, L > 600. Climate effect (annual reduction in kilo tonnes of $CO_{2e(GTP,\ Norway)}$): H > 400, M = 200-400 and L < 200. Health effect (annual health benefit in million NOK): H > 100, M = 50-100, L < 50.

Table S.1: Assessment matrix[3]

Measure	Primary component reduced in $CO_{2e(GTP10,Norway)}$	Climate effect in kilotonnes of $CO_{2e(GTP10,Norway)}$/yr	Health effect in NOK million/yr	Cost effectiveness in NOK/tonne	Instrument Emission reduction effectiveness (colour)
1. Reduced food waste	Methane	221	-	-4686	Information and outreach
2. Accelerated introduction of new stoves and pellet burners	BC, OC	318	808	-2433	Financial support combined with information and outreach
3. Energy efficiency in parts of industry	BC	183	54	-1255	Financial support (ENOVA) combined with information and outreach
4. Transition from red to white meat	Methane	781	-	-593	Information and outreach (consumer side) Financial support (production side)
5. Improved combustion practices, inspection and maintenance	BC, OC	94	222	-208	Inspection, information and outreach
6. Reducing the filling need and use of HFCs with low climate effect	HFCs	137	-	14	Regulatory requirement
7. Retrofitting of diesel particulate filters (DPFs) on construction machinery*	BC	314	133	67	Regulatory requirement. Low-emission zones
8. Increased recycling of nmVOCs and methane when loading crude oil offshore	nmVOCs, methane	101	-	71	Regulatory requirement. possible financial start-up support
9. Retrofitting and phasing in of DPFs on coastal vessels	BC	367	-	104	Regulatory requirement combined with financial support
10. Phasing in and retrofitting DPFs on fishing boats	BC	143	-	171	Regulatory requirement combined with financial support
11. Monitoring leak control and containment of HFCs	HFCs	445	-	236	Inspection/audit and supervision of the regulations
12. Retrofitting and phasing in of DPFs on mobile rigs	BC	171	-	465	Regulatory requirement and financial support
13. Conversion to Freiland process in the silicon carbide industry	CO	128	-	533	Regulatory requirement combined with financial support
14. Retrofitting of DPFs on light vehicles*	BC	226	216	589	Regulatory requirement combined with financial support. Low-emission zones.
15. Phasing in biogas from manure on buses	BC, methane	380	61	1591	Financial support
16. Retrofitting of DPFs on tractors	BC	224	-	2538	Regulatory requirement combined with financial support
17. Phasing in biogas from food waste on buses	BC, methane	110	81	3169	Financial support
18. Retrofitting of DPFs on heavy vehicles*	BC	54	17	18514	Regulatory requirement combined with financial support Low-emission zones.

[3] **Measure that could give an increase in NO_2 that reduces the positive health effects of the BC reductions. **DPF** = diesel particulate filter. Light brown = Low, Medium brown = Moderate, Dark brown = High. **Cost effectiveness (NOK/tonne $CO_{2e(GTP10, Norway)}$):** High < 0, Moderate = 0-600, Low > 600. **Climate effect (annual reduction in kilo tonnes of $CO_{2e(GTP, Norway)}$):** High > 400, Moderate = 200-400 Low < 200. **Health effect (annual health benefit in million NOK):** High > 100, Moderate = 50-100, Low < 50. In the column for instruments, the colour describes the degree of emission reduction effectiveness.*

Potential emission reduction strategies

We have made an integrated assessment of our measures based on climate, health and environmental effects. The analysis of measures has highlighted both conflicting targets and win-win situations. In addition, the costs of the measures are also better reflected because the health effects are included. The basis for decision making is therefore more complete.

Even so, which measures should be chosen depends on a number of assumptions, not least the scaling of the measures and which selection criteria are used. We illustrate here six different groups of measures based on different strategies for emission reductions. Five of the strategies entail choosing measures based on one or more of the following criteria: cost effectiveness, emission reduction effectiveness, climate effect and health effect. The sixth group of measures consists of the measures which contribute towards fulfilling our obligations under the Kyoto protocol.

The first reduction strategy is based on cost effectiveness as the only selection criteria and results in the largest number of measures, that is the 14 measures that cost less than NOK 600 per tonne of $CO_{2e(GTP10,\ Norway)}$ when the health effect is included. The next reduction strategy results in a group consisting of the 12 cost-effective measures that have moderate or high emission reduction effectiveness, i.e. two cost-effective measures with low emission reduction effectiveness are excluded from this group.

The third reduction strategy results in a group consisting of the five (of the 12) measures which are cost- and emission reduction effective and have a moderate or high climate effect. Correspondingly, the fourth reduction strategy results in a group consisting of the five (of the 12) measures which are cost- and emission reduction effective and have a moderate or high health effect.

The fifth reduction strategy results in a group consisting of the three measures that are cost- and emission reduction effective and have both a moderate or high climate effect and a moderate or high health effect.

Finally, we discuss the measures that contribute to fulfil our obligations under the Kyoto protocol. These are the five measures that primarily reduce HFCs and methane.

Reduction strategy 1: Cost effectiveness as the only selection criterion (14 measures)

If we remove all measures with poor cost effectiveness (i.e. over NOK 600 per tonne of $CO_{2e(GTP10,Norway)}$ in the green curve, shown outside the shaded area in Figure S.7), this means that four of the 18 assessed measures are deemed too expensive to be implemented in this context. These are the biogas measures and the measures for fitting diesel particulate filters to existing heavy duty vehicles and tractors. It should be noted that these measures may be relevant to implement even though they do not meet the criteria that forms the basis of this analysis.

Figure S.8 is a graphical presentation of these 14 cost effective measures. Measures are numbered according to the numbering in Table S.1. The position of the circles illustrates the cost effectiveness and emission reduction effectiveness of the individual measures. The size of the circles indicates low, moderate or high climate and health effect. Filled circles represent the climate effect, while hatched circles represent the health effect.

If the strategy is to identify cost effective measures only, it would be relevant to implement the 14 measures as shown in Figure S.8. Measures 1-5 have negative cost effectiveness. These are *Reduced food waste, Accelerated introduction of new stoves and pellet burners, Energy efficiencies in parts of industry, Transition from red to white meat and Improved combustion practices, inspection and maintenance*. The five measures are listed here by rising cost per reduced tonne of $CO_{2e(GTP10,\ Norway)}$, i.e. by diminishing cost effectiveness (Table S.1, Figure S.6 first five green dots). The cost effectiveness of measures 6-14 is positive but below 600 NOK per tonne of $CO_{2e(GTP10,Norway)}$.

Average annual reduction potential would be approximately 3.7 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives a 12% reduction in 2030 in relation to the short-lived climate forcers in the reference scenario which is 31 million tonnes of $CO_{2e(GTP10,Norway)}$. Annual health benefits would be approximately NOK 1.4 billion.

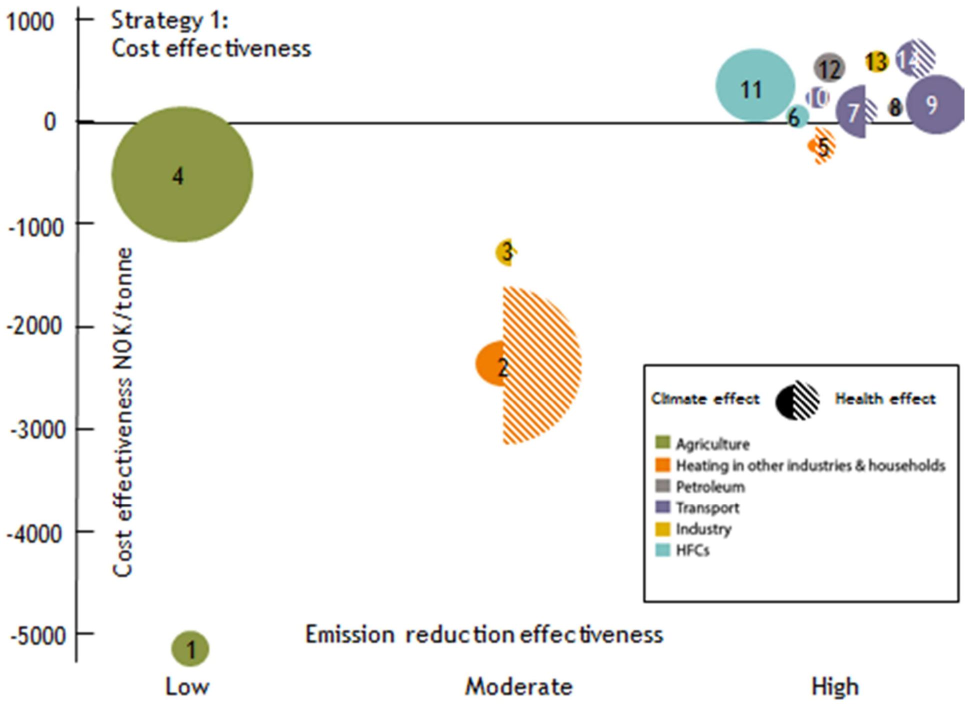

Figure S.8: Graphical presentation of measures resulting from Reduction strategy 1. Measures are numbered according to increasing cost per reduced tonne $CO_{2e(GTP10,Norway)}$ (decreasing cost effectiveness) *as in Table S.1*

Reduction strategy 2: Emission reduction effectiveness as an additional criterion to cost effectiveness (12 measures)

If the strategy is to identify cost effective measures that also have moderate and high emissions reduction effectiveness, the two agricultural measures would not be relevant to implement (*Transition from red to white meat* and *Reduced food waste*, number 4 and 1 in Figure S.8). Excluding these two measures would mean that the possibility for reducing methane emissions is substantially reduced.

Average annual reduction potential for these 12 measures would be approximately 2.6 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives an 8% reduction in 2030 in relation to the short-lived climate forcers in the reference scenario. Annual health benefits remain at NOK 1.4 billion, since the agricultural measures have no health effect in this analysis.

It should nevertheless be considered to implement the agricultural measures, especially *Reduced food waste*, since they are calculated to have a cost substantially below 0 NOK per tonne reduced $CO_{2e(GTP10, Norway)}$, contribute to fulfilling the Kyoto targets and could complement the Waste Strategy (MD, 2013) in relation to climate. Emission reduction effectiveness could be considerably improved if the measures were scaled down.

Reduction strategy 3: Cost and emission reduction effective measures with a moderate or high climate effect (5 measures)

If the strategy is to identify measures with moderate and high climate effects among the 12 cost and emission reduction effective measures resulting from Reduction strategy 2, these would be *Monitoring leak control and containment of HFCs, Retrofitting and phasing in of diesel particulate filters (DPFs) on coastal vessels, Accelerated introduction of new stoves and pellet burners, Retrofitting of DPFs on construction machinery* and *Retrofitting of DPFs on light vehicles i.e. measures 11, 9, 2, 7 and 14 as shown in Figure S.9.* The measures are listed here by diminishing climate effect. There is some uncertainty linked to the climate effect of particulate filters since these measures could give a small increase in CO_2 emissions. This should be further investigated.

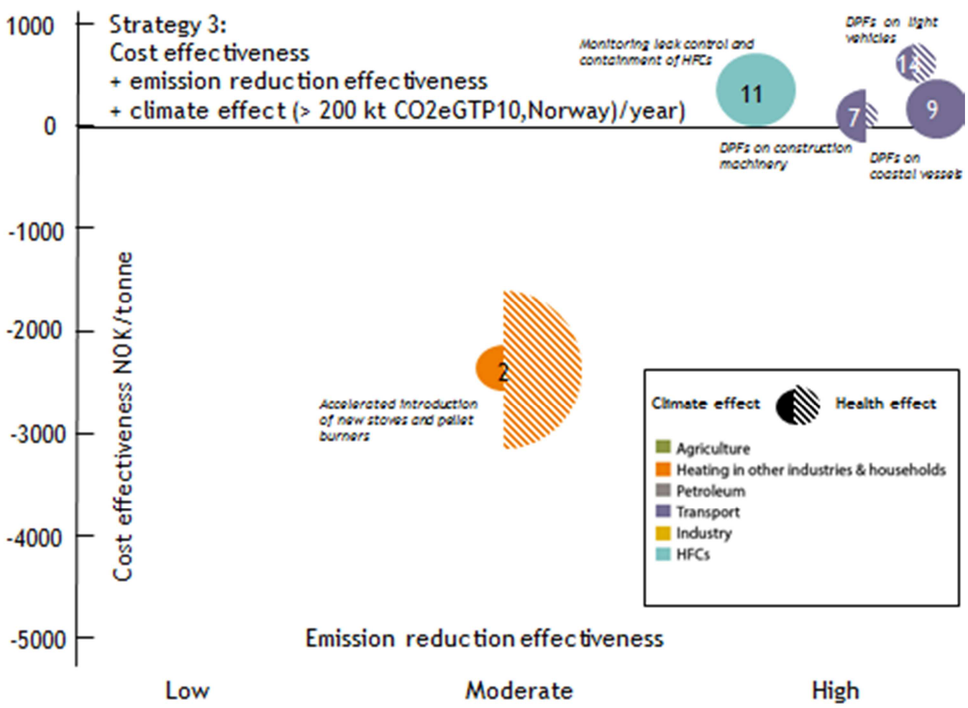

Figure S.9: Graphical presentation of measures resulting from Reduction strategy 3. Measures are numbered according to increasing cost per reduced tonne $CO_{2e(GTP10,Norway)}$ (decreasing cost effectiveness) *as in Table S.1*

Average annual reduction potential would be approximately 1.7 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives a 5% reduction in 2030 in relation to the short-lived climate forcers in the reference scenario. Three of these measures have a valued health effect and would have an annual health benefit of approximately NOK 1.1 billion.

Reduction strategy 4: Cost and emission reduction effective measures with a moderate or high health effect (5 measures)

If the strategy is to identify measures with moderate and high health effects among the 12 cost and emission reduction effective measures in Reduction strategy 2, these would be *Accelerated introduction of new stoves and pellet burners, Improved combustion practices, inspection and maintenance, Retrofitting of diesel particulate filters (DPFs) on light vehicles, Retrofitting of DPFs on construction machinery* and *Energy efficiencies in parts of industry i.e. measures 2, 5, 14, 7 and 3 as shown in Figure S.8.* The measures are listed here by diminishing health effect. There is some uncertainty linked to the health effect of the two particulate filter measures, since these could give a small increase in NO_2 emissions. This should be further investigated.

Average annual reduction potential would be approximately 1.1 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives a 4% reduction in 2030 in relation to the short-lived climate forcers in the reference scenario. Annual health benefits for these five measures, i.e. the entire health benefit for the 14 cost-effective measures, would be approximately NOK 1.4 billion.

Reduction strategy 5: Cost and emission reduction effective measures with both a moderate/high climate effect and a moderate/high health effect (3 measures, win-win)

If the strategy is to identify measures with moderate and high climate and health effect among the 12 cost- and emission reduction effective measures in Reduction strategy 2, these three would be *Accelerated introduction of new stoves and pellet burners, Retrofitting of diesel particulate filters (DPFs) on construction machinery* and *Retrofitting of DPFs on light vehicles i.e. measures 2, 7 and 14 as shown in Figure S.10.* There is some uncertainty linked to the climate and health effect of the two particulate filter measures. This should be further investigated.

Average annual reduction potential would be approximately 0.9 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives a 3 % reduction in 2030 in relation to the short-lived climate forcers in the reference scenario. Annual health benefits would be approximately NOK 1.2 billion.

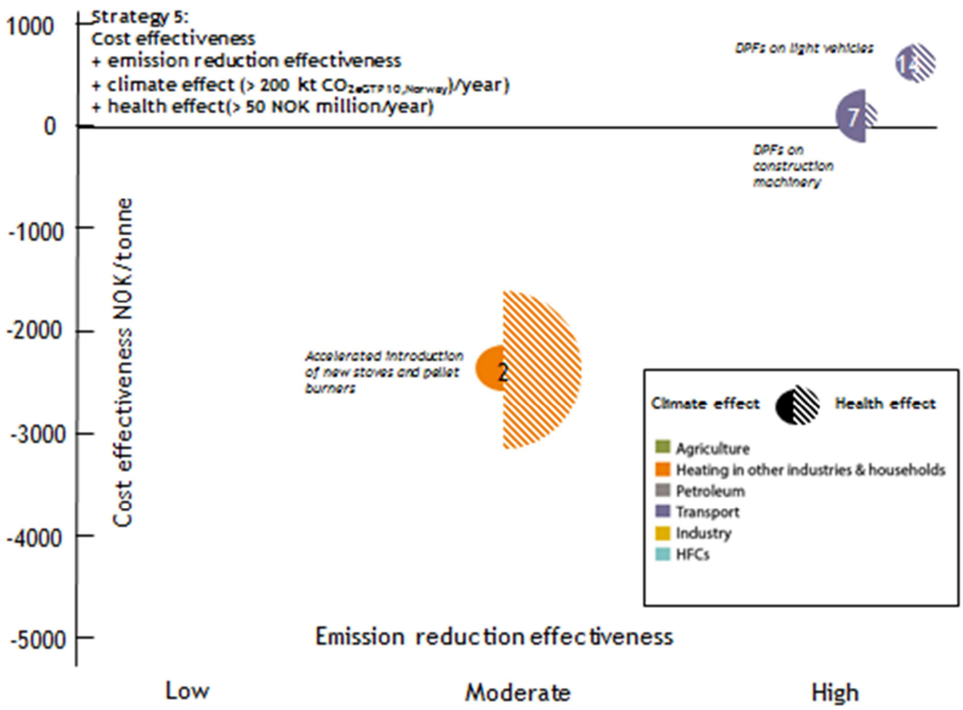

Figure S.10: Graphical presentation of measures included in Reduction strategy 5. Measures are numbered according to increasing cost per reduced tonne $CO_{2e(GTP10,Norway)}$ (decreasing cost effectiveness) *as in Table S.1*

Measures contributing to fulfilling our obligations under the Kyoto Protocol

Five of the measures reduce only HFCs or primarily methane, which are regulated under the Kyoto Protocol. The HFC measures are *Reducing the filling need and use of HFCs with low climate effect* and *Monitoring leak control and containment of HFCs*. The measures that primarily reduce methane are *Reduced food waste, Transition from red to white meat* and *Increased recycling of nmVOCs and methane when loading crude oil offshore*. These measures would help to comply with the national climate targets for greenhouse gases.

Average annual reduction potential would be approximately 1.7 million tonnes of $CO_{2e(GTP10,Norway)}$. This gives a 5% reduction in 2030 in relation to the short-lived climate forcers in the reference scenario. In this analysis, no health effects have been valued for these measures as they have no direct health effects under normal circumstances.

The average annual reduction potential, the percentage reduction in relation to the short-lived climate forcers in the reference scenario and the average annual health benefits for these six reductions strategies are summarised in Table S.2 below.

Table S.2: The effects of measures based on different reduction strategies

	Reduction strategy	Reduction potential in million tonnes of CO_{2e} $_{(GTP10,Norway)}$/ year	Reduction in relation to the short-lived climate forcers in the 2030 reference scenario	Health benefits in billion NOK / year
1.	Cost-effective measures	3.7	12%	1.4
2.	Cost and emission reduction effective measures	2.6	8%	1.4
3.	Cost and emission reduction effective measures with a moderate/high climate effect	1.7	5%	1.1
4.	Cost and emission reduction effective measures with a moderate/high health effect	1.1	4%	1.4
5.	Cost and emission reduction effective measures with both a moderate/high climate effect and a moderate/high health effect	0.9	3%	1.2
6.	Regulated under the Kyoto Protocol	1.7	5%	0

Uncertainties

As with other analyses of measures, there are uncertainties associated with this analysis. Such uncertainties are i.a. associated with the cost of measures, the technological maturity of several largely untested technologies and the degree to which instruments can be introduced so as to obtain the measures' full technical reduction potential. For particulate filters, there is uncertainty regarding the extent to which these lead to an increase in fuel consumption and NO_2 emissions.

Some other types of uncertainty derive from the basis of scientific knowledge being immature and having developed in parallel with the work on the action plan. These uncertainties are mainly associated with emission inventories and the calculation of emission reductions and climate, health and environmental effects. The uncertainties are generally largest for BC and to some extent also OC and SO_2. For health effects, the uncertainty is largest for BC reductions, which have been valued in principle as PM_{10} reductions. More research and investigation must be done to reduce these uncertainties.

There are also uncertainties relating to the metric (as a result of uncertainty in modelling) and the choice of metric. Sensitivity analyses with various metrics indicate that the climate effect of the measures is generally reduced if the time horizon is increased from 10 to 100 years. The wood-burning measures are primarily health measures in the long term (little climate effect).

Even though there are un-quantified uncertainties related to the climate effect of measures, we consider that all the assessed measures has climate effect in the short term. The measures will be more expensive if the climate effect is overestimated. We assume that uncertainty regarding the health effect is considerably less than for the climate effect. For the eight measures that have a health effect, we cannot judge whether the health effect is over- or underestimated.

Need for further assessments and comparison with other studies

In addition to the 18 measures discussed above, we have identified a number of reduction possibilities that cannot currently be analysed quantitatively because of a lack of basic data and knowledge. We see a need to obtain more information, so as to assess whether there may be useful measures among these reduction possibilities. Reductions of short-lived climate forcers in traditional CO_2 measures should also be looked at, in order to assess how emissions of short-lived climate forcers can be reduced most effectively. Given the necessity for rapid climate mitigation, this should not hamper implementation of the most appropriate measures analysed in this report.

It is worth noting that it is not possible to make any direct comparisons between the cost effectiveness of the measures for short-lived climate forcers analysed in this action plan either with traditional climate measures such as in Climate Cure 2020 (Klif, 2010) and the McKinsey curve (Enkvist et al., 2007) or with the price of carbon offsets. Climate Cure 2020 covered the long-lived greenhouse gases CO_2, N_2O, PFCs and SF_6, and also CH_4 and HFCs. Emission reductions in Climate Cure 2020 are calculated as$CO_{2e(GWP100,\ global)}$, while this action plan has used $CO_{2e(GTP10,Norway)}$ as a basis for calculating climate effects.

National monitoring

There is a need to strengthen the planned national monitoring of black carbon, organic carbon and methane. Norwegian participation in the Integrated Carbon Observation System (ICOS) network would help to cover the need for monitoring methane. There is a further need for local monitoring of black carbon.

Possible national targets for short-lived climate forcers

Norway currently has national climate targets in connection with the greenhouse gases regulated by the Kyoto Protocol under the UN Framework Convention on Climate Change (UNFCCC), i.e. CO_2, methane, HFCs, PFCs, N_2O and SF6. The obligations are linked to long-term temperature stabilisation.

Consideration could be given to establishing a short-term target for reducing the rate of warming, in addition to the present long-term targets. Any short-term target should cover all the components that have a temperature response in the short term, i.e. both short-lived climate forcers and CO_2 and other long-lived components.

Since several of the short-lived climate forcers are also air pollutants, it is important to see the achievement of targets for climate change and air pollution in relation to each other. When establishing targets for climate and air pollution, one should consider taking the mutual effects these have on each other into consideration.

Improved coordination of work on short-lived climate forcers

Public administration involves many decisions influencing both climate change and air pollution. This work is performed in conjunction with various national and international initiatives, and there are a number of different groups involved. There is therefore a need for increased coordination, both within public administration and in relation to external organizations in order to ensure coherent policies.

International collaboration

Norway already participates in a number of global and regional initiatives aiming to reduce emissions of short-lived climate forcers. The regional initiatives include work in connection with the LRTAP, the EU, the Arctic Council and the Nordic Council. The global initiatives include the Climate and Clean Air Coalition (CCAC)/UNEP, the Montreal Protocol (the inclusion of HFCs is being considered), the Climate Convention (methane and HFCs), the UN International Maritime Organisation (IMO) and the Global Methane Initiative.

Norway should work actively to establish an international definition of and measurement methods for BC, as well as guidelines for reporting of emissions. Norway should in addition promote harmonised international monitoring of the short-lived climate forcers. Norway should also work towards a binding international collaboration, to reduce BC emissions especially. Methane and HFCs are covered by the Kyoto Protocol, and ozone precursors are covered by the Gothenburg Protocol.

In the short term, this should occur through regional initiatives such as the LRTAP and possibly the Arctic Council. In the longer term, this could possibly be done through the Climate Convention or other global initiatives. Because of the regional nature of the short-lived climate forcers, further consideration must be given to whether the Climate Convention is a suitable arena.

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The main tasks of the Norwegian Environment Agency are the reduction of greenhouse gas emissions, nature management and the prevention of pollution.

We are an agency under the Ministry of Climate and Environment with 700 employees in Trondheim and Oslo. The agency also includes the Norwegian Nature Inspectorate, which has more than sixty local offices

Our primary functions are to monitor the state of the environment, provide environment-related information, exercise regulatory authority, oversee and guide regional and municipal authorities, collaborate with the authorities of relevant government sectors, act as an expert adviser, and assist in international environmental measures..